Food Research 6 (4) : 30 - 46 (August 2022)
Journal homepage: https://www.myfoodresearch.com

FOOD RESEARCH

REVIEW

Mycotoxins and mycotoxigenic fungi in spices and mixed spices: a review

Syamilah, N., Nurul Afifah, S., Effarizah, M.E. and *Norlia, M.

Food Technology Division, School of Industrial Technology, Universiti Sains Malaysia, 11800 Minden, Pulau Pinang, Malaysia

Article history:
Received: 2 December 2021
Received in revised form: 2 February 2022
Accepted: 30 March 2022
Available Online: 3 July 2022

Keywords:
Spices,
Aspergillus spp.,
Mycotoxins,
Aflatoxins,
Ochratoxin A,
Food safety

DOI:
https://doi.org/10.26656/fr.2017.6(4).971

Abstract

Mycotoxins are secondary metabolites produced by fungi mainly from the genus *Aspergillus*, *Penicillium*, *Fusarium*, and *Alternaria*. The occurrence of mycotoxin contamination has been reported in various types of food, including spices such as chilli, black pepper, white pepper, cumin, coriander seed, and the ground mix spices. Aflatoxins (AFs) and ochratoxin A (OTA) are the primary mycotoxins in spices produced by *Aspergillus* spp. and *Penicillium* spp. Among these spices, chilli is more susceptible to the invasion of these mycotoxigenic fungi, especially during prolonged storage and inappropriate storage conditions, resulting in mycotoxin production. The storage conditions, processing methods, and handling practices of spices may affect the growth of fungi and subsequent mycotoxin production. This paper reviewed mycotoxigenic fungi and mycotoxin contamination in spices, the impact on humans, and the regulatory limit adopted by many countries worldwide.

1. Introduction

Spices are dried commodities derived from different parts of plants such as roots, seeds, buds, leaves, flowers, and stigmas. Since ancient times, spices have been used in cuisines, medicine, preservatives, and colour. The word "spices" is derived from the Latin word "species", which means a specific kind (Raghavan, 2007). Spices are known for their popularity in their distinctive flavouring, aromatising properties, preservative, antimicrobial, and antioxidant effects (Pickova *et al*., 2020). Spices have a unique flavour profile used in small quantities to flavour or impart aroma to food. They are widely grown in tropical countries, mainly India and Southeast Asia. However, spices are susceptible to fungal invasion if the conditions are suitable for fungal growth.

Fungi are multicellular organisms made up of long filaments called hyphae. They are plant-like organisms but are not considered a member of the plant kingdom due to the lack of chlorophyll and filamentous structure (Adeyeye, 2016). Fungi are common spoilage organisms that can deteriorate stored crops and food products. The spoilage fungi can be classified into two groups; field and storage fungi. Field fungi consist of various genera such as *Alternaria*, *Fusarium*, and *Cladosporium*, which attack crops in the field (Hashem and Alamri, 2010). On the contrary, storage fungi can grow in stored crops if the temperature, humidity, and moisture level are relatively high to support their growth (Mandeel, 2005; Hashem and Alamri, 2010). According to Yogendrarajah *et al.* (2014), *Aspergillus* and *Penicillium* are the most common storage fungi contaminating stored crops. These fungal genera are known as mycotoxigenic fungi because they can produce harmful secondary metabolites known as mycotoxins.

Mycotoxins can occur naturally in foods and agricultural commodities, including spices. According to Cinar and Onbasi (2019), more than 400 types of mycotoxins have been identified. Nevertheless, the most important mycotoxins in foods are aflatoxin B_1, B_2, G_1, G_2 (AFB_1, AFB_2, AFG_1, and AFG_2), and ochratoxin A (OTA). AFB_1 and OTA are the most hazardous mycotoxins (Adam *et al*., 2017). Mycotoxins can cause illness or death to humans and animals, regardless of how they are ingested, i.e., through breathing, swallowing, or absorption in the skin. Hence, this review aimed to provide an overview and updated information on mycotoxin and mycotoxigenic fungal contamination in spices, focusing on chilli as the most affected commodity. In addition, the mycotoxin regulation limits and the impact of mycotoxin on humans are also discussed in this paper.

*Corresponding author.
Email: *norlia.mahror@usm.my*

eISSN: 2550-2166

2. Spice production worldwide

Spices are usually marketed as a whole, ground, or mixed ground spices. Cinnamon, clove, star anise, cardamom, cumin, fennel, coriander seeds, black pepper, white pepper, paprika, chilli, and turmeric are commonly used in Asian cuisines, as shown in Table 1. However, the attributes of spices will differ depending on the geographical area, soil conditions, and processing methods during postharvest.

Spices have been cultivated in many countries, mainly in India. According to FAOSTAT (2019), the worldwide production of spices was 2.8 million tonnes from 1.4 M ha of area harvested in 2019. Asia contributed to 86% of spice production by region, followed by Africa (12.4%) and America (1.5%). India is the primary producer of spices, with 1.4 M tonnes of spices produced in 2019 (FAOSTAT, 2019).

Chilli is the world's second most widely consumed spice after black pepper. In 2016, the global production region of chilli was 1,798,847 ha, with an annual crop of 3,918,159 tonnes (FAO, 2016). China, Mexico, and Turkey were the top three producers of chillies in 2016. The output statistics demonstrate the importance of the chilli crop, which is vital for developing economies.

3. Some important mycotoxins in food commodities

Mycotoxins are secondary metabolites produced by fungal species such as *Aspergillus*, *Penicillium*, *Alternaria* and *Fusarium.* Some researchers have reported the occurrence of mycotoxins in spices, mainly AFs and OTA. Besides that, other mycotoxins that might be present in food commodities are fumonisins (FBs), zearalenone (ZEN), deoxynivalenol (DON), trichothecenes (Selvaraj *et al.*, 2015; Pickova *et al.*, 2020).

3.1 Aflatoxins (AFs)

AFs are potent, mutagenic, carcinogenic, and immunosuppressants. They are highly toxic compared to other mycotoxins (Mahato *et al.*, 2019). Among all AFs (AFB_1, AFB_2, AFG_1, and AFG_2), AFB_1 is the most toxigenic and has proven to be a human carcinogen (Group 1; IARC, 1993a). AF is one of the most important mycotoxins produced by fungi from the genus *Aspergillus*. Among all *Aspergillus* species, *Aspergillus flavus*, *A. parasiticus*, and *A. nomius* are the most frequent producers of AFs (Ali *et al*., 2015). The optimum temperature for the survival of *A. flavus* is 30° C, while the optimum temperature for AF production is between 25 to 30°C (Pitt and Hocking, 2009; Yogendrajajah *et al*., 2014). AFs commonly occur in peanuts, nuts, figs, corn, rice, spices, and dried fruits (Martinez-Miranda *et al*., 2019).

3.2 Ochratoxin A (OTA)

OTA is known to be carcinogenic, nephrotoxic, and immunotoxic (Wang *et al*., 2016). The International Agency for Research on Cancer (IARC, 1993a) has classified OTA as the most probable carcinogen to humans (Group 2B). OTA is commonly produced by *Aspergillus niger*, *Aspergillus ochraceus*, *Aspergillus carbonarius*, and *Penicillium verrucosum.* Tropical commodities are typically infected with *A. ochraceus* and *A. carbonarius*, while *P. verrucosum* usually infects the commodities in the temperate region (Steyn, 1995; Richard, 2007; Turner *et al*., 2009). The ideal temperature for OTA production is 25–30°C. The tropical climates are favourable for the growth of OTA-producing fungi and support OTA production (Nguegwouo *et al*., 2016). According to Turner *et al.* (2009), OTA can usually be found in dried products, including spices.

3.3 Citrinin

Citrinin (CIT) was first isolated in 1931 from

Table 1. List of spices commonly used in the Asian cuisines

English name	Family	Scientific name	Part of plant
Chilli pepper	*Capsicum*	*Capsicum* spp.	Fruits
Black pepper	*Piperaceae*	*Piper nigrum*	Berries
Cardamom seed	*Zingiberaceae*	*Amomum* spp.	Fruits
Cinnamon	*Lauraceae*	*Cinnamomum* spp.	Barks
Clove	*Myrtaceae*	*Szygium aromaticum* (L.)	Flower buds
Coriander seed	*Apiaceae*	*Coriandrum sativum* L.	Fruits
Cumin seed	*Apiaceae*	*Cuminum cyminum* L.	Seeds
Fennel seed	*Apiaceae*	*Foeniculum vulgare* Mill.	Fruits
Ginger	*Zingiberaceae*	*Allium sativum* L.	Rhizomes
Nutmeg	*Myristicaceae*	*Myristica fragrans* Houtt.	Seeds
Star anise	*Illiaceae*	*Illicium verum*	Fruits
Turmeric	*Zingibearaceae*	*Curcuma longa* L.	Rhizomes
White pepper	*Piperaceae*	*Piper nigrum*	Berries

Penicillium citrinum isolates (Silva *et al*., 2020). Other fungi that can produce CIT include *Penicillium expansum, Penicillium viridicatum, Aspergillus niveus, Aspergillus terreus* (Silva *et al*., 2021), *Monascus purpureus*, and *Monascus ruber* (Pickova *et al*., 2020). Citrinin is proven nephrotoxic, proven to target the kidney from a previous study of contaminated chicken fed by *P. citrinum* (Bhatnagar *et al*., 2002). According to IARC, CIT is classified as a group 3 carcinogen, i.e., not carcinogenic to humans.

3.4 Fumonisin

Fumonisins are known as *Fusarium* mycotoxins, mainly produced by *Fusarium verticillioides* (formerly known as *Fusarium monoliforme*). To date, 28 fumonisins were identified and classified into four different groups (A, B, C, and P; Rheeder *et al*., 2002). The most occurring group is fumonisin B (FB), comprising FB_1, FB_2, and FB_3, with FB_1 being the most isolated fumonisin, mainly from corn and corn-based products (Alshannaq and Yu, 2017; Reddy et al., 2010). In 1970, *F. verticillioides* was associated with a field disease outbreak, leukoencephalomalacia (ELEM), in South Africa, as the species was the most isolated fungi in corn (Marasas, 2001). The disease can be described as liquefactive necrotic lesions in the white matter of the horses' brain (Marasas, 2001). Other studies have proven that this toxin targets the liver and kidneys of animals and cultured human cells (Seefelder *et al*., 2003; Fink-Gremmels, 2008; Afsah-Hejri *et al*., 2013). The assessment of fumonisins by IARC (1993b) showed their carcinogenic risk to humans and classified them as group 2B carcinogens, i.e., probably carcinogenic to humans.

The incidence of FBs in spices has piqued the interest of researchers to investigate them. In China, Kong *et al.* (2012) investigated the incidence of FB_1 and FB_2 in spices and herbs. The authors found mouldy samples (42.5%) were contaminated with FB_1 and FB_2, with the mean value of 129.0 and 165.9 µg/kg. Meanwhile, normal samples (8.6%) were contaminated with 165.9 and 256.8 µg/kg of FB_1 and FB_2. Waśkiewicz *et al.* (2013) screened herbs and spices from Poland markets and found FBs from the samples ranging from 5.29 to 62.78 µg/kg for total FBs.

3.5 Trichothecene (TC)

Trichothecene (TC) is a huge group of TC toxins, and the first member of this group was identified in 1949 produced by *Trichothecium roseum* (Glenn, 2007). More than 150 TC variants were identified, but only a few commonly occur in agricultural products (Yazar and Omurtag, 2008; Alshannaq and Yu, 2017) and 40 TC variants were identified as *Fusarium* mycotoxins. *Fusarium* species generally invade plants in the field and produce TC (Bennet and Klich, 2003). Commonly occurring *Fusarium* species in commodities are *Fusarium graminearum* and *Fusarium culmorum*. Other species that could produce TCs include *Cephalosporium*, *Cylindrocarpon*, *Dendrodochium*, *Myrothecium*, *Trichoderma*, *Trichothecium*, and *Stachybotrys* species (Bottalico and Perrone, 2002; Alshannaq and Yu, 2017). TCs commonly produced by *Fusarium* species are deoxynivalenol (DON), T-2 toxin, diacetoxyscirpenol, and nivalenol (Afsah-Hejri *et al*., 2013; Glen, 2007). TCs commonly contaminate agricultural commodities such as wheat, barley, oats, rye, corn, and rice (Yazar and Omurtag, 2008). The incidence of *Fusarium* toxins in food commodities was reported elsewhere (Nathanail *et al*., 2015; Almeida *et al*., 2016; Bryla *et al*., 2018; Torović, 2018; Mahdjoubi *et al.,* 2020).

3.6 Zearalenone (ZEA)

Zearalenone (ZEA, formerly known as F-2 toxin) is a non-steroid oestrogen mycotoxin (Zinedine *et al*., 2007). ZEA has a molecular structure similar to natural oestrogens, allowing them to bind to oestrogenic receptor sites, resulting in increased oestrogenicity. Exposure to this toxin is associated with lower levels of progesterone and serum testosterone in the circulation, resulting in infertility and lower pregnancy rates in cows, pigs, and rats (Yang *et al*., 2007; Rai *et al*., 2019; Mahato *et al*., 2021). ZEA is produced by some *Fusarium sp.*, mainly *Fusarium graminearum* and *Fusarium semitectum* (Mahato *et al.,* 2021). Other ZEA producers include *Fusarium culmorum, Fusarium verticillioides, Fusarium cerealis, Fusarium crookwellense, Fusarium pseudograminearum,* and *Fusarium equiseti.* (European Commission, 2000; Glenn, 2007; Afsah-Hejri *et al*., 2013). Fungi-producing ZEA is mainly found in plants grown in temperate and warmer climates and is usually found in corn, wheat, oats, barley, and sorghum (Mally *et al.,* 2016). The incidence of ZEA in these commodities have been reported worldwide (Ayalew *et al*., 2006; Almeida-Fereira *et al*., 2013; Nathanail *et al*., 2015; Piacentini *et al*., 2018; Golge and Kabak, 2020). ZEA has also been reported in spices (Patel *et al*., 1996; Schollenberger *et al*., 2005). IARC classified ZEA as a group 3 carcinogen, i.e., not classifiable as carcinogenic to humans. It has less severe toxicity, but due to its high oestrogenic activity, long-term exposure to it may pose a health concern.

4. Regulatory limits

Implementing prevention and control measures and establishing regulatory limits are vital to avoiding mycotoxin exposure to consumers. The primary goal is to establish a maximum level of mycotoxins in foods to enable fair trade while preserving consumers' health. The regulatory limits for mycotoxins have been established in over a hundred countries (van Egmond, 2013). Currently, the regulation limit of mycotoxins in spices ranges from 5–30 µg/kg depending on each country (FAO 2004; van Egmond *et al*., 2007; Reddy *et al*., 2010). Although each country has its mycotoxin regulations, standardised regulations are yet to be implemented (Iha and Trucksess, 2019). For example, certain countries did not prescribe AFs specifically in spices; therefore, spices fall under "other types of food." Moreover, OTA regulations are only available in coffee and cereal-based foods for infants in most countries.

According to the European Union (EU) standard, the AFB_1 maximum limit in spices like chilli, peppers, nutmeg, ginger, turmeric, and a mixture of spices is 5 µg/kg, while the sum of AFB_1, AFB_2, AFG_1, and AFG_2 in spices is 10 µg/kg (European Commission, 2010). Meanwhile, the maximum regulated limit of OTA in spices is 15 µg/kg (European Commision, 2012).

5. Fungal and mycotoxin contamination in spices

Spices are prone to fungal contamination, mainly by mycotoxigenic species during pre- and post-harvest. In addition, most of these products are sold without being properly processed. In most cases, they are packed upon being dried and ground and sold to the public (Kneifel and Berger, 1994; Costa *et al*., 2019). The entire spice production must be carefully managed to minimise fungal infection and mycotoxin contamination.

Spoilage fungi present in spices can alter the organoleptic properties of the spice products, lowering their commercial value (Garcia *et al*., 2018). Apart from that, high fungal contamination can lead to mycotoxin contamination, affecting consumer wellbeing since mycotoxins are heat-stable and difficult to be eliminated (Alshannaq and Yu, 2017; Kabak and Dobson, 2017). The occurrence of fungi in spices, mainly *A. flavus* and *A. niger*, has been extensively studied worldwide (Table 2). The incidence of mycotoxins (AFs and OTA) in spices produced by these species is summarised in Table 3.

5.1 Chilli

Chillies are the fruit of the capsicum plant belonging to the family Solanaceae, which originates from America. Several types of chillies are available in the market, such as fresh chillies, dried chillies, chilli pastes, chilli powder, and chilli flakes. Chilli can be consumed right after being harvested; however, most chilli production is devoted to processed dried chilli, often used to make seasonings such as spice powder mix. According to Khadka *et al*. (2017), most fungi are likely a pathogen or contaminant instead of native to the plant. Thus, controlling water activity (a_w), humidity, temperature, and hygiene conditions during the drying, storage, packing, and distribution stages is critical to ensure a low level of mycoflora in chilli after processing. After the drying process, chilli can be contaminated with xerophilic fungi such as *Aspergillus* and *Penicillium*. These could be due to the xerophilic properties of these fungi, where they gain a competitive advantage over other fungal pathogens in low a_w conditions (Sanzani *et al*., 2016). According to Costa *et al.* (2019), chilli products are hygroscopic. Efficient packaging systems, such as modified atmosphere systems, can avoid moisture reabsorption during the post-processing stage to reduce the risk of mycotoxin contamination.

High levels of fungi have been recorded in food products that contain chilli (Khan *et al*., 2014; Singh and

Table 2. Isolation frequency of mycotoxigenic fungi in spices

Spice samples	Isolation frequency (%)		References
	A. flavus	*A. niger*	
Black pepper	28	52	Garcia *et al*. (2018)
Chilli	31	4	Wikandari *et al.* (2020)
Red Chilli	96	62	Mandeel (2005)
Red pepper	10	26	Saidi *et al.,* (2021)
Cinnamon	12	10	Kong *et al.* (2014)
Cumin	ND	15.2	Kong *et al.* (2014)
Cumin	40	60	Hashem and Alamri (2010)
Clove	ND	25	Hashem and Alamri (2010)
Coriander	12	36	Saidi *et al.,* (2021)
Coriander	15	12	Kulshrestha *et al.* (2014)
Fennel	12	32	Garcia *et al*. (2018)
Fennel	19	7	Kulshrestha *et al.* (2014)
Star anise	ND	ND	Kong *et al.* (2014)
White pepper	32	40	Garcia *et al*. (2018)
Mixed spices	57	ND	Makhlouf *et al.* (2019)

ND: Not detected

Table 3. Worldwide occurrence of mycotoxin in spices

Country	Spices	Positive samples (%)	Amount of mycotoxins in samples (μg/kg)	No. of samples exceeding the EU limit (%)	Reference
Malaysia	Dried chilli	AFs: 65.00 OTA: 81.25	AFs: 0.20-79.70 OTA: 0.20-101.20	NA	Jalili and Jinap (2012)
Indonesia	Dried chilli	NA	AFB_1: 39.30–139.50 AFB_2: 2.60–33.30 OTA: 23.70–84.60	NA	Wikandari *et al.* (2020)
Italy	Peppers, chilli, cinnamon, cloves, coriander, mixed spices	AFs: 15.40 AFB_1: 8.50 OTA: 23.80	AFs: 0.96 AFB_1: 0.31 OTA: 6.18	AFs: NA OTA: 2.30	Prelle *et al.*, (2014)
Malaysia	Chilli, peppers, cumin	AFB_1: 93.33	AFB_1: 1.20-3.26	NA	Reddy *et al.* (2011)
Pakistan	Chilli powder, whole chilli, chilli sauce and crushed chilli	AFs: 56.40 OTA: 40.40	AFs: 12.50-15.16 OTA: 16.68-120.90	AFs: 26.30 OTA: 32.70	Iqbal *et al.* (2017)
Thailand	Chilli powder	AFB_1: 100.00	AFB_1: 5.32 -11.14	AFB_1: 0.00	Thanaboripat *et al.* (2016)
Qatar	Black pepper	AFs: 41.7	AFs: 1.85-70.33	NA	Hammami *et al.*, (2014)
Malaysia	Dried chilli, fennel, cumin, black pepper, white pepper, coriander and mixed spices	AF: 85 OTA: 79	AFs: 0.01-9.34 OTA: 0.14-20.40	NA	Ali *et al.*, (2015)
Benin	Pepper, chilli, cumin, cinnamon, anise	AFB_1: 84	AFB_1: 0.46-84.84	40.00	Akpo-Djènontin *et al.*, (2018)
Turkey	Red chilli powder, black pepper, cumin	AFB_1: 43.75 OTA:26.56	AFB_1: 0.13-35.77 OTA: 0.63-98.2	AF: 13.60 OTA: 13.60	Ozbey and Kabak, (2012)
Hungary	Black pepper, mixed spices, chilli	31.25	AFB_1: 0.16-8.10 OTA:2.1	AFB_1: 20.00 OTA: NA	Fazekas *et al.*, (2005)
India	Black pepper	AFB_1: 45.24 AFs: 76.00 OTA: 78.57	AFB_1: NA AFs: 4.80-26.40 OTA: 4.60-13.80	NA	Jeswal and Kumar (2015)
India	Red chilli	AFB_1: 56.36 AFs: 85.45 OTA: 72.73	AFB_1: NA AFs: 4.30-33.60 OTA: 3.50-8.60	NA	Jeswal and Kumar (2015)
Ethiopia	Pepper	AFs: 42.00	AFs: 3.10-19.20	AFs: 98.00	Tsehaynesh *et al.* (2021)
Korea	Chilli powder, chilli paste	AFs: 13.60	AFs: 0.08-4.66	AFs: 0.00	Cho *et al.* (2008)
Turkey	Chilli powder	AFs: 63.60 OTA: 54.50	AFs: O.20-35.77 OTA: 0.78-98.20	AFs: 4.50 OTA: 13.60	Ozbey and Kabak (2012)

NA: Not available, AFs: Aflatoxins, OTA: Ochratoxin A

Cotty, 2017; Gambacorta *et al.*, 2018). According to Costa *et al.* (2019), antifungal substances and low a_w in spices are the key obstacles to microbial growth in these products. However, fungal growth cannot be fully inhibited in chillies due to the fungal metabolic plasticity that helps to adapt to adverse conditions throughout chilli production. Previous researchers reported a significant level of fungal contamination in chillies primarily by *Aspergillus*, *Penicillium*, and *Fusarium* species and some soil-borne fungi such as *Cladosporium* and *Mucor*. Moreover, Mandeel (2005) revealed that of the 17 spices tested, chillies had the highest fungal contamination from *A. flavus* and *A. niger*.

Singh and Cotty (2017) studied the occurrence of AFs in chilli from various markets in Nigeria and the United States of America (USA). The authors discovered that 93% of Nigerian chilli were contaminated with AFB_1, while the chilli samples from the USA recorded 64% contamination. Nigerian chilli had comparatively higher AFB_1 concentrations, with the most contaminated sample having 156 μg/kg AFB_1. Approximately 38% of USA chillies were contaminated with > 5 μg/kg AFB_1. On the other hand, Pakistani chillies have lost their international market share due to mycotoxin contamination despite having exceptional sensorial qualities. Another study by Khan *et al.* (2014) also reported a high level of AFs in Pakistani chilli, with most samples exceeding the EU regulation limit.

Reddy *et al.* (2001) investigated AFB_1 contamination in fresh chillies and chilli powders from various markets in Andra Pradesh, India. They discovered that AFB_1 was detected in 59% of the chilli samples, and fresh chilli recorded the highest amount of AFB_1 (969 µg/kg). The physical damage to fresh chillies could be the reason for the high AF level of the fresh chilli since most of the samples were discoloured with noticeable fungal infestation.

Previous studies have stated that chilli sauce, chilli flakes, chilli powder, and dried chillies were contaminated with OTA (Ozbey and Kabak, 2012; Prelle *et al.,* 2014; Iqbal *et al.,* 2017; Wikandari *et al.,* 2020). Mycotoxin contamination levels are directly influenced by geography, climate conditions, and crop management practices. Almela *et al.* (2007) identified 115 fungal strains, with 85 of them being *A. carbonarius*, *A. niger*, and *A. ochraceus* in the assessment of OTA in chilli samples grown in Spain, Zimbabwe, Brazil, and Peru. Furthermore, they also observed the climatic conditions of the sample's origin, and the cultural, and technological practices of chilli crops. They revealed that Peru has the highest OTA contamination in chilli, which may be associated with high humidity levels in chilli-growing regions.

5.2 Cinnamon

Cinnamon is the tree's inner bark of the genus *Cinnamomum*, derived from the Greek word *kinamon* (Raghavan, 2007). Although more than 250 varieties of cinnamon were identified (Rao and Gan, 2014), four types are most commonly used in various cuisines, including Chinese cinnamon (*Cinnamomum cassia*), Sri Lanka cinnamon (*C. zeylanicum)*, Indonesian cinnamon *(C. burmannii*), and Vietnamese cinnamon (*C. loureirii*; Nabavi *et al.*, 2015). Cinnamon mainly contains volatile compounds such as cinnamaldehyde (65%–80%) and eugenol (5%–10%) in the plant's bark (Rao and Gan, 2014). These two compounds are responsible for their spicy sweetness and act as effective compounds against bacteria and moulds (Davidson and Naidu, 2000; Tajkarimi *et al*., 2010).

Cinnamon has been used for cooking since ancient times. It is used in several cuisines as an aromatic condiment and flavouring additive. It also has great importance in medicine due to its antioxidant and antimicrobial properties (Nabavi *et al*., 2015). In the market, cinnamon can be found as whole or ground spices. The whole and ground cinnamon are widely used in Asian and Latin American countries, while the European and Mediterranean countries prefer the ground form.

Several studies had reported a low incidence of fungi in cinnamon samples. In Indonesia, cinnamon recorded low fungal counts, with the most occurring species of *Eurotium chevalieri* (Nurtjahja *et al.*, 2019). *A. flavus* and *A. carbonarius* were also recorded at low levels. Similarly, a study in Tanzania found that cinnamon was among the less contaminated samples (Temu, 2016). A similar study in Saudi Arabia found *A. flavus* and *A. niger* in cinnamon samples at 33% and 75% (Hashem and Alamri, 2010). Meanwhile, some significant species isolated from cinnamon in Bahrain were *A. niger* (25%) and *Rhizopus stolonifer* (56%) (Mandeel, 2005).

A study in Benin by Akpo-Djènontin reported a mixture of spices, including cinnamon, contaminated with 8.86 µg/kg of AFB1 (Akpo-Djènontin, 2018). Cho *et al*. (2007) found no detectable AF from cinnamon samples in Korea. Similarly, Ozbey and Kabak (2002) and Riordan and Wilkinson (2008) demonstrated an undetectable limit of AFs in cinnamon samples from Turkey and Ireland.

5.3 Clove

Cloves are dried flower buds of *Syzygium aromaticum* in the family of Myrtaceae (Raghavan, 2007). The name "clove" is derived from Latin *clavus*, Spanish *clavo*, French *clou*, and German *nelke,* which means "nail" due to its resemblance to a nail's shape (Raghavan, 2007). The flower buds are picked before opening and sun-dried. After drying, the colour of the cloves turns dark brown with a slightly light brown content. Cloves have an intensely bitter and woody flavour and release a spicy-sweet aroma. The volatile oil of clove buds ranges from 5% to 20%, with eugenol, eugenyl acetate, and β-caryophyllene as the main components. The volatile oil has a significant amount of eugenol, which exhibits biological and antimicrobial properties (Leela and Sapna, 2008). In a recent study, Hlebová *et al.* (2021) revealed that clove oil has the highest inhibitory effect against all *Aspergillus* species tested, i.e., *A. flavus*, *A. fumigatus*, *A. terreus*, and *A. niger* (Hlebová *et al*., 2021). Eugenol volatile oils may inhibit the growth of microorganisms such as *A. niger*, *Saccharomyces cerevisiae*, *Mycoderma* sp., *Lactobacillus acidophilus*, and *Bacillus cereus* to varying degrees (Meena and Sethi, 1994; Leela and Sapna, 2008).

Cloves function best in a whole form because the flavour will disappear once the cloves are ground. Sweet, fruity, caramelised, chocolatey, and meaty flavours all pair well with clove. It is used in various dishes such as salad dressings, desserts, and fruitcakes in the USA. Cloves are used in the whole form or ground in garam masala, biryani, meat dishes, and pickles by Sri Lankans

eISSN: 2550-2166

and North Indians.

Several studies have shown little to no occurrence of fungi in cloves. Nurtjahja *et al.* (2019) examined the clove samples from the markets in Indonesia and found cloves among the less contaminated samples of all the studied samples. Similarly, Hashem and Alamri (2010) and Elshafie *et al.* (2002), who studied clove samples in Saudi Arabia and the Sultanate of Oman, also reported less incidence of fungi. Temu (2016) revealed that cloves showed no fungal colonies after multiple culturing. Volatile oils could be the main reason for low fungal counts in cloves (Hashem and Alamri, 2010; Guyenot *et al*., 2003; Eilsen and Rios, 2000). Aiko and Mehta (2016) also reported no occurrence of fungi from clove samples in India.

5.4 Star anise

Star anise or *Illicium verum* is a tree containing a star -shaped fruit used as a spice. The fruits have eight carpels with a seed inside each carpel. Star anise turns to reddish-brown colour after it is sun-dried. The plant is indigenous to China and Vietnam. Nowadays, star anise is cultivated in many countries such as India, Japan, Korea, Laos, and the Philippines. Star anise has almost the same taste as fennel. It has a sweetish and spiciness flavour due to its volatile oil, such as anethole, contributing to 85–90% of total volatile oils (Chempakam and Balaji, 2008). According to the authors, anethole may also contribute to the antimicrobial properties of star anise.

The sweetness and spiciness of star anise are enhanced when it is cooked. Star anise symbolises Chinese cuisines. It is usually blended with other spices such as clove, fennel, cassia, and Sichuan pepper (George, 2004). The mixture is called the Chinese five-spice, and it is commonly used for batters, meat marinade, stews, and soups (George, 2004; Raghavan, 2007). Apart from China, star anise is also used as a five-spice powder mix in Vietnam, mainly to make beef soups. In Malaysia, star anise is used in various cuisines, such as soup and curry.

The study of fungal and mycotoxin occurrence in star anise is scarce. From the previous screenings of fungi, several researchers found no occurrence of fungi in star anise samples (Kong *et al*., 2014; Aiko and Mehta, 2016). This can be explained by the presence of anethole, the major essential oil in star anise that inhibits fungal growth. Moreover, studies have shown the antifungal activity of star anise against *A. flavus* and *A. parasiticus* (Freire *et al.,* 2011; Aly *et al*., 2016).

5.5 Coriander seeds

Coriander that is used as a spice is referred to as coriander seeds. It is the spherical seeds of *Coriandrum sativum* from the family Apiaceae. Coriander originated from Asia and is now cultivated in other countries such as India, Argentina, Mexico, Morocco, and the USA (Raghavan, 2007). It has a yellowish-brown colour and is available whole or ground. Coriander is added to various cuisines as a flavouring. Coriander seeds contain 0.2%–2% of volatile oils, mainly *d*-linalool, which contribute to the fragrance. Coriander is most commonly used as a ground spice. It is the main ingredient of blended powdered spices like curry and korma. Coriander seeds will produce a strong aroma when it is dry-fried.

Saidi *et al*. (2021) studied coriander samples from military caterings and found *Aspergillus* spp. (36%) as the most occurring genera, primarily *A. niger* (36%) and *A. flavus* (12%), commonly known as mycotoxin-producing fungi. Similarly, Jeswal and Kumar (2015) investigated 30 coriander samples from local markets in Bihar, India, and isolated 3 most dominant fungal species; *A. niger* (10.6%), *A. flavus* (8.0%), and *P. verrucosum* (6.3%). In contrast, a recent study by Nurtjahja *et al.* (2019) revealed a low occurrence of toxigenic *Aspergillus* spp. from coriander samples purchased from traditional markets in Medan, Indonesia.

The incidence of mycotoxins, mainly AFs and OTA, in coriander seeds has been extensively reported in various countries. Jeswal and Kumar (2015) reported the incidence of AFB_1 and OTA in 50% and 30% of coriander samples. Darra *et al.* (2019) reported 75.3 µg/kg of total AFs and no occurrence of OTA in coriander samples. In addition, a study in Tunisia reported a high incidence of OTA in 50% of coriander samples ranging from 74 to 576 µg/kg (Zaied *et al.*, 2010).

5.6 Pepper

Pepper is a dried small berry called peppercorn from the flowering vine *Piper nigrum* in the family Piperaceae. The word pepper is derived from the Sanskrit term *pippali*, which means Indian long pepper, a close relative of black pepper. There are many types of pepper, including black and white pepper. The difference between black and white pepper is they were picked at different stages of growth and the way it was processed (Raghavan, 2007).

Black peppercorn is harvested from green, dried, unripe berries from the pepper plant. Black pepper is prepared by boiling the harvested berries for a short time (Farkas and Mohácsi-Farkas, 2014). After boiling, the berries are dried until they become blackened or brownish with a hard wrinkled surface (Farkas and Mohácsi-Farkas, 2014). White peppercorn is near ripe berries. Unlike the black pepper, white pepper is made up of only the inside seed of peppercorn, not the whole fruit. The outer pericarp of white peppercorns is prepared by soaking the berries in water to soften the skin, and the pericarp, along with the pulpy coating, is removed by rubbing. Then, it is bleached, rinsed, and dried. White pepper can also be made from black peppercorns by removing the outer shells manually by a process known as decortication (Farkas and Mohácsi-Farkas, 2014). This kind of white pepper will partly resemble the taste of black pepper.

Pepper fruits are pungent and aromatic. Black and white pepper have two basic components contributing to their pungency and aroma. The pungency of black and white pepper is due to a non-volatile chemical compound called *piperine.* The pungent aroma of black pepper is due to its volatile oil, monoterpenes, which consists of sabinene, α-pinene, β-pinene, limonene, and 1,8-cineole (Raghavan, 2007). Similarly, white pepper also contains *piperine* which contributes to pungency. Nevertheless, white pepper has less aroma than black pepper because it lacks essential oil, primarily present in the pericarp (Raghavan, 2007). Globally, peppers are the most widely used table spices. Black pepper is often known as "black gold" and "king of spices." Peppers are used to alter the taste of food on the table, added during cooking, or used as marinades. In Southeast Asia, including Malaysia, peppers are generally used in soups, curries, and to marinate meat and poultry.

Several studies have reported a high occurrence of fungi in black pepper samples. Nurtjahja *et al*. (2019) reported a high incidence of fungi, mainly *Aspergillus* spp., from black and white pepper in Indonesia. Garcia *et al.* (2018) reported that black pepper was among the most contaminated samples by toxigenic *Aspergillus* spp., i.e., *A. flavus*, *A.parasiticus*, *A. nomius*, *A. ochraceus*, *A. niger*, and *A. carbonarius* in Brazil. Temu (2016) reported black pepper contaminated with AF-producing fungi, *A. flavus*, *A. parasiticus*, and *A. nomius* in Tanzania. In contrast, white pepper was among the less contaminated samples, with only two genera, *Aspergillus* and *Rhizopus* spp. Black pepper samples from Bahrain was contaminated with 1.12×10^3 CFU/g of fungi, mostly by the *A. flavus* species (78%; Mandeel, 2005).

Some studies reported on the presence of mycotoxins in black pepper. In Korea, Cho *et al.* (2007) reported the presence of mycotoxin below the detection limit in black pepper. Fewer mycotoxins detected in black pepper samples compared to other countries could be due to the climate in Korea with low temperature and humidity, which is not ideal for fungal growth and mycotoxin production. In contrast, Hammami *et al*. (2014) reported a high level of AFs in black pepper at 84.09 µg/kg in Qatar. Meanwhile, a study in Turkey found that 30.4% of black pepper samples were detected for AFs, mainly AFB1 and AFB2, ranging from 0.13 to 0.42 µg/kg and 0.04 to 0.05 µg/kg. In comparison, OTA was detected in 17.4% of the samples at concentrations of 0.87 to 3.48 µg/kg (Ozbey and Kabak, 2012). Similarly, in Cameroon, OTA was detected in 10% of black pepper samples at 1.53 µg/kg and 40% of white pepper samples at 3.30 µg/kg.

5.7 Fennel

Fennel (*Foeniculum vulgare* Mill.) is a member of the Apiaceae family. Fennel seed is oval-shaped with a pale green to yellowish-brown colour. The flavour of fennel resembles the star anise, which comes from its chemical compound, anethole (Shamina Azeez, 2008). Fennel exists in various types, and the most commonly used are sweet fennel (*F. vulgare* var.) and bitter fennel (*F. vulgare* Mill). Fennel seeds comprise 1% to 6% volatile oil, which distinguishes the bitter and sweet fennel. Bitter fennel contains 1% to 6% volatile oil, with anethole as the major compound, comprising 50% of the oil. Meanwhile, the sweet fennel has 50% to 80% anethole.

In India, Jeswal and Kumar (2015) demonstrated moderately contaminated fennel samples with *A. flavus* (12.3%), *A. niger* (5.3%), and *A. ochraceus* (5.0%). Kulshrestha *et al.* (2014) also revealed that the fennel samples in India were mostly contaminated by *A. flavus* (18.51%) and *Fusarium oxysparum* (14.81%). Simultaneously, *A. flavus* and *A. fumigatus* were also detected at 7.40%.

Consequently, Garcia *et al.* (2018) reported only 12.5% (1 out of 8) of *A. niger* strains isolated from fennel could produce OTA. Ali *et al*. (2015) reported the presence of AFs from 0.01 to 5.29 µg/kg and OTA was from undetectable levels to 1.26 µg/kg in fennel samples.

5.8 Cumin

Cumin is a dried, ripe fruit from the flowering plant *Cuminum cyminum* in the family Apiaceae. The name cumin is from the word *sughandan*, which means pleasant smell. Cumin is a long oval-shaped, greenish or light-brown seed. It has a spicy, earthy, and bitter taste. Cumin is native to India, Iran, Egypt, the eastern Mediterranean, China, Indonesia, and Syria (Raghavan, 2007). Cumin is sold as ground or whole spices. The main volatile components in cumin are cuminaldehyde, β -pinene, terpinene, and ρ-cymene. The presence of cuminaldehyde contributes to its flavour and aroma (Amin, 2001). Whole and ground cumin is used in a wide range of cuisine. In India, cumin is used to make pickles or blended spices called *sombar padi* (Amin, 2001; Raghavan, 2007).

The study by Mandeel (2005) in Bahrain demonstrated contaminated cumin samples with 4.6×10^2 CFU/g fungi, with *A. niger* the most isolated species (36%). In addition, Hashem and Alamri (2010) reported *A. niger* (60%) as the most frequently occurring *Aspergillus* species, followed by *A. flavus* (40%) and *A. fumigat*us (20%). These three species are known as OTA - and AF-producing fungi. Temu (2016) reported that cumin samples were among the less contaminated spices in Tanzania.

Zinedine *et al.* (2007) demonstrated that 57% of cumin samples purchased from popular markets in Morocco exhibited very low occurrence of AFB_1 and total AFs, with the mean values of 0.03 µg/kg and 0.05 µg/kg. Additionally, Bircan (2005) observed no AF contamination in cumin samples in Turkey at the detection limit of 0.2 µg/kg. Riordan and Wilkison (2007) also reported no AFs in cumin samples from the Irish market. Reddy *et al.* (2011) reported that 67% of positive samples of cumin for AFB1 ranged from 1.89 to 4.64 µg/kg and a mean level of 3.26 µg/kg. This level did not exceed the EU regulation (5 µg/kg). However, a study by Mwangi *et al*. (2014) reported a very high incidence of AF (98 µg/kg) in cumin samples from the Kenyan market, which exceeded the EU regulatory limits.

5.9 Mixed spices

Mixed spice is a blend of different types of spice. Commercial blend spices are convenient and easy to use and can be found easily in the market. Some foods require a lot of spices; therefore, mixed spices are useful to reduce the preparation time. Mixed spices can create a consistent flavour, colour, and texture of the cuisines. They usually consist of spices, salt, sugar, monosodium glutamate (MSG), anti-caking agents, and a lot more. The other ingredients were added to enhance the overall flavour and improve the quality of the mixed spices. Some popular mixed spices in the markets are curry and korma mix.

Curry powder is a mixture of many spices. The main spices in curry powder include coriander seeds, cumin, turmeric, and ginger (Ravindran and Kallupurackal, 2001). Other minor ingredients are fenugreek, celery, black pepper, red pepper, cinnamon, nutmeg, cloves, caraway, fennel, cardamom, and salt. The ingredients differ depending on the desired outcome (Sharma and Sharma, 2004). Curry powders are widely used in cooking worldwide, especially in South Asian cuisines (Ravindran and Kallupurackal, 2001). Besides curry powder, korma mix is an instant powder of various spices. It consists of coriander seeds, cumin, fennel, white pepper, star anise, cinnamon, dhal, dry ginger, cardamom, clove, and black pepper. Korma powder is widely used in Malaysia to prepare many delectable cuisines.

A study in Qatar revealed no occurrence of fungi in curry samples (Hammami *et al.*, 2014). Likely, Temu (2016) reported that curry was among the less contaminated samples. Hammami *et al.* (2014) emphasised that some spices in the curry mixture exhibit antifungal properties. This could be explained by the minimal contamination of the curry samples. In contrast, Makhlouf *et al.* (2019) found high fungal contamination in spice mixtures. Corroborating their findings, the authors explained that the mixture of various spices in these products contributed to higher fungal contamination as each ingredient used in the mixed spices might be exposed to a different source of contamination.

Ali *et al.* (2015) reported the incidence of total AFs, AFB_1, and OTA in curry and korma mix ranging 0.03 to 3.04 µg/kg, 0.03 to 2.26 µg/kg, and 0.14 to 9.59 µg/kg, respectively. Another study revealed that the amount of AFB_1 in mixed spices purchased from different cities in Malaysia was above the EU legislation limit (5 µg/kg), ranging from 4.7 to 14.36 µg/kg (Alsharif *et al.*, 2019).

6. Conditions of fungal growth

Spices are susceptible to fungal contamination despite the low a_w of the commodities. Contamination can occur depending on the place of cultivation, harvest, and processing (Nguegwouo *et al*., 2018). Spices are mainly cultivated in tropical countries with high temperatures and humidity, suitable for fungal contamination and mycotoxin production (Vyhnánek *et al*., 2018). During preharvest, pest and insect infestation in the spices contribute to fungal contamination (Cinar and Onbasi, 2019). Fungi can contaminate spices from the farm to the market. Once the spices are infected in the field, the fungi will continue to grow during storage in favourable conditions (Reddy *et al*., 2010). In addition, the processing of spices is one of the primary sources of contamination. For example, since sun drying is cost-efficient, spices are usually sun-dried to reduce the moisture content and extend the shelf life (Thanushree *et al*., 2019). However, inadequate drying could result in fungal growth during storage, leading to the deterioration in the quality and safety of the spices

(Thanushree *et al*., 2019).

Aspergillus spp. is generally known as storage fungi that can contaminate various food and feedstuffs during prolonged storage. *Aspergillus* species are xerophilic fungi and able to survive at very low aw and produce mycotoxins. Several researchers have reported the occurrence of toxigenic fungi in spices. *A. flavus* and *A. niger* are the most predominant toxigenic fungi usually found in spices. Table 2 shows the isolation frequency of mycotoxigenic fungi in some common spices.

Penicillium is another storage fungi that can produce mycotoxins, especially in countries with tropical climates (Pardo *et al*., 2006). *Penicillium* has a wide range of species and habitats, and some of the species are known as mycotoxin producers (Pitt and Hocking, 2009). It can grow in various environments such as soil, air, interior spaces, and many food products (Visagie *et al*., 2014). However, the conditions that promote fungal growth do not confirm the presence of mycotoxins (Sanchis and Magan, 2004; Pardo *et al*., 2006). According to the authors, the fungi can grow abundantly in certain conditions without producing mycotoxins.

7. Impact of mycotoxin contamination

Mycotoxicoses can be classified as acute or chronic, just like any toxicological syndrome. Acute toxicity is defined by a rapid onset and an obvious toxic response. In contrast, chronic toxicity is defined by a low-dose exposure over a long period, likely to result in cancers and other typically irreversible effects (Zain, 2011). Aflatoxicosis is a type of toxic hepatitis that causes jaundice, and in more severe cases, may lead to death (Lewis *et al*., 2005). Chronic dietary exposure is usually the source of the most significant risk of AF in humans. Human hepatocellular carcinomas have been linked to dietary AF exposure, which may be exacerbated by the hepatitis B virus. Hepatocellular carcinomas are responsible for fatalities in Sub-Saharan Africa and China. The disease is linked to several risk factors, such as high daily consumption of AFs (1.4 µg) and high cases of hepatitis B (Wild *et al*., 1992; Zain, 2011). In Gambian children, consumption of AF-contaminated food was linked to lower levels of secretory immunoglobulin A (IgA; Turner *et al*., 2003). AFs contamination has also caused functional changes in particular lymphocyte subsets and changes in differential subset distributions in Ghanaian adults, demonstrating that AFs may impair individual cellular immunity, lowering resistance to infections (Jiang *et al*., 2005).

8. Management and control strategies of mycotoxin contamination in spices

Globally, mycotoxin contamination in spices is widespread, primarily in tropical areas. Proper pre and postharvest practices are the best mitigation strategy to prevent the increased level of mycotoxins (Moses *et al.*, 2014; Iha and Truckses, 2019). Besides, the implementation of good agricultural practices (GAP), good storage practices (GSP), and good manufacturing practices (GMP) can mitigate the production of mycotoxin (Kamle *et al.*, 2019). Preharvest practices such as irrigation, pest control, fungicides and fertilisers are useful to control mycotoxin production (Bhatnagar *et al*., 2002; Iha and Trucksess, 2019). Nevertheless, irrigation application during preharvest might be challenging as it is costly and difficult to adapt to a new technique in agricultural practices. The use of fungicides can also retard the growth of AF-producing fungi such as *A. flavus* (Santos *et al*., 2010). The authors revealed that the most effective fungicides against *A. flavus* strains and AF production were tebuconazole 25% and mancozeb 80%.

Postharvest control measures are fundamental to ensure the safety and quality of commodities. Various methods are implemented to degrade and remove mycotoxins from contaminated plants (Jallow *et al*., 2021). For instance, postharvest practices such as sorting and removing the damaged and mouldy fruits are important to prevent increased mycotoxin production (Iha and Trucksess, 2019). In addition, prompt drying of spices after cleaning is crucial as moisture is an important factor in fungi proliferation (Iha and Trucksess, 2019). Besides, physical, chemical, and biological methods are also tested and implemented. Chemical methods such as acids, bases, and oxidising and reducing agents are useful to degrade and detoxify mycotoxins (Jallow *et al*., 2021). Weng *et al.* (1994) revealed that the use of ammonia caused high degradation rates of AF. This can be explained by the fact that AFs are not stable under alkaline conditions and will reduce the toxins into less toxic substances (Moerck *et al*., 1980; Jallow *et al*., 2021). Oxidising agents such as ozone treatment and irradiation (sunlight, gamma, and ultraviolet [uv]) have the potential to control mycotoxins (Iha and Trucksess, 2019) and maintain the quality of agricultural commodities (Mahato *et al*., 2019). Moreover, atoxigenic fungi and non-aflatoxin forming strains of *A. flavus* have been used as a biological control to protect the crops from mycotoxin contamination (Dorner *et al*., 2003; Udomkun *et al*., 2017; Mahato *et al*., 2019).

REVIEW

9. Conclusion

In conclusion, spices are vulnerable to fungal infection, leading to mycotoxin contamination if the conditions are favourable for fungal growth. However, the level of mycotoxins in spices varies depending on the types of spices, processing methods, storage conditions, and others. AFs and OTA are the main mycotoxins reported in spices, especially chilli products. The high consumption of chilli-based products may expose consumers to the harmful effect of mycotoxins. Hence, implementing preventive and control measures is crucial to control the growth of mycotoxigenic fungi and prevent mycotoxin contamination in spices.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

This research was funded by the Short-Term Grant [304/PTEKIND/6315516] from Universiti Sains Malaysia. The first author would like to acknowledge the Institute of Postgraduate Studies, USM for the financial support under the GRA Assist scheme.

References

Adam, M.A.A., Tabana, Y.M., Musa, K.B. and Sandai, D.A. (2017). Effects of different mycotoxins on humans, cell genome and their involvement in cancer. *Oncology Reports,* 37(3), 1321–1336. https://doi.org/10.3892/or.2017.5424

Adeyeye, S.A.O. (2016). Fungal mycotoxins in foods: A review. *Cogent Food and Agriculture*, 2(1), 1213127. https://doi.org/10.1080/23311932.2016.1213127

Afsah-Hejri, L., Jinap, S., Hajeb, P., Radu, S. and Shakibazadeh, S. (2013). A review on mycotoxins in food and feed: Malaysia case study. *Comprehensive Reviews in Food Science and Food Safety,* 12(6), 629–651. https://doi.org/10.1111/1541-4337.12029

Aiko, V. and Mehta, A. (2016). Prevalence of toxigenic fungi in common medicinal herbs and spices in India. *Biotech*, 6, 159. https://doi.org/10.1007/s13205-016-0476-9

Akpo-Djènontin, D.O.O., Gbaguidi, F., Soumanou, M.M. and Anihouvi, V.B. (2018). Mold infestation and aflatoxins production in traditionally processed spices and aromatic herbs powder mostly used in West Africa. *Food Science and Nutrition*, 6(3), 541–548. https://doi.org/10.1002/fsn3.579

Ali, N., Hashim, N.H. and Shuib, N.S. (2015). Natural occurrence of aflatoxins and ochratoxin A in processed spices marketed in Malaysia. *Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment,* 32 (4), 518–532. https://doi.org/10.1080/19440049.2015.1011712

Almela, L., Rabe, V., Sánchez, B., Torrella, F., López-Pérez, J.P., Gabaldón, J.A. and Guardiola, L. (2007). Ochratoxin A in red paprika: Relationship with the origin of the raw material. *Food Microbiology*, 24 (4), 319–327. https://doi.org/10.1016/j.fm.2006.08.001

Almeida, A.P. de, Lamardo, L.C.A., Shundo, L., Silva, S.A. da, Navas, S.A., Alaburda, J., Ruvieri V. and Sabino, M. (2016). Occurrence of deoxynivalenol in wheat flour, instant noodle and biscuits commercialised in Brazil. *Food Additives and Contaminants: Part B*, 9(4), 251–255. https://doi.org/10.1080/19393210.2016.1195880

Almeida-Ferreira, G.C., Barbosa-Tessmann, I.P., Sega, R. and Machinski Junior, M. (2013). Occurrence of zearalenone in wheat- and corn-based products commercialized in the State of Paraná, Brazil. *Brazilian Journal of Microbiology*, 44(2), 371–375. https://doi.org/10.1590/S1517-83822013005000037

Alshannaq, A. and Yu, J.H. (2017). Occurrence, toxicity, and analysis of major mycotoxins in food. *International Journal of Environmental Research and Public Health*, 14(6), 632. https://doi.org/10.3390/ijerph14060632

Alsharif, A., Choo, Y.M. and Tan, G.H. (2019). Detection of Five Mycotoxins in Different Food Matrices in the Malaysian Market by Using Validated Liquid Chromatography Electrospray Ionization Triple Quadrupole Mass Spectrometry. *Toxins,* 11(4), 196. https://doi.org/10.3390/toxins11040196

Aly, S.E., Sabry, B.A., Shaheen, M.S. and Hathout, A.S. (2016). Assessment of antimycotoxigenic and antioxidant activity of star anise (*Illicium verum*) in vitro. *Journal of the Saudi Society of Agricultural Sciences,* 15(1), 20–27. https://doi.org/10.1016/j.jssas.2014.05.003

Amin, G. (2001). Cumin. In Peter, K.V. (Ed). Handbook of Herbs and Spices, 1st Ed. England: CRC press. https://doi.org/10.1201/9781439823002.ch13

Ayalew, A., Fehrmann, H., Lepschy, J., Beck, R. and Abate, D. (2006). Natural occurrence of mycotoxins in staple cereals from Ethiopia. *Mycopathologia*, 162, 57–63. https://doi.org/10.1007/s11046-006-0027-8

Bhatnagar, D., Yu, J. and Ehrlich K.C. (2002). Toxins of Filamentous Fungi. In Breitenbach M., Crameri R., Lehrer S.B. (Eds). Fungal Allergy and Pathogenicity, p. 167–206. Basel, Karger. https://doi.org/10.1159/000058867

Bottalico, A. and Perrone, G. (2002). Toxigenic *Fusarium* species and mycotoxins associated with head blight in small-grain cereals in Europe. *European Journal of Plant Pathology*, 108, 611–624. https://doi.org/10.1023/A:1020635214971

Bryla, M., Ksieniewicz-Wózniak, E., Wáskiewicz, A., Szymczyk, K. and Jedrzejczak, R. (2018). Natural occurrence of nivalenol, deoxynivalenol, and deoxynivalenol-3-glucoside in polish winter wheat. *Toxins*, 10(2), 81. https://doi.org/10.3390/toxins10020081

Chempakam, B. and Balaji, S. (2008). Star anise. In Parthasarathy, V.A. (Ed) *Chemistry of Spices.* Oxfordshire, United Kingdom: CAB International. https://doi.org/10.1079/9781845934057.0319

Cinar, A. and Onbaşi, E. (2019). Mycotoxins: The Hidden Danger in Foods. In Sabuncuoğlu, S. (Ed). Mycotoxins and Food Safety. IntechOpen E-Book. https://doi.org/10.5772/intechopen.89001

Cho, S.H., Lee, C.H., Jang, M. R., Son, Y.W., Lee, S.M., Choi, I.S., Kim, S.H. and Kim, D.B. (2008). Aflatoxins contamination in spices and processed spice products commercialized in Korea. *Food Chemistry*, 107(3), 1283–1288. https://doi.org/10.1016/j.foodchem.2007.08.049

Costa, J., Rodríguez, R., Garcia-Cela, E., Medina, A., Magan, N., Lima, N., Battilani, P. and Santos, C. (2019). Overview of fungi and mycotoxin contamination in *Capsicum* pepper and in its derivatives. *Toxins*, 11(1), 1–16. https://doi.org/10.3390/toxins11010027

Davidson, P.M. and Naidu, A.S. (2000). Phytophenols. In Naidu, A.S. (Ed). Natural Food Antimicrobial Systems, p. 265–295. Boca Raton, Florida: CRC Press.

Dorner, J.W., Cole, R.J., Connick, W.J., Daigle, D.J., McGuire, M.R. and Shasha, B.S. (2003). Evaluation of biological control formulations to reduce aflatoxin contamination in peanuts. *Biological Control*, 26(3), 318–324. https://doi.org/10.1016/S1049-9644(02)00139-1

European Commission (EU) (2010). Commission Regulation (EC) No. 165/2010 of 26 February 2010 amending Regulation (EC) No. 1881/2006 setting maximum levels for certain contaminants in foodstuffs as regards aflatoxins. *Official Journal of the European Union*, 50, 8-12.

European Commission (EU) (2012). Commission Regulation (EC) No. 594/2012 of 5 July 2010 amending Regulation (EC) No. 1881/2006 as regards the maximum levels of the contaminants ochratoxin A, non dioxin-like PCBs and melamine in foodstuffs. *Official Journal of the European Union*, 176, 43-45.

European Commission (2000). Opinion of the Scientific Committee on Food on Fusarium toxins: Part 2: Zearalenone (ZEA). Brussels, Belgium: European Commission.

FAOSTAT (2019). Compare data. Food and Agriculture Organization of the United Nations. Retrieved from FAOSTAT website: http://www.fao.org/faostat/en/#compare

Farkas, J. and Mohácsi-Farkas, C. (2014). Safety of food and beverages: Spices and seasonings. *Encyclopedia of Food Safety*, 3, 324–330. https://doi.org/10.1016/B978-0-12-378612-8.00290-0

Fink-Gremmels, J. (2008). Mycotoxins in cattle feeds and carry-over to dairy milk: A review. *Food Additives and Contaminants: Part A*, 25(2), 172–180. https://doi.org/10.1080/02652030701823142

Food and Agriculture Organization (FAO). (2004). Worldwide regulations for mycotoxins in food and feed in 2003. FAO Food and Nutrition Paper no. 81, p. 1–180. Rome: Food and Agriculture Organization.

Food and Agriculture Organization (FAO). (2016). Climate change, agriculture and food security. Retrieved from FAO website: https://www.fao.org/publications/sofa/2016/en/

Freire, J.M., Cardoso, M.G., Batista, L.R. and Andrade, M.A. (2011). Essential oil of *Origanum majorana* L., *Illicium verum Hook*. f. and *Cinnamomum zeylanicum* Blume: chemical and antimicrobial characterization. *Revista Brasileira de Plantas Medicinais,* 13(2), 209–214. https://doi.org/10.1590/S1516-05722011000200013

Gambacorta, L., Magistá, D., Perrone, G., Murgolo, S., Logrieco, A.F. and Solfrizzo, M. (2018). Co-occurrence of toxigenic moulds, aflatoxins, ochratoxin A, *Fusarium* and *Alternaria* mycotoxins in fresh sweet peppers (*Capsicum annuum*) and their processed products. *World Mycotoxin Journal*, 11 (1), 159–173. https://doi.org/10.3920/WMJ2017.2271

Garcia, M.V., Parussolo, G., Moro, C.B., Bernardi, A.O. and Copetti, M.V. (2018). Fungi in spices and mycotoxigenic potential of some *Aspergilli* isolated. *Food Microbiology*, 73, 93–98. https://doi.org/10.1016/j.fm.2018.01.013

George, C.K. (2004). Star anise. In Peter, K.V. (Ed). Handbook of Herbs and Spices, p. 290-296. New York: CRC press. https://doi.org/10.1533/9781855738355.2.290

Glenn, A.E. (2007). Mycotoxigenic Fusarium species in animal feed. *Animal Feed Science and Technology*, 137 (3-4), 213–240. https://doi.org/10.1016/j.anifeedsci.2007.06.003

Golge, O. and Kabak, B. (2020). Occurrence of deoxynivalenol and zearalenone in cereals and cereal products from Turkey. *Food Control,* 110, 10698. https://doi.org/10.1016/j.foodcont.2019.106982

Hammami, W., Fiori, S., al Thani, R., Ali Kali, N., Balmas, V., Migheli, Q. and Jaoua, S. (2014). Fungal and aflatoxin contamination of marketed spices. *Food Control*, 37(1), 177–181. https://doi.org/10.1016/j.foodcont.2013.09.027

Hashem, M. and Alamri, S. (2010). Contamination of common spices in Saudi Arabia markets with potential mycotoxin-producing fungi. *Saudi Journal of Biological Sciences,* 17(2), 167–175. https://doi.org/10.1016/j.sjbs.2010.02.011

Hlebová, M., Hleba, L., Medo, J., Kováčik, A., Čuboň, J., Ivana, C., Uzsáková, V., Božik, M. and Klouček P. (2021). Antifungal and synergistic activities of some selected essential oils on the growth of significant indoor fungi of the genus *Aspergillus. Journal of Environmental Science and Health, Part A,* 56 (12), 1335-1346. https://doi.org/10.1080/10934529.2021.1994801

Iha, M.H. and Trucksess, M.W. (2019). Management of mycotoxins in spices. *Journal of AOAC International,* 102(6), 1732–1739. https://doi.org/10.5740/jaoacint.19-0117

International Agency of Research on Cancer (IARC) (1993a). Some naturally occurring substances, food items and constituents, heterocyclic aromatic amines and mycotoxins. *WHO IARC Monographs*, 56, 489-521.

International Agency for Research on Cancer (IARC) (1993b). Toxins derived from *Fusarium moniliforme*: fumonisins B_1 and B_2 and Fusarin C. *In* IARC Monographs on the evaluation of the carcinogenic risks to humans: Some naturally occurring substances: Food items and constituents, heterocyclic aromatic amines and mycotoxins. Lyon, France: World Health Organization International Agency for Research on Cancer.

Iqbal, S.Z., Asi, M.R., Mehmood, Z., Mumtaz, A. and Malik, N. (2017). Survey of aflatoxins and ochratoxin A in retail market chilies and chili sauce samples. *Food Control*, 81, 218–223. https://doi.org/10.1016/j.foodcont.2017.06.012

Jalili, M. and Jinap, S. (2012). Natural occurrence of aflatoxins and ochratoxin A in commercial dried chili. *Food Control*, 24(1–2), 160–164. https://doi.org/10.1016/j.foodcont.2011.09.020

Jallow, A., Xie, H., Tang, X., Qi, Z. and Li, P. (2021). Worldwide aflatoxin contamination of agricultural products and foods: From occurrence to control. *Comprehensive Reviews in Food Science and Food Safety*, 20(3), 2332–2381. https://doi.org/10.1111/1541-4337.12734

Jeswal, P. and Kumar, D. (2015). Mycobiota and natural incidence of aflatoxins, ochratoxin A, and citrinin in Indian spices confirmed by LC-MS/MS. *International Journal of Microbiology,* 2015, 242486. https://doi.org/10.1155/2015/242486

Jiang, Y., Jolly, P.E., Ellis, W.O., Wang, J.S., Phillips, T.D. and Williams, J.H. (2005). Aflatoxin B_1 albumin adduct levels and cellular immune status in Ghanaians. *International Immunology*, 17(6), 807–814. https://doi.org/10.1093/intimm/dxh262

Kabak, B. and Dobson, A.D.W. (2017). Mycotoxins in spices and herbs–An update. *Critical Reviews in Food Science and Nutrition*, 57(1), 18–34. https://doi.org/10.1080/10408398.2013.772891

Kamle, M., Mahato, D.K., Devi, S., Lee, K.E., Kang, S.G. and Kumar, P. (2019). Fumonisins: Impact on Agriculture, Food, and Human Health and their Management Strategies. *Toxins*, 11(6), 328. https://doi.org/10.3390/toxins11060328

Khadka, R.B., Marasini, M., Rawal, R., Gautam, D.M. and Acedo, A.L. (2017). Effects of variety and postharvest handling practices on microbial population at different stages of the value chain of fresh tomato (*Solanum lycopersicum*) in Western Terai of Nepal. *BioMed Research International*, 2017, 7148076. https://doi.org/10.1155/2017/7148076

Khan, M.A., Asghar, M.A., Iqbal, J., Ahmed, A. and Shamsuddin, Z.A. (2014). Aflatoxins contamination and prevention in red chillies (*Capsicum annuum* L.) in Pakistan. *Food Additives and Contaminants: Part B Surveillance*, 7(1), 1–6. https://doi.org/10.1080/19393210.2013.825330

Kneifel, W. and Berger, E. (1994). Microbiological criteria of random samples of spices and herbs retailed on the Austrian market. *Journal of Food Protection*, 57(10), 893–901. https://doi.org/10.4315/0362-028X-57.10.893

Kong, W., Wei, R., Logrieco, A., Wei, J., Jing, W., Xiaoe, X. and Yanga, M. (2014). Occurrence of toxigenic fungi and determination of mycotoxins by HPLC-FLD in functional foods and spices in China markets. *Food Control,* 146, 320-326. https://doi.org/10.1016/j.foodchem.2013.09.005

Kong, W., Xie, T., Li, J., Wei, J., Qiu, F., Qi, A., Zheng, Y. and Yang, M. (2012). Analysis of fumonisins B_1 and B_2 in spices and aromatic and medicinal herbs by HPLC-FLD with on-line post-column derivatization and positive confirmation by LC-MS/MS. *The Analyst*, 137, 3166. https://doi.org/10.1039/c2an35164a

Kulshrestha, P., Singh, C., Gupta, A., Mahajan, S. and Sharma, R. (2014). Mycoflora Associated with Spices. *International Journal of Current Micriobiology and Applied Sciences,* 3(5), 741-746.

Leela, N.K. and Sapna, V.P. (2008). Clove. In Parthasarathy, V.A. (Ed). Chemistry of Spices, p. 146. Oxfordshire, United Kingdom: CAB International. https://doi.org/10.1079/9781845934057.0146

Lewis, L., Onsongo, M., Njapau, H., Schurz-Rogers, H., Luber, G., Kieszak, S., Nyamongo, J., Backer, L., Dahiye, A.M., Misore, A., DeCock, K., Rubin, C., Nyikal, J., Njuguna, C., Langat, A., Kilei, I.K., Tetteh, C., Likimani, S., Oduor, J. and Gupta, N. (2005). Aflatoxin contamination of commercial maize products during an outbreak of acute aflatoxicosis in Eastern and Central Kenya. *Environmental Health Perspectives*, 113(12), 1763–1767. https://doi.org/10.1289/ehp.7998

Mahato, D.K., Devi, S., Pandhi, S., Sharma, B., Maurya, K.K., Mishra, S., Dhawan, K., Selvakumar, R., Kamle, M., Misha, A.K. and Kumar, P. (2021). Occurrence, impact on agriculture, human health, and management strategies of zearalenone in food and feed: A review. *Toxins*, 13(2), 92. https://doi.org/10.3390/toxins13020092

Mahato, D.K., Lee, K.E., Kamle, M., Devi, S., Dewangan, K.N., Kumar, P. and Kang, S.G. (2019). Aflatoxins in food and feed: An overview on prevalence, detection and control strategies. *Frontiers in Microbiology*, 10, 2266. https://doi.org/10.3389/fmicb.2019.02266

Mahdjoubi, C.K., Arroyo-Manzanares, N., Hamini-Hadar, N., García-Campaña, A.M., Mebrouk, K. and Gámiz-Gracia, L. (2020). Multi-mycotoxin occurrence and exposure assessment approach in foodstuffs from Algeria. *Toxins*, 12, 194. https://doi.org/10.3390/toxins12030194

Mally, A., Solfrizzo, M. and Degen, G.H. (2016). Biomonitoring of the mycotoxin Zearalenone: Current state-of-the art and application to human exposure assessment. *Archives of Toxicology*, 90(6), 1281–1292. https://doi.org/10.1007/s00204-016-1704-0

Mandeel, Q.A. (2005). Fungal contamination of some imported spices. *Mycopathologia*, 159(2), 291–298. https://doi.org/10.1007/s11046-004-5496-z

Marasas, W.F.O. (2001). Discovery and occurrence of the fumonisins: A historical perspective. *Environmental Health Perspectives,* 109(Supplement 2), 239-243. https://doi.org/10.2307/3435014

Martinez-Miranda, M.M., Rosero-Moreano, M. and Taborda-Ocampo, G. (2019). Occurrence, dietary exposure and risk assessment of aflatoxins in arepa, bread and rice. *Food Control,* 98, 359–366. https://doi.org/10.1016/j.foodcont.2018.11.046

Meena, M.R. and Sethi, V. (1994) Antimicrobial activity of essential oils from spices. *Journal of Food Science and Technology,* 31(1)*,* 68–70.

Moerck, K.E., Mcelfresh, P., Wohlman, A. and Hilton, B.W. (1980). Aflatoxin destruction in corn using sodium bisulfite, sodium hydroxide and aqueous ammonia. *Journal of Food Protection*, 43(7), 571–574. https://doi.org/10.4315/0362-028X-43.7.571

Moses, J.A., Alagusundaram, K. and Kavitha, C.V. (2014). Curing and drying of cardamom. Processed Food Industry, p. 21-28.

Nabavi, S.F., Di Lorenzo, A., Izadi, M., Sobarzo-Sánchez, E., Daglia, M. and Nabavi, S. (2015). Antibacterial effects of cinnamon: From farm to food, cosmetic and pharmaceutical industries. *Nutrients,* 7(9), 7729–7748. https://doi.org/10.3390/nu7095359

Nathanail, A.V., Syvähuoko, J., Malachová, A., Jestoi, M., Varga, E., Michlmayr, H., Adam, G., Sieviläinen, E., Berthiller, F. and Peltonen, K. (2015). Simultaneous determination of major type A and B trichothecenes, zearalenone and certain modified metabolites in Finnish cereal grains with a novel liquid chromatography-tandem mass spectrometric method. *Analytical and Bioanalytical Chemistry*, 407(16), 4745–4755. https://doi.org/10.1007/s00216-015-8676-4

Nguegwouo, E., Sone, L.E., Tchuenchieu, A., Tene, H.M., Mounchigam, E., Njayou, N.F. and Nama, G.M. (2018). Ochratoxin A in black pepper, white pepper and clove sold in yaoundé (Cameroon) markets: Contamination levels and consumers' practices increasing health risk. *International Journal of Food Contamination,* 5, 1. https://doi.org/10.1186/s40550-017-0063-9

Ozbey, F. and Kabak, B. (2012). Natural co-occurrence of aflatoxins and ochratoxin A in spices. *Food Control*, 28(2), 354–361. https://doi.org/10.1016/j.foodcont.2012.05.039

Pardo, E., Marín, S., Ramos, A.J. and Sanchis, V. (2006). Ecophysiology of ochratoxigenic *Aspergillus ochraceus* and *Penicillium verrucosum* isolates. Predictive models for fungal spoilage prevention - A review. *Food Additives and Contaminants*, 23(4), 398–410. https://doi.org/10.1080/02652030500376102

Patel, S., Hazel, C.M., Winterton, A.G.M. and Mortby, E. (1996). Survey of ethnic foods for mycotoxins. *Food Additives and Contaminants*, 13(7), 833–841. https://doi.org/10.1080/02652039609374470

Pickova, D., Ostry, V., Malir, J., Toman, J. and Malir, F. (2020). A review on mycotoxins and microfungi in spices in the light of the last five years. *Toxins,* 12 (12), 789. https://doi.org/10.3390/toxins12120789

Pitt, J.I. and Hocking, A.D. (2009). Fungi and food spoilage*,* 3rd Ed. New York, USA: Springer. https://doi.org/10.1007/978-0-387-92207-2

Piacentini, K.C., Rocha, L.O., Savi, G.D., Carnielli-Queiroz, L., Almeida, F.G., Minella, E. and Corrêa, B. (2018). Occurrence of deoxynivalenol and zearalenone in brewing barley grains from Brazil. *Mycotoxin Research*, 34(3), 173–178. https://doi.org/10.1007/s12550-018-0311-8

Prelle, A., Spadaro, D., Garibaldi, A. and Gullino, M.L. (2014). Co-occurrence of aflatoxins and ochratoxin A in spices commercialized in Italy. *Food Control,* 39, 192–197. https://doi.org/10.1016/j.foodcont.2013.11.013

Raghavan, S. (2007). Handbook of spices, seasonings, and flavorings*,* 2nd ed. Boca Raton, Florida: CRC Press. https://doi.org/10.1201/b13597

Rai, A., Das, M. and Tripathi, A. (2019). Occurrence and toxicity of a *Fusarium* mycotoxin, zearalenone. *Critical Reviews in Food Science and Nutrition,* 60 (16), 2710-2729. https://doi.org/10.1080/10408398.2019.1655388

Rao, P.V. and Gan, S.H. (2014). Cinnamon: A multifaceted medicinal plant*. Evidence-Based Complementary and Alternative Medicine,* 2014, 642942. https://doi.org/10.1155/2014/642942

Ravindran, P.N. and Kallupurackal, J.A. (2001). Black pepper. In Peter, K.V. (Ed). Handbook of Herbs and Spices. Vol. 2, p. 62-110. New York: CRC press. https://doi.org/10.1533/9781855736450.62

Reddy, K.R.N., Salleh, B., Saad, B., Abbas, H.K., Abel, C.A. and Shier, W.T. (2010). An overview of mycotoxin contamination in foods and its implications for human health. *Toxin Reviews,* 29(1), 3–26. https://doi.org/10.3109/15569541003598553

Reddy, K.R.N., Farhana, N.I. and Salleh, B. (2011). Occurrence of *Aspergillus* spp. and aflatoxin B_1 in Malaysian foods used for human consumption*. Journal of Food Science,* 76(4), T99–T104. https://doi.org/10.1111/j.1750-3841.2011.02133.x

Reddy, S.V., Kiran Mayi, D., Uma Reddy, M., Thirumala-Devi, K. and Reddy, D.V.R. (2001). Aflatoxins B_1 in different grades of chillies (*Capsicum annum* L.) in India as determined by indirect competitive-ELISA. *Food Additives and Contaminants*, 18(6), 553–558. https://doi.org/10.1080/02652030119491

Rheeder, J.P., Marasas, W.F.O. and Vismer, H.F. (2002). Production of fumonisin analogs by *Fusarium* species*. Applied and Environmental Microbiology*, 68(5), 2101–2105. https://doi.org/10.1128/AEM.68.5.2101-2105.2002

Richard, J.L. (2007). Some major mycotoxins and their mycotoxicoses - An overview*. International Journal of Food Microbiology,* 119(1), 3-10. https://doi.org/10.1016/j.ijfoodmicro.2007.07.019

Saidi, R., Gritli, A., Ben Rhaiem, M., Mnejja, I. and Jemli, B. (2021). Fungal contaminants of spices used in Tunisia*. International Journal of Food Science and Agriculture,* 5(4), 698-703. https://doi.org/10.26855/ijfsa.2021.12.018

Sanchis, V. and Magan, N. (2004). Environmental conditions affecting mycotoxins. In Magan, N. and Olsen, M. (Eds) Mycotoxins in food. *Detection and control,* p. 174–189. Cambridge: Woodhead Publishing Limited. https://doi.org/10.1533/9781855739086.2.174

Santos, L., Marín, S., Sanchis, V. and Ramos, A.J. (2010)*. In vitro* effect of some fungicides on growth and aflatoxins production by *Aspergillus flavus* isolated from Capsicum powder*. Food Additives and Contaminants: Part A,* 28(1), 98–106. https://doi.org/10.1080/19440049.2010.529622

Sanzani, S.M., Reverberi, M. and Geisen, R. (2016). Mycotoxins in harvested fruits and vegetables: Insights in producing fungi, biological role, conducive conditions, and tools to manage postharvest contamination. *Postharvest Biology and Technology*, 122, 95–105. https://doi.org/10.1016/j.postharvbio.2016.07.003

Schollenberger, M., Müller, H.M., Rüfle, M., Suchy, S., Planck, S. and Drochner, W. (2005). Survey of *Fusarium* toxins in foodstuffs of plant origin marketed in Germany. *International Journal of Food Microbiology,* 97(3), 317–326. https://doi.org/10.1016/j.ijfoodmicro.2004.05.001

Seefelder, W. (2003). Induction of apoptosis in cultured human proximal tubule cells by fumonisins and fumonisin metabolites*. Toxicology and Applied Pharmacology,* 192(2), 146–153. https://doi.org/10.1016/S0041-008X(03)00262-X

Selvaraj, J.N. Wang, Y., Zhou, L., Zhao, Y., Xing, F., Dai, X. and Liu, Y. (2015). Recent mycotoxin survey data and advanced mycotoxin detection techniques reported from China: A review. *Food Additives*

REVIEW

Contaminants. Part A, 32, 440–452. https://doi.org/10.1080/19440049.2015.1010185

Sharma, M.M. and Sharma, R.K. (2004). Coriander. In Peter, K.V. (Ed). Handbook of Herbs and Spices. New York: CRC press. https://doi.org/10.1201/9780203023945.ch9

Silva, L.J.G., Pereira, A.M.P.T., Pena, A. and Lino, C.M. (2020). Citrinin in foods and supplements: A review of occurrence and analytical methodologies. *Foods,* 10(1), 14. https://doi.org/10.3390/foods10010014

Singh, P. and Cotty, P.J. (2017). Aflatoxin contamination of dried red chilies: Contrasts between the United States and Nigeria, two markets differing in regulation enforcement. *Food Control*, 80, 374–379. https://doi.org/10.1016/j.foodcont.2017.05.014

Steyn, P.S. (1995). Mycotoxins, general view, chemistry and structure. *Toxicology Letters*, 82-83, 843-851. https://doi.org/10.1016/0378-4274(95)03525-7

Tajkarimi, M.M., Ibrahim, S.A. and Cliver, D.O. (2010). Antimicrobial herb and spice compounds in food. *Food Control,* 21(9), 1199–1218. https://doi.org/10.1016/j.foodcont.2010.02.003

Thanaboripat, D., Petcharawan, O. and Sukonthamut, S. (2016). Aflatoxin contamination of chilli powder in canteens of King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand. *KMITL Science and Technology Journal*, 16(1), 11–17.

Thanushree, M.P., Sailendri, D., Yoha, K.S., Moses, J.A. and Anandharamakrishnan, C. (2019). Mycotoxin contamination in food: An exposition on spices. *Trends in Food Science and Technology*, 93, 69–80. https://doi.org/10.1016/j.tifs.2019.08.010

Torović, L. (2018). *Fusarium* toxins in corn food products: A survey of the Serbian retail market. *Food Additives and Contaminants: Part A,* 35(8), 1596 - 1609. https://doi.org/10.1080/19440049.2017.1419581

Turner, N.W., Subrahmanyam, S. and Piletsky, S.A. (2009). Analytical methods for determination of mycotoxins: A review. *Analytica Chimica Acta,* 632 (2), 168-180. https://doi.org/10.1016/j.aca.2008.11.010

Tsehaynesh, T., Abdi, M., Hassen, S. and Taye, W. (2021). *Aspergillus* species and aflatoxin contamination in pepper (*Capsicum annuum* L.) in West Gojjam, Ethiopia. *African Journal of Food, Agriculture, Nutrition and Development*, 21(1), 17178–17194. https://doi.org/10.18697/ajfand.96.18815

Turner, P.C., Moore, S.E., Hall, A.J., Prentice, A.M. and Wild, C.P. (2003). Modification of immune function through exposure to dietary aflatoxin in Gambian children. *Environmental Health Perspectives*, 111 (2), 217–220. https://doi.org/10.1289/ehp.5753

Udomkun, P., Wiredu, A.N., Nagle, M., Müller, J., Vanlauwe, B. and Bandyopadhyay, R. (2017). Innovative technologies to manage aflatoxins in foods and feeds and the profitability of application – A review. *Food Control,* 76, 127–138. https://doi.org/10.1016/j.foodcont.2017.01.008

Van Egmond, H.P. (2013). Mycotoxins: Risks, regulations and European co-operation. *Zbornik Matice Srpske Za Prirodne NaukeMatica Srpska Journal for Natural Sciences*, 25(125), 7–20. https://doi.org/10.2298/ZMSPN1325007V

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

Visagie, C.M., Houbraken, J., Frisvad, J.C., Hong, S.B., Klaassen, C.H.W., Perrone, G., Seifart, K.A., Varga, J., Yaguchi, T. and Samson, R.A. (2014). Identification and nomenclature of the genus *Penicillium*. *Studies in Mycology*, 78, 343–371. https://doi.org/10.1016/j.simyco.2014.09.001

Vyhnánek, T., Hanáček, P., Šafránková, I., Dordević, B., Beranová, H., Trojan, V. and Havel, L. (2018). Molecular detection of fungi in paprika, chili powder and black pepper. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* 66(4), 927–937. https://doi.org/10.11118/actaun201866040927

Wang, Y., Wang, L., Liu, F., Wang, Q., Selvaraj, J.N., Xing, F., Zhao, Y. and Liu, Y. (2016). Ochratoxin A producing fungi, biosynthetic pathway and regulatory mechanisms. *Toxins*, 8(3), 83. https://doi.org/10.3390/toxins8030083

Waśkiewicz, A., Beszterda, M., Bocianowski, J. and Goliński, P. (2013). Natural occurrence of fumonisins and ochratoxin A in some herbs and spices commercialized in Poland analyzed by UPLC–MS/MS method. *Food Microbiology,* 36(2), 426–431. https://doi.org/10.1016/j.fm.2013.07.006

Weng, C.Y., Martinez, A.J. and Park, D.L. (1994). Efficacy and permanency of ammonia treatment in reducing aflatoxin levels in corn. *Food Additives and Contaminants*, 11(6), 649–658. https://doi.org/10.1080/02652039409374266

Wikandari, R., Mayningsih, I.C., Sari, M.D.P., Purwandari, F.A., Setyaningsih, W., Rahayu, E.S. and Taherzadeh, M.J. (2020). Assessment of microbiological quality and mycotoxin in dried chilli by morphological identification, molecular detection, and chromatography analysis. *International Journal of Environmental Research and Public Health*, 17 (6), 1847. https://doi.org/10.3390/ijerph17061847

Wild, C.P., Chapot, B., Hall, A.J., Montesano, R., Hudson, G.J., Sabbioni, G., Wogan, G.N., Whittle, H. and Groopman, J.D. (1992). Dietary intake of aflatoxins and the Level of albumin-bound aflatoxin in peripheral blood in the Gambia, West Africa. *Cancer Epidemiology Biomarkers and Prevention*, 1 (3), 229–234.

Yang, J., Wang, G., Liu, J., Fan, J. and Cui, S. (2007). Toxic effects of zearalenone and its derivatives α-zearalenol on male reproductive system in mice. *Reproductive Toxicology,* 24(3-4), 381–387. https://doi.org/10.1016/j.reprotox.2007.05.009

Yazar, S. and Omurtag, G.Z. (2008). Fumonisins, trichothecenes and zearalenone in cereals. *International Journal of Molecular Sciences*, 9(11), 2062–2090. https://doi.org/10.3390/ijms9112062

Yogendrarajah, P., Deschuyffeleer, N., Jacxsens, L., Sneyers, P.J., Maene, P., De Saeger, S., Devlieghere, F. and De Meulenaer, B. (2014). Mycological quality and mycotoxin contamination of Sri Lankan peppers (*Piper nigrum* L.) and subsequent exposure assessment. *Food Control*, 41(1), 219–230. https://doi.org/10.1016/j.foodcont.2014.01.025

Zain, M.E. (2011). Impact of mycotoxins on humans and animals. *Journal of Saudi Chemical Society*, 15(2), 129–144. https://doi.org/10.1016/j.jscs.2010.06.006

Zinedine, A., Soriano, J.M., Moltó, J.C. and Mañes, J. (2007). Review on the toxicity, occurrence, metabolism, detoxification, regulations and intake of zearalenone: An oestrogenic mycotoxin. *Food and Chemical Toxicology*, 45(1), 1–18. https://doi.org/10.1016/j.fct.2006.07.030

eISSN: 2550-2166