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

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 Yogendraarajah 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 B₁, B₂, G₁, G₂ (AFB₁, AFB₂, AFG₁, and AFG₂), and ochratoxin A (OTA). AFB₁ 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.
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 (AFB₁, AFB₂, AFG₁, and AFG₂), AFB₁ is the most toxicogenic 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; Yogendraajah 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 (Nguegwou 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| Anomum spp.                   | Fruits        |
| Cinnamon     | Lauraceae    | Cinnamomum spp.               | Barks         |
| Clove        | Myrtaceae    | Syzygium aromaticum (L.)      | Flower buds   |
| Coriander seed| Apiaceae    | Coriandrum sativum L.         | Fruits        |
| Cumin seed   | Apiaceae     | Cuminum cymimum L.            | Seeds         |
| Fennel seed  | Apiaceae     | Foeniculum vulgare Mill.      | Fruits        |
| Ginger       | Zingiberaceae| Allium sativum L.             | Rhizomes      |
| Nutmeg       | Myristaceae  | Myristica fragrans Houtt.     | Seeds         |
| Star anise   | Illiciaceae  | Illicium verum                | Fruits        |
| Turmeric     | Zingiberaceae| 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). CITrin 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 moniliforme). 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 FB1, FB2, and FB3, with FB1 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 FB1 and FB2 in spices and herbs. The authors found mouldy samples (42.5%) were contaminated with FB1 and FB2, 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 FB1 and FB2. 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 Trichotheccene (TC)

Trichotheccene (TC) is a huge group of TC toxins, and the first member of this group was identified in 1949 produced by Trichotheccium 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 Klitch, 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-Ferreira 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 AFB1 maximum limit in spices like chilli, peppers, nutmeg, ginger, turmeric, and a mixture of spices is 5 µg/kg, while the sum of AFB1, AFB2, AFG1, and AFG2 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 mycotoxicogenic 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

| Spices         | 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
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.

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          | AFs: 0.20-79.70                          | NA                                       | Jalili and Jinap (2012)     |
|                |                                                  | OTA: 81.25          | OTA: 0.20-101.20                         |                                          |                             |
| Indonesia      | Dried chilli                                     |                       | AFB$_1$: 39.30–139.50                    | NA                                       | Wikandari et al. (2020)    |
|                |                                                  |                      | AFB$_2$: 2.60–33.30                      |                                          |                             |
|                |                                                  |                      | OTA: 23.70–84.60                         |                                          |                             |
| Italy          | Peppers, chilli, cinnamon, cloves, coriander, mixed spices | AFs: 15.40          | AFB$_1$: 0.96                           | AFs: NA                                  | Prell et al., (2014)       |
|                |                                                  |                      | AFB$_2$: 0.31                           | OTA: 6.18                                |                             |
|                |                                                  |                      |                                          |                                          |                             |
| 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          | AFB$_1$: 12.50–15.16                    | AFs: 26.30                               | Iqbal et al. (2017)        |
|                |                                                  | OTA: 40.40          | OTA: 16.68–120.90                       | OTA: 32.70                               |                             |
| 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            | AFB$_1$: 1.85-70.33                     | NA                                       | Hammami et al., (2014)     |
| Malaysia       | Dried chilli, fennel, cumin, black pepper, white pepper, coriander and mixed spices | AF: 85              | AFB$_1$: 0.01-9.34                      | NA                                       | Ali et al., (2015)         |
|                |                                                  | OTA: 79             | OTA: 0.14-20.40                         |                                          |                             |
| Benin          | Pepper, chilli, cumin, cinnamon, anise           | AFB$_1$: 84          | AFB$_1$: 0.46-8.84                       | 40.00                                    | Akpo-Djérontin et al., (2018) |
| Turkey         | Red chilli powder, black pepper, cumin           | AFB$_1$: 43.75       | AFB$_1$: 0.13-35.77                     | AF: 13.60                                | Ozbey and Kabak, (2012)    |
|                |                                                  | OTA: 26.56          | OTA: 0.63-98.2                          | OTA: 13.60                               |                             |
| Hungary        | Black pepper, mixed spices, chilli               | 31.25                | AFB$_1$: 0.16-8.10                      | AFB$_1$: 20.00                           | Fazekas et al., (2005)     |
|                |                                                  |                      | OTA: 2.1                                | OTA: NA                                  |                             |
| India          | Black pepper                                     | AFB$_1$: 45.24       | AFB$_1$: 0.16-8.10                      | NA                                       | Jeswal and Kumar (2015)    |
|                |                                                  | AFs: 76.00          | OTA: 4.80-26.40                         | NA                                       |                             |
|                |                                                  | OTA: 78.57          | OTA: 4.60-13.80                         |                                          |                             |
| India          | Red chilli                                       | AFB$_1$: 56.36       | AFB$_1$: NA                             | NA                                       | Jeswal and Kumar (2015)    |
|                |                                                  | AFs: 85.45          | AFs: 4.30-33.60                         |                                          |                             |
|                |                                                  | OTA: 72.73          | OTA: 3.50-8.60                          |                                          |                             |
| Ethiopia       | Pepper                                           | AFs: 42.00          | AFB$_1$: 3.10-19.20                     | AFB$_1$: 98.00                           | Tsehaynesh et al. (2021)   |
| Korea          | Chilli powder, chilli paste                      | AFs: 13.60          | AFB$_1$: 0.08-4.66                      | AFB$_1$: 0.00                            | Cho et al. (2008)          |
| Turkey         | Chilli powder                                    | AFs: 63.60          | AFB$_1$: 0.20-35.77                     | AFB$_1$: 4.50                            | Ozbey and Kabak (2012)     |
|                |                                                  | OTA: 54.50          | OTA: 0.78-98.20                         | OTA: 13.60                               |                             |

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.
Reddy et al. (2001) investigated AFB1 contamination in fresh chillies and chilli powders from various markets in Andra Pradesh, India. They discovered that AFB1 was detected in 59% of the chilli samples, and fresh chilli recorded the highest amount of AFB1 (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 (Ozbeey 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 chilling-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-Djénontin reported a mixture of spices, including cinnamon, contaminated with 8.86 μg/kg of AFB1 (Akpo-Djénontin, 2018). Cho et al. (2007) found no detectable AF from cinnamon samples in Korea. Similarly, Ozbeey 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.
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-spike, 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-spike 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 yellow-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 AFB₁ 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-pinen, 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. Tenu (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 1.12×10^7 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 oxysporum (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. fumigatus (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 AFB1 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, AFB1, 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 AFB1 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 (Nguegwou et al., 2018). Spices are mainly cultivated in tropical countries with high temperatures and humidity, suitable for fungal contamination and mycotoxin production (Vyhnanek 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.
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 mycotoxicogenic 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

Mycotoxoses 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 Truckses, 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 Truckses, 2019). In addition, prompt drying of spices after cleaning is crucial as moisture is an important factor in fungi proliferation (Iha and Truckses, 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 Truckses, 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).
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-Djénotintin, 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 commercialized 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 antioxidiant 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., Fahrmann, 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.,
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., Ksie niewicz-Wóźniak, E., Wąskiewicz, 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/10.1097/9781845934057.0319

Cinar, A. and Onbaşi, E. (2019). Mycotoxins: The Hidden Danger in Foods. In Sabuncuoğlu, S. (Ed). Hidden Danger in Foods. In Sabuncuoğlu, S. (Ed). Oxfordshire, United Kingdom: CAB International. https://doi.org/10.1080/02652030701823142

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., Rodriguez, 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). Phytoph enols. 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.

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 Aspergillus 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

Hamamami, W., Fiori, S., al Thani, R., Ali Kali, N., Balmas, V., Miglieli, 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., Božík, 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

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 B₁ and B₂ 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 Safety*, 20(3), 2332–2381. https://doi.org/10.1111/1541-4337.12734

Jeswal, P. and Kumar, D. (2015). Mycobacteria 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 B₁ 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 chilli (*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-JFLD.1994.2.893

Kong, W., Wei, R., Logrieco, A., Wei, J., Jing, W., Xiao, X. and Yang, 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.foodcont.2013.09.005

Kong, W., Xie, T., Li, J., Wei, J., Qiu, F., Qi, A., Zheng, Y. and Yang, M. (2012). Analysis of fumonisins B₁ and B₂ 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 Microbiology 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., Kieszkai, S., Nyamongo, J., Backer, L., Daijye, A.M., Misoere, 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 Gámicz-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

Mandeer, 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 arena, 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/10.3315/jfp-0282X-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., Sieväläinen, 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., Mouchigam, E., Njayou, N.F. andNama, 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., Marin, 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

Prell, 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 B1 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 B1 in different grades of chilies (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 Rhaïm, M., Mnejea, 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., Marin, 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 and Contaminants: Part A, 32(7), 964–997. https://doi.org/10.1080/19440049.2014.903620

© 2022 The Authors. Published by Rynnye Lyan Resources
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

Tschaynesh, T., Abdi, M., Hassen, S. and Taye, W. (2021). *Aspergillus* species and aflatoxin contamination in pepper (*Capsicum annuum* L.) in West Gojam, 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 Nauke*Matica 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., Houbraiken, 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

Vyhnanék, T., Hanáček, P., Šťárnková, 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/actua201866040927

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

Waszkiewicz, A., Beszerterda, M., Bocianski, J. and Golinski, 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, trichotheccenes and zearalenone in cereals. *International Journal of Molecular Sciences, 9*(11), 2062–2090. https://doi.org/10.3390/ijms9112062

Yogendrarajah, P., Deschuyffeleer, N., Jaexsens, 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