11 Mycological Biosafety and Biosecurity in the Philippines

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11.1 INTRODUCTION

Mycotoxin contamination is a recurring theme in the agriculture and food industries. The ubiquity of the fungi which produce them makes mycotoxins common contaminants in animal and human food supply (Murphy et al., 2006). The Food and Agriculture Organization (FAO) estimates that 25% of global food and feed outputs are contaminated with mycotoxins (Moretti et al., 2017), and major losses due to this, specifically financial, can be as diverse as the reduction in quality and production, and increased cost in finding alternative foods and better management (Marroquín-Cardona et al., 2014). Direct implications to humans have been recorded due to contaminants present in food such as in fruits and their processed products (Fernández-Cruz et al., 2010), spices such as chili and black pepper (Yogendrarajah et al., 2014), and infant foods (Asam & Rychlik, 2013), among others. Even as early as the middle ages, records show the frequency of ergotism throughout Europe, a mycotoxin-induced disease caused by contamination of rye bread by the fungus *Claviceps purpurea*, leading to burning sensations resulting in gangrene, neurological disease, and death (van Dongen & de Groot, 1995).

It is important to manage and control the contamination of food and feed products by mycotoxin-producing fungi to ensure a safe and secure food and agricultural environment. Mycotoxins may enter the food supply directly through the growth of molds on the actual food or indirectly through the use of contaminated raw materials in food processing and manufacture (Bullerman, 1979). FAO and the World Health Organization (WHO) declared high priority on mycotoxins due to their impact on human and animal health, and countries have set legal limits for specific mycotoxins (Fumagalli et al., 2021).

Fungi have already caused biosafety and biosecurity concerns in history. Disease outbreaks caused by the mycotoxins trichothecene and fumonisin were recorded in India in 1987 and 1995 due to contaminated wheat, sorghum, and maize (Raghavender & Reddy, 2009). Other cases link mycotoxin exposure to poor nutrition, the development of cancers, and even death (Bhat et al., 2010; Lukwago et al., 2019; Shephard, 2008). Mycotoxicosis in animals fed with contaminated feed also represents a rising concern in hog-raising (Magnoli et al., 2019), aquaculture (Gonçalves et al., 2020), and poultry (Murugesan et al., 2015) because of poor nutritional value, low performance, and increased susceptibility to disease.

Management of mycotoxin also has a serious economic impact. Data would show that losses in cereals, for example, are highest in years with the highest mycotoxin levels (Focker et al., 2021). For instance, the socioeconomic impact of mycotoxin contamination in Africa is among the rural poor, contributing more to threats to human health (Gbashi et al., 2019). Even in developed countries such as the United States, illnesses and death contribute to the cost associated with mycotoxins (Abbas, 2005). In Southeast Asia, mitigation strategies are recommended to control mycotoxins contamination in raw feed materials, specifically in rice and maize (Siri-anusornsak et al., 2022), a risk also reported to be high in the Philippines (Salvacion et al., 2015).

After the initial discovery of aflatoxin contamination in the Philippines in 1972, additional knowledge has been acquired regarding mycotoxins and the fungi that produce them. Despite the progress made in understanding mycotoxigenic fungi and mycotoxins in the country, there is still a lack of comprehensive knowledge regarding effective practices and measures to control fungi and toxins (Balendres et al., 2019). From the historical point of view, several mycotoxigenic fungi were discovered and isolated in the Philippines over the past two decades of scientific efforts (Figure 11.1).

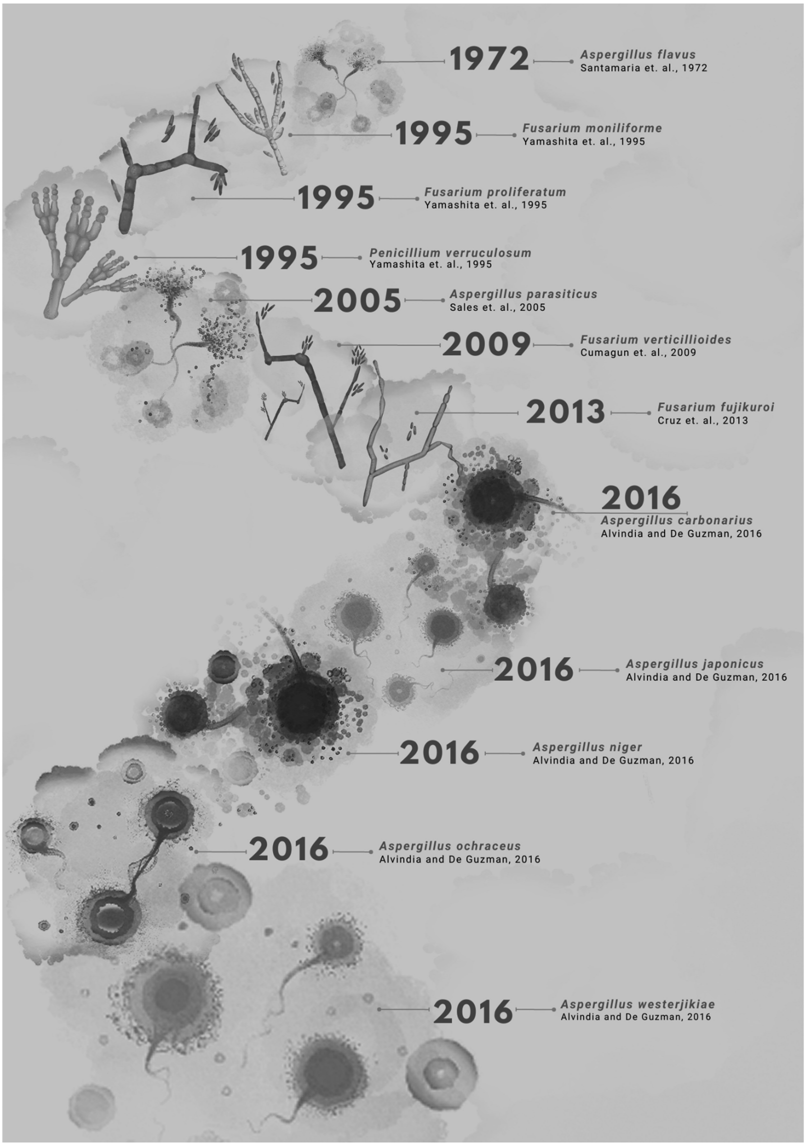

FIGURE 11.1 The historical timeline of mycotoxigenic fungi isolated in the Philippines

11.2 TRADITIONAL USES OF MACROFUNGI IN THE PHILIPPINES

Aside from mycotoxins, the wide use of mushrooms may also pose potential safety and security concerns. Studies of indigenous groups from Luzon Island in the Philippines, including the Aeta, Bugkalot, Gaddang, Kalanguya, and other Igorot groups, have revealed that gathering and utilization of wild edible mushrooms are influenced by the ecological environment and ethnicity where many of these mushroom species are utilized for medicinal and nutritional purposes (Dulay et al., 2023; dela Cruz and De Leon, 2023). In particular, many of the macrofungal species documented in these surveys were widely consumed as food, the most commonly eaten species being *Schizophyllum commune* (split-gill mushroom), *Auricularia polytricha* (wood ear mushroom), *Volvariella volvacea* (straw mushroom), *Pleurotus* (oyster mushroom), and *Termitomyces*. Beyond their culinary and medicinal uses, these fungi also serve diverse purposes: house decorations, utilized for body detoxification, base for a coffee-like beverage, natural insect repellents, and even as eye drop formulation from an ascomycete species (Table 11.1).

It was also noted that the different provinces have different species of mushrooms, with some areas having a more abundant fungal diversity than others (Dulay et al., 2023). For example, the coniferous type of forest in Benguet and Mt. Province areas are conducive to the growth of wild edible mushrooms, resulting in a stronger tradition of mushroom gathering in these areas than in Apayao, Kalinga, and Ifugao, where non-coniferous types of forests prevail (Licyayo, 2018). While there are numerous ethnomycological studies on Luzon, particularly in the Northern and Central regions, it is worth noting that there are limited studies on the Visayas and Mindanao regions, except for one in Northern Samar (Flores, Jr. et al., 2014). This is surprising given these regions' rich macrofungal diversity and robust cultural landscape. This vast knowledge gap, therefore, warrants more studies highlighting other ethnic and indigenous groups to expand further our understanding of macrofungi uses and associated risks among local communities.

Accordingly, the importance of management practices in the handling and storage of edible macrofungi species in the Philippines cannot be overstated, mainly because the Basidiomycota phylum, which includes many of these species, is the same group of fungi that produce mycotoxins. Improper handling and storage conditions can lead to mycotoxin contamination of various agriculturally-relevant commodities, putting consumers at risk. The risk of mycotoxin contamination is further exacerbated by the country's tropical, warm, and humid conditions, which are ideal for the growth and development of mycotoxigenic fungi. Expanding studies on the safe consumption of wild edible macrofungi in the Philippines is therefore crucial, especially considering their gaining commercial interest and recognition by the government as one of the priority crops in the recent road-mapping for agricultural development (Dulay et al., 2021). To date, edible macrofungi species are already commercially cultivated, including *Pleurotus* spp., *Volvariella volvacea*, and *Auricularia* spp., among other species. However, despite these species' commercialization success, research on their potential risks for mycotoxin contamination or production is still limited.

TABLE 11.1
Species List and Distribution of Ethnomycologically Important Macrofungi Species in the Philippines

Family	Species Name[a]	Local Name	Sites	Uses	Reference/s
Agaricaceae	*Agaricus* sp.	*Chaminor*	Ifugao	Food	De Leon et al. (2019)
	Coprinus cinereus (Schaeff.) Gray	*Kulat pinkalan*	Nueva Vizcaya	Food	Torres et al. (2020a; 2020b)
	Leucoagaricus cepaestipes (Fr.)	*Gum-gumot*	Nueva Ecija	Food	De Leon et al. (2016)
	Vascellum pratense (Pers.) Kreisel	*Damurasin*	Ifugao	Food	De Leon et al. (2019)
Albatrellaceae	*Albatrellus* sp.	*Shapannan*	Benguet, Mt. Province	Food	Licyayo (2018)
Amanitaceae	*Amanita javanica* (Corner & Bas) T. Oda, C. Tanaka & Tsuda	*Bagel*	Benguet, Mt. Province	Food	Licyayo (2018)
Auriculariaceae	*Auricularia* spp. [4]	*Tengang-daga, lapa-lapayag, Ballutak, Gargarot*	Nueva Vizcaya, Kalinga, Apayao, Ifugao. Mt. Province	Food	Maslang et al. (2021); Licyayo (2018)
	Auricularia auricula (L. ex Hooker) Underwood	*Tengang-daga, Kuwat malabalugbog dagis, Kuwat kuling baki, Kuwat tangkiki*	Pampanga, Zambales, Nueva Vizcaya, Ifugao	Food	De Leon et al. (2012); Lazo et al. (2015); De Leon et al. (2019)

(*Continued*)

TABLE 11.1 (CONTINUED)
Species List and Distribution of Ethnomycologically Important Macrofungi Species in the Philippines

Family	Species Name[a]	Local Name	Sites	Uses	Reference/s
	Auricularia auricula-judae (Bull.) J. Schrott	*Tengang-daga, kulat kolang-kolang*	Bataan, Nueva Vizcaya	Food	Tantengco and Ragragio, (2018); Torres et al. (2020a; 2020b); Maslang et al. (2021)
	Auricularia fusco-succinea (Mont.) Henn.	*Tengang-daga*	Nueva Vizcaya	Food	Lazo et al. (2015)
	Auricularia polytricha (Mont.) Sacc.	*Kulat alenga baboy, Kuwat malabalugbog dagis, Kuwat kuling baki, Kuwat tangkiki*	Pampanga, Zambales, Northern Samar, Bataan, Nueva Vizcaya, Camarines Sur	Food	De Leon et al. (2012); Flores, Jr et al. (2014); Tantengco and Ragragio, (2018); Torres et al. (2020a; 2020b); Undan et al. (2021); Maslang et al. (2021)
Bolbitaceae	*Agrocybe* sp.	*Kuwat mayo*	Tarlac	Food	De Leon et al. (2012)
Boletaceae	*Boletus* spp.[2]	*Kulat pungkulan, Dangkiyan*	Nueva Vizcaya, Benguet, Mt. Province	Food	Torres et al. (2020a; 2020b); Licyayo (2018)
	Boletus speciosus Frost.	*Sinabog*	Benguet, Mt. Province	Food	Licyayo (2018)
Cantharellaceae	*Cantharellus* sp.	*Bagelni bishing*	Benguet, Mt. Province	Food	Licyayo (2018)

(*Continued*)

TABLE 11.1 (CONTINUED)
Species List and Distribution of Ethnomycologically Important Macrofungi Species in the Philippines

Family	Species Name[a]	Local Name	Sites	Uses	Reference/s
	Cantharellus cibarius Fr.	*Banay*	Northern Samar	Food	Flores, Jr et al. (2014)
Fomitopsidaceae	*Fomitopsis* sp.	*Kulat bungkog*	Nueva Vizcaya	Medicine	Torres et al. (2020a; 2020b)
Ganodermataceae	*Ganoderma* spp. [3]	*Kulat baklag/Kulat bungkog*	Nueva Vizcaya	Medicine	Torres et al. (2020a; 2020b)
	Ganoderma applanatum (Pers.) Pat	*Kulat bungkog*	Nueva Vizcaya	Medicine	Torres et al. (2020a; 2020b)
	Ganoderma australe (Fr.) Pat.	*Kulat bungkog*	Nueva Vizcaya	Medicine	Torres et al. (2020a; 2020b)
	Ganoderma lucidum (Curtis) Karst.	*Kulat baklag, Kulat betang, Kuwat kahoy, Kabuteng-kahoy, Tibig*	Zambales, Bataan, Nueva Vizcaya	Medicine, food (as coffee), decoration	De Leon et al. (2012); Tantengco and Ragragio, (2018); Torres et al. (2020a; 2020b)
	Ganoderma tsugae Murrill	*Kulat betang*	Nueva Vizcaya	Medicine	Torres et al. (2020a; 2020b)
Gomphaceae	*Ramaria botrytis* (Pers.) Ricken	*Pansit-pansitan*	Benguet, Mt. Province	Food	Licyayo (2018)
Hygrophoraceae	*Hygrophorus russula* (Schaeff.) Kauffman	*Lumsek*	Benguet, Mt. Province	Food	Licyayo (2018)
Hymenochaetaceae	*Phellinus* sp.	*Gorgor*	Ifugao	Food, medicine	De Leon et al. (2019)
Inocybaceae	*Inocybe rimosa* (Bull.) P. Kumm.	*Ligbos*	Northern Samar	Food	Flores, Jr et al. (2014)

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TABLE 11.1 (CONTINUED)
Species List and Distribution of Ethnomycologically Important Macrofungi Species in the Philippines

Family	Species Name[a]	Local Name	Sites	Uses	Reference/s
Meripilaceae	*Meripilus giganteus* (Pers.) P. Karst.	*Bang-ugan*	Nueva Ecija	Food	De Leon et al. (2016)
Mycenaceae	*Mycena* spp. [3]	*Uong ginikan, Kulat kalansepay*	Pampanga, Ifugao, Nueva Vizcaya	Food, medicine	De Leon et al. (2012); De Leon et al. (2019); Torres et al. (2020a; 2020b)
Lycoperdaceae	*Calvatia* sp.	*Kuwat Bola/Duldul*	Tarlac	Food	De Leon et al. (2012)
Lyophyllaceae	*Lyophyllum fumosum* (Pers.) P.D. Orton	*Bagel*	Benguet	Food	Licyayo (2018)
	Termitomyces spp. [9]	*Kuwat mayo, Kuwat yabot, Kuwat malakamawey, Kuwat malakamay, Kwatkuyog/kidlat/ susongbuyok, Kabuteng-mamarang, O-ong bunton*	Pampanga, Tarlac, Zambales, Bataan, Nueva Vizcaya, Apayao, Ifugao, Kalinga, Mt. Province	Food, medicine	De Leon et al. (2012); Tantengco and Ragragio, (2018); Licyayo (2018); Maslang et al. (2021)
	Termitomyces albuminosus (Berk.) R. Heim	*Tariktik*	Nueva Vizcaya	Food	Maslang et al. (2021)

(*Continued*)

TABLE 11.1 (CONTINUED)
Species List and Distribution of Ethnomycologically Important Macrofungi Species in the Philippines

Family	Species Name[a]	Local Name	Sites	Uses	Reference/s
	Termitomyces clypeatus R. Heim.	*Kuwat gilatgilatan, Kuwat kuyog, Kuwat lupa/Uong*	Pampanga, Tarlac, Zambales, Nueva Vizcaya	Food	De Leon et al. (2012); Maslang et al. (2021)
	Termitomyces robustus (Beeli) R. Heim.	*Kuwat malakamawey, Kuwat malakamay*	Pampanga, Zambales, Nueva Vizcaya	Food	De Leon et al. (2012); Maslang et al. (2021)
Physalacriaceae	*Oudemansiella canarii* (Jungh.) Hohn	*Balutak*	Ifugao	Food	De Leon et al. (2019)
Pleurotaceae	*Pleurotus* spp. [8]	*Kuwat kasoy, Tarulok/ Uong*	Zambales, Nueva Vizcaya, Ifugao, Apayao, Kalinga	Food	De Leon et al. (2012); Lazo et al. (2015); Licyayo (2018)
	Pleurotus djamor (Rumph. ex Fr.) Boedijn	*Kabuteng kawayan*	Camarines Sur	Food	Undan et al. (2021)
	Pleurotus dryinus (Pers.) P. Kumm.	*Kulat paangan*	Nueva Vizcaya	Food	Torres et al. (2020a; 2020b)
	Pleurotus ostreatus (Jacq. ex Fr.) Kumm.	*Gek-gek*	Ifugao	Food	De Leon et al. (2019)
	Pleurotus pulmunarius (Fr.) Quél.	*Kabuteng kawayan*	Pampanga, Tarlac, Zambales	Food	De Leon et al. (2012)

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TABLE 11.1 (CONTINUED)
Species List and Distribution of Ethnomycologically Important Macrofungi Species in the Philippines

Family	Species Name[a]	Local Name	Sites	Uses	Reference/s
Pluteaceae	*Volvariella volvacea* (Bull.) Singer	*Uong ti saba, Kwat-saging, Kuwat ginikan, Kuwat amucao*	Pampanga, Tarlac, Zambales, Nueva Vizcaya, Bataan, Ifugao, Camarines Sur	Food	De Leon et al. (2012); Lazo et al. (2015); Tantengco and Ragragio, (2018); De Leon et al. (2019); Undan et al. (2021)
Podoscyphaceae	*Podoscypha brasiliensis* D.A. Reid	*Kuyupan*	Nueva Ecija	Food	De Leon et al. (2016)
Polyporaceae	*Lentinus* spp. [3]	*Kulat bitkalan anoy/ lukong, Tarulok*	Nueva Vizcaya	Food	Lazo et al. (2015); Torres et al. (2020a; 2020b)
	Lentinus sajor-caju (Fr.) Fr.	*Ulat, Kuwat kawayan*	Tarlac, Ifugao	Food	De Leon et al. (2019)
	Lentinus squarrosulus Mont.	-	Tarlac	Food	De Leon et al. (2012)
	Lentinus tigrinus (Bull.) Fr.	*Kuwat kikitban, Kuwat miyapol, Kulat bitkalan sipsip*	Pampanga, Tarlac, Zambales, Nueva Vizcaya	Food	De Leon et al. (2012); Torres et al. (2020a; 2020b)
	Lenzites elegans (Spreng.) Pat.	*Kiki*	Ifugao	Food, medicine	De Leon et al. (2019)
	Microporus sp.	*But-taytay*	Nueva Ecija	Food	De Leon et al. (2016)
	Polyporus spp. [4]	*Tarulok/Uong, Kulat kaneg, Kulat kuyong, Kulat simbed*	Nueva Vizcaya	Food, medicine	Lazo et al. (2015); Torres et al. (2020a; 2020b)

(*Continued*)

TABLE 11.1 (CONTINUED)
Species List and Distribution of Ethnomycologically Important Macrofungi Species in the Philippines

Family	Species Name[a]	Local Name	Sites	Uses	Reference/s
	Polyporus grammocephalus Berk.	-	Zambales	Food	De Leon et al. (2012)
	Polyporus picipes Fr.	*Kulat kaneg*	Nueva Vizcaya	Medicine	Torres et al. (2020a; 2020b)
	Polyporus squamosus (Huds.) Fr.	*Bannog*	Ifugao	Food	Licyayo (2018)
	Trametes sp.	*Fatang*	Ifugao	Remedy for stomach ache and headache, and used for body detoxification	De Leon et al. (2019)
	Trametes elegans (Spreng.) Fr.	*Fatang*	Ifugao	Medicine	De Leon et al. (2019)
Psathyrellaceae	*Coprinellus disseminatus* (Pers.) J.E. Lange	*Uong kawayan*	Ifugao	Food	De Leon et al. (2019)
	Coprinopsis atramentaria (Bull.) Redhead, Vilgalys & Moncalvo	*Kulat guko-guko*	Nueva Vizcaya	Food	Torres et al. (2020a; 2020b)
	Coprinopsis cinerea (Schaeff.) Redhead, Vilgalys & Moncalvo	*Kabuteng mais*	Camarines Sur	Food	Undan et al. (2021)

(*Continued*)

TABLE 11.1 (CONTINUED)
Species List and Distribution of Ethnomycologically Important Macrofungi Species in the Philippines

Family	Species Name[a]	Local Name	Sites	Uses	Reference/s
	Coprinopsis lagopus (Fr.) Redhead, Vilgalys & Moncalvo	*Kulat guko-guko*	Nueva Vizcaya	Food	Torres et al. (2020a; 2020b)
	Panaeolus sp.	*Kulat awang*	Nueva Vizcaya	Food	Torres et al. (2020a; 2020b)
	Psathyrella sp.	*Kuwat kunyayabi*	Zambales	Food	De Leon et al. (2012)
Pyronemataceae	*Trichaleurina celebica* (Hennings) M. Carbone, Agnello & P. Alvarado	*Lateg-lateg, Lateg kabayo, Lusi lusi*	Nueva Vizcaya	Food, eye drop	Maslang et al. (2021)
Russulaceae	*Lactarius volemus* (Fr.) Fr.	*Gatas-gatasan*	Benguet, Mt. Province	Food	Licyayo (2018)
	Russula virescens (Schaeff.) Fr.	*Kapputan, Ofot/Upot*	Nueva Ecija, Benguet, Mt. Province	Food	Licyayo (2018); De Leon et al. (2016)
Sarcosomataceae	*Galiella celebica* (Henn.) Nannf.	*Lusi-lusi, Fofotoy*	Kalinga, Apayao	Food	Licyayo (2018)

(*Continued*)

TABLE 11.1 (CONTINUED)
Species List and Distribution of Ethnomycologically Important Macrofungi Species in the Philippines

Family	Species Name[a]	Local Name	Sites	Uses	Reference/s
Schizophyllaceae	*Schizophyllum commune* Fr.	*Utchipe, Kuwat kuritdit, Kwat-kawayan, Kurakding/Kuratding*	Pampanga, Zambales, Northern Samar, Nueva Vizcaya, Bataan, Apayao, Ifugao, Kalinga, Camarines Sur	Food	De Leon et al. (2012); Lazo et al. (2015); Flores, Jr et al. (2014); Tantengco and Ragragio, (2018); Licyayo (2018); De Leon et al. (2019); Torres et al. (2020a; 2020b); Undan et al. (2021); Maslang et al. (2021)
Sclerodermataceae	*Scleroderma citrinum* Pers.	*Buo*	Nueva Ecija	Food	De Leon et al. (2016)
Sparassidaceae	*Sparassis crispa* (Wulfen) Fr.	*Mala-koli*	Benguet, Mt. Province	Medicine	Licyayo (2018)
Stereaceae	*Stereum* sp.	*Kwat-kawayan*	Bataan	Food	Tantengco and Ragragio, (2018)
	Stereum lobatum (Kunze ex Fr.) Fr.	*Kulat kagkagen*	Nueva Vizcaya	Food	Torres et al. (2020a; 2020b)
Tricholomataceae	*Clitocybe* sp.	*Kulat tegatan*	Nueva Vizcaya	Food	Torres et al. (2020a; 2020b)
	Collybia reineckeana Henn.	*O-ong dir-an*	Ifugao	Food	Licyayo (2018)

(*Continued*)

TABLE 11.1 (CONTINUED)
Species List and Distribution of Ethnomycologically Important Macrofungi Species in the Philippines

Family	Species Name[a]	Local Name	Sites	Uses	Reference/s
	Tricholoma robustum (Alb. & Schwein.) Ricken	*Panggayya*	Benguet, Mt. Province	Food	Licyayo (2018)

[a]Numbers enclosed in brackets [ ] indicate the number of different morphotaxa bearing the same genera reported in the literature but not yet identified to species level

Additionally, climate change scenarios pose an additional challenge to managing edible macrofungi, complicating efforts to ensure their safety along the food supply chain. Changes in temperature and precipitation patterns favor some mycotoxigenic fungal species over others (Mannaa & Kim, 2017), requiring continuous evaluation and monitoring of handling and storage practices. The lack of clear regulation for mycotoxins in macrofungi adds to the concern. While some mycotoxins have been found in various agricultural products, well-established national standards for mycotoxins per commodity are still poorly defined, considering the diverse range of mycotoxins reported in the country (Table 11.4). Climate change, inadequate regulations, and limited research call for a proactive approach to mycotoxins in the country. A strengthened food safety system backed by science is key, and if properly managed, macrofungi will continue to play an important role in food security, health, and cultural heritage in the Philippines.

11.3 Current Mycotoxin Research in the Philippines

Much of the current research in mycotoxins and fungi-associated risks in the Philippines are focused on agricultural commodities, specifically during post-harvest period. Due to conditions during storage such as humidity, light, and temperature, mycotoxigenic fungi thrive among grains and other stored agricultural products. *Aspergillus* and *Fusarium* species are the most commonly encountered, with *Penicillium* species also reported (Table 11.2). A list of mycotoxins and their associated mycotoxicogenic fungi in agricultural commodities can be found in the works of Balendres et al. (2019).

11.4 MYCOTOXICOSES

It is important to differentiate mycotoxicoses from other conditions, such as mycoses and mushroom poisoning, which are excluded from this discussion. Mycotoxicosis results from exposure to or poisoning from mycotoxins which are toxic secondary metabolites produced by molds or microfungi (Bennett et al., 2003), generally a condition affecting vertebrates. In contrast, mycoses are the diseases that result from the growth of fungi on their hosts, while mushroom poisoning, the result of exposure to macrofungi, is arbitrarily excluded among the mycotoxicoses (Bennett et al., 2003). While there are several hundred mycotoxins that have been identified (Alshannaq et al., 2017) with a wide variety of chemical composition and properties, only a few dozen are currently considered of medical importance, and from these, the most relevant and clinically significant are highlighted (Table 11.3).

Poisoning from these mycotoxins can be acute, that is, their effects occur with a rapid onset from the time of exposure, or they can be chronic (e.g., occurring several months or years after repeated low-level exposure) (Ostry et al., 2017), which is mostly the case as a result of ingestion of contaminated food (Peraica et al., 2014). However, there is a paucity of information about how many people are affected by mycotoxicoses (Bennett et al., 2003).

TABLE 11.2
Mycotoxin Research in the Philippines in the Last 20 Years

Mycotoxin	Fungi	Substrate	Location	Focus of Research	Reference
Fumonisin	*Fusarium* spp.	Corn		Fuzzy modeling of mycotoxin risk under current and projected climate conditions	(Salvacion et al., 2015)
Ochratoxin A Sterigmatocystin	*Aspergillus* is the dominant species	Coffee	Benguet	Post-harvest assessment of mycotoxin contamination	(Culliao & Barcelo, 2015)
Ochratoxin A	*Aspergillus ochraceus, A. westerdijkiae, A. japonicus, A. carbonarius, Penicillium verruculosum*	Coffee	Benguet, Ifugao, Abra, Cavite	Assessment of the distribution of mycotoxigenic fungi and associated mycotoxin	(Alvindia & de Guzman, 2016)
Fumonisin	*Fusarium* spp.	Corn	Cauayan, Isabela Kibawe, Bukidnon	Modeling using insect damage to ears and weather variables as predictor	(Campa et al., 2005)
Fumonisin	*Fusarium verticillioides*	Corn Soil	Sampling areas in Visayas and Mindanao	Identification and quantification of fumonisin-producing fungi in corn and soil samples	(Hussien et al., 2017)
Fumonisin	*Fusarium verticillioides, F. proliferatum, F. graminearum, Fusarium spp.*	Corn	Corn-producing regions in the Philippines	Identification of *Fusarium* species in corn with Fusarium ear-rot disease of corn contaminated with fumonisin	Pascual et al., 2016

(*Continued*)

TABLE 11.2 (CONTINUED)
Mycotoxin Research in the Philippines in the Last 20 Years

Mycotoxin	Fungi	Substrate	Location	Focus of Research	Reference
Fumonisin	*Fusarium verticillioides*	Corn	Laguna Isabela	Genetic characterization of *F. verticillioides* Detection of fumonisin was one of the analysis	(Cumagun et al., 2009)
Aflatoxin	*Aspergillus nomius, A. flavus*	Peanut Soil	Various locations in Visayas and Mindanao	Classify isolated aflatoxigenic fungi into chemo and genotypes	AboDalam et al., 2020
Aflatoxin		Corn and corn products	Ilocos, Isabela, Iloilo, South Cotabato, Davao	Detection of aflatoxin using the minicolumn method designed initially for copra (coconut) meal	(Arim et al., 1999)
Fumonisin	*Fusarium verticillioides*	Corn	Isabela Laguna	Genetic diversity of fumonisin-producing *F. verticillioides*	(Magculia & Cumagun, 2011)
Aflatoxin	*Aspergillus* spp.	Peanut		Risk profiling of aflatoxin in peanut to consumers in the Philippines	Rustia et al., 2022
Aflatoxin	*Aspergillus flavus*	Cavendish banana	Davao del Norte	Evaluation of natural and in vitro aflatoxin production	(Sales et al., 2003)
Fumonisin	*Fusarium fujikoroi*	Rice	Muñoz, Nueva Ecija Victoria, Laguna	Phylogenetic analysis, fumonisin production, and pathogenicity of *F. fujikoroi*	(Cruz et al., 2013)
Ochratoxin Zearalenone		Pig feed		Evaluation of the effect of the mycotoxin-deactivating agent on the growth performance of pigs	(Acda et al., 2008)

TABLE 11.3
Medically Important Mycotoxins

Toxin	Mechanism of Toxic Action	Targets Organs/ Associated Toxic effects
Aflatoxins	Binding to cellular macromolecules (proteins and nucleic acids) leading to cytotoxic effects (Alshannaq et al., 2017)	Acute aflatoxicosis: vomiting, abdominal pain, pulmonary & cerebral edema, coma, convulsions, death (Alshannaq et al., 2017; Choudhuri et al., 2019) Chronic: Hepatotoxicity Hepatocellular carcinoma Carcinogen (IARC group I) Immune suppression (Choudhuri et al. 2019; Klaassen, 2019; Alshannaq et al., 2017)
Ergot alkaloids	Mimic vasoactive monoamines	Ergotism Blood Vessels: Vasospasm Gangrene Central Nervous System Effects: Convulsions Abortion (Klaassen, 2019; Choudhuri et al., 2019)
Fumonisins	Interference in sphingolipid metabolism (Alshannaq et al., 2017)	Esophageal cancer Liver & renal cancer (Klaassen, 2019; Choudhuri et al., 2019) IARC Group 2B (possibly carcinogenic) Gastrointestinal: Abdominal pain, borborygmus, diarrhea Neural tube defects in experimental animals
Ochratoxins	Inhibition of phenylalanine metabolism Inhibition of mitochondrial ATP production Stimulation of lipid peroxidation (Alshannaq et al., 2017)	Nephrotoxicity (Choudhuri et al., 2019) Immunosuppression Hepatotoxicity Teratogenicity in animal studies IARC Group 2B (possibly carcinogenic) (Alshannaq et al., 2017).

(*Continued*)

TABLE 11.3 (CONTINUED)
Medically Important Mycotoxins

Toxin	Mechanism of Toxic Action	Targets Organs/ Associated Toxic effects
Patulins		Nausea, vomiting, ulceration, and hemorrhage Hepatotoxicity IARC Group C (Alshannaq et al., 2017; Klaassen, 2019)
Trichothecenes	Inhibition of protein synthesis (Alshannaq et al., 2017)	Gastrointestinal: GI hemorrhage, vomiting Dermatitis on direct contact Alimentary toxic aleukia (Alshannaq et al., 2017; Choudhuri et al. 2019)
Zearalenone	Mimics 17β-estradiol binds to estrogen receptors	Estrogenic effects Endocrine disruption IARC Group C (Alshannaq et al., 2017; Klaassen, 2019)

The clinical manifestations of mycotoxicoses are diverse and depend on the properties of the specific mycotoxin, host factors, and the characteristics of the exposure (dose, frequency, and duration of exposure). The mechanisms of the toxic action of mycotoxins are varied and specific organs may be more affected than others leading to a variety of possible clinical effects. For example, the liver is the primary target of aflatoxin B1, considered the most toxic and significant (Bennett et al., 2003; Alshannaq et al., 2017). On the other hand, ochratoxin A is known for its nephrotoxic effects. Evidence for the epidemiologic link between mycotoxin exposure and human disease may be abundant. For example, aflatoxin B1 is known to be the most potent natural carcinogen (Bennett et al., 2003; Joint FAO/WHO Expert Committee on Food Additives et al., 2002) and is associated with hepatocellular carcinoma (Peraica et al., 2014; Alshannaq et al., 2017). In contrast, ochratoxins are considered severely toxic in laboratory animals, but cases are scarce in humans (Peraica et al., 2014).

Patient characteristics, including age, nutrition, genetic background, and comorbidities, may contribute to increased susceptibility to the toxic effects of mycotoxins. For example, children may be more susceptible to the toxic effects of mycotoxins because of their lower body mass, faster metabolic rate, immature organ functions, and detoxification mechanisms (Peraica et al., 2014). In addition, patients with hepatitis B infection with concomitant exposure to aflatoxin are at increased risk for hepatocellular carcinoma (Bennett et al., 2003). Genetic variations in metabolism, as in aflatoxicosis, would have different effects as aflatoxins are metabolized to reactive metabolites by cytochrome P450 enzymes (Bennett et al., 2003).

The route of exposure to mycotoxins is mostly through ingestion from contaminated food (Peraica et al., 2014). However, depending on the toxin, dermal and inhalation exposures can also happen. Generally, it is not communicable from person to person (Bennett et al., 2003). While it is impossible to eliminate mycotoxins from food, regulatory agencies have set regulatory standards. The Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives (JECFA) is responsible for evaluating the risks of mycotoxins to human health. It sets tolerable intake limits, while the Codex Alimentarius Commission establishes the standards to limit exposures based on the JECFA evaluation (World Health Organization, 2018; Habschied et al., 2021).

Diagnosis of mycotoxicosis is difficult. Human biological monitoring, while needing validation, can be a helpful tool and provide information for exposure assessment. Biological samples that can be used include urine, plasma, serum, and breast milk (Escrivá et al., 2017; Habschied et al., 2021). Some of the most commonly used methods for detecting mycotoxins in biological samples include high-performance liquid chromatography coupled with fluorescence detection (HPLC-FLD), enzyme-linked immunosorbent assays (ELISA), liquid chromatography-tandem mass spectrometry (LC-MS/MS), and gas chromatography-tandem mass spectrometry (GCMS) (Habschied et al., 2021; Escrivá et al., 2017).

In general, there is no specific treatment for mycotoxicosis. Management consists of supportive therapy (e.g., adequate hydration) (Bennett et al., 2003) and management of the sequelae (e.g., referral to a specialist for those with hepatocellular carcinoma associated with chronic exposure to aflatoxin B1). Since most of the associated chronic effects are nearly irreversible (carcinogenesis), emphasis is placed on exposure prevention strategies.

11.5 MYCOTOXIN CHEMISTRY AND DETECTION

The commonly tested mycotoxins in the Philippines are aflatoxin B1 (AFB1), aflatoxin B2 (AFB2), aflatoxin G1 (AFG1), aflatoxin G2 (AFG2), fumonisin B1 (FB1), ochratoxin A (OTA), and zearalenone (ZEN) (Figure 11.2). The analytical methods used to analyze mycotoxins are immunochemical-based methods, biosensors (Zhang et al., 2023), and chromatographic techniques. Enzyme-linked immunosorbent assay (ELISA) is an example of an immunochemical-based method that is simple, cheap, and portable. This method is used for first-level screening and survey studies (Anfossi et al., 2016). Chromatographic techniques such as high-performance liquid chromatography (HPLC) with an ultraviolet (UV) or fluorescence (FLD) detector and gas chromatography (GC) are for the quantitative determination of single or few related mycotoxin compounds for confirmatory analysis. In comparison, liquid chromatography-tandem with triple quadrupole mass spectrometry (LCMS/MS) and ultrahigh performance LC with high-resolution mass spectrometry (UHPLC-HRMS) provides a more sensitive, accurate, and selective method for the determination of mycotoxin.

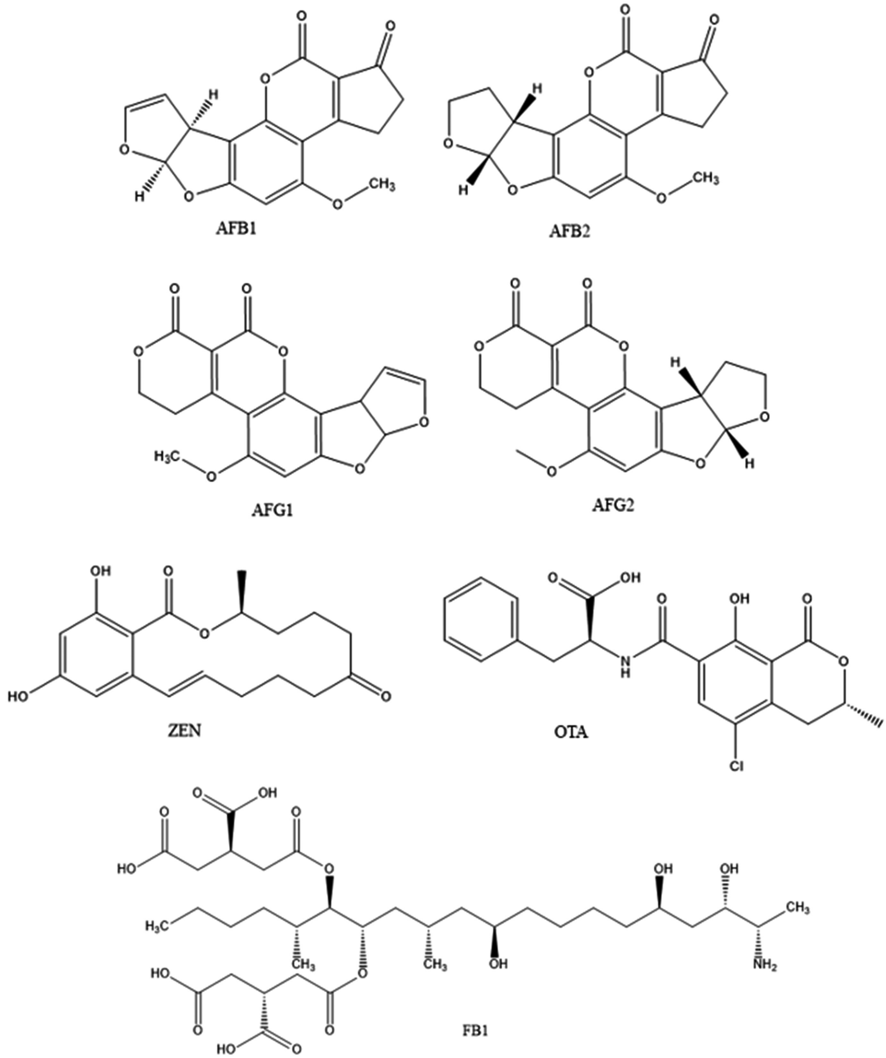

FIGURE 11.2 Structure of commonly tested mycotoxins in the Philippines. Aflatoxin B1 (AFB1), Aflatoxin B2 (AFB2), Aflatoxin G1 (AFG1), Aflatoxin G2 (AFG2), Zearalenone (ZEN), fumonisin B1 (FB1), ochratoxin A (OTA)

These instruments are used for multi-residue analysis and structure elucidation of unknown compounds (Leite et al., 2023).

Before instrumentation, the samples are subjected to extraction methodologies to isolate and concentrate the compound. Examples of extraction methodologies are liquid-liquid extraction (LLE), solid-liquid extraction (SLE), solid phase extraction (SPE), immunoaffinity column (IAC) (Kim et al., 2017), and QuEChERS (Quick, Easy, Cheap, Effective, Rugged, and Safe) (Rodríguez-Cañás et al., 2023). After the extraction, clean-up can be employed to remove other interferences. The chosen method and clean-up method will vary depending on the matrix compatibility (Castell et al., 2023).

Mycotoxins are naturally occurring contaminants, and therefore, imposing a ban on them is impossible. In order to assure food safety and protection of consumers, maximum admissible levels of mycotoxins are regulated by various national and international agencies depending on the commodity or compound and its intended use (Anfossi et al., 2016). These organizations are the European Union (EU) Commission, United States Food and Drug Administration (US-FDA), World Health Organization (WHO), Codex Alimentarius Commission (CODEX), and Food and Agriculture Organization (FAO) (Abdolmaleki et al., 2021). Most of the set regulatory limits of different countries are based on the EU Commission regulation (EC) No. 1881/2006, while the criteria for sample preparation and confirmatory methods of analysis used for food control purposes are in the EU Commission regulation (EC) No 401/2006. In the Philippines, the maximum levels for mycotoxin are published in the Philippine National Standard/Bureau of Agriculture and Fisheries Standard (PNS/BAFS) 194:2022 (Table 11.4).

The strategies to control mycotoxin contamination in commercially important food and feed products are outlined in the standards set in the Philippine National Standards (PNS) developed by the Bureau of Agriculture and Fisheries Products Standards (BAFPS) under the Department of Agriculture (Table 11.5). So far, the available PNS dealing with mycotoxins are only for agricultural products and none for fishery products. While PNS 194:2002 also includes aquatic food commodities, the standards for these products only apply to maximum limits for cadmium, lead, and methylmercury. Mycotoxin management generally relies on controlling the crucial level of moisture contents, water activities, relative humidity, and temperature storage, depending on the product.

11.6 Way Forward

Biosafety and biosecurity concerns surrounding fungi depend largely on sound policies and practices to avoid adverse effects. Risk reduction principles are similar to how laboratories manage risks from bacteria, viruses, and other hazards and threats. Health implications and agricultural losses can be detrimental, even catastrophic, when the risks remain uncontrolled. Thus, it is important to continuously monitor and evaluate existing practices and policies to respond to the dynamic challenges of mycological safety and security. Research, both in the Philippines and neighboring ASEAN countries, may be done to better understand the network of factors at play that shape mycotoxin vulnerability, and institute mitigation measures to reduce risk to the minimum.

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TABLE 11.4
Maximum Level (ML) of Mycotoxin per Commodity

		Maximum Level (µg/kg)	
Mycotoxin	**Commodity**	**PNS/BAFS 194:2022**	**EU EC No. 1881/2006**
Total Aflatoxin	Nuts, almonds, dried figs, maize grain, rice, spices	10–15	15
	Cereals	-	4
Aflatoxin M1	Milk	0.50	
DON	Meal derived from wheat or maize	1,000	1,750
	Cereal grains for further processing	2,000	1,250
	Pasta	-	750
	Bread	-	500
	Processed cereal-based foods and baby foods for infants and young children	-	200
Fumonisins	Raw maize grain	4,000	4,000
	Maize meal	2,000	1,000
Ochratoxin A	Wheat, barley, rye	5.0	
	Cereals	-	3–5
	Dried vine fruit	-	10
	Coffee	-	5–10
	Wine, juice	-	2
	Processed cereal-based and dietary foods for infants and young children	-	0.5
	Spices	-	15–30
Patulin	Fruit juices, spirit drinks, cider, and other fermented drinks from apple	-	50
	Apple products	-	25
	Baby foods, apple juice, and apple products for infants and young children	-	10
Zearalenone	Unprocessed cereals	-	100
	Unprocessed maize	-	350
	Cereals	-	75
	Refined maize oil	-	400
	Bread, pastries, biscuits, and cereals	-	50
	Processed cereal-based foods, processed maize-based food, and baby foods for infants and young children	-	20

TABLE 11.5
Philippine National Standards for Preventing and Controlling Mycotoxins in Specific Agricultural Commodities

PNS/BAFPS Number	Title	Salient Recommendation to Prevent Mycotoxin Contamination
44:2009	Code of Practice for the Prevention and Reduction of Aflatoxin Contamination in Copra	Copra moisture content (MC) of 6% to 7%
130:2014	Code of Practice for the Prevention and Reduction of Ochratoxin A Contamination in Philippine Cacao Beans	Cacao beans maximum MC at 7.5%
131:2014	Code of Practice for the Prevention and Reduction of Ochratoxin A Contamination in Philippine Tablea	Removal of shell or husk after roasting
173:2015	Code of Practice for the Prevention and Reduction of Aflatoxin Contamination in Tree Nuts	Storage conditions: water activities less than 0.7; relative humidity below 70%; temperatures below 10°C Maximum allowable levels for total aflatoxins in tree nuts (almonds, Brazil nuts, hazelnuts, pistachios: 10 μg/kg for ready-to-eat nuts; 15 μg/kg for further processing)
175:2015	Code of Practice for the Prevention and Reduction of Aflatoxin Contamination in Peanuts	Storage conditions: water activities less than 0.7; relative humidity below 70%; temperatures between 0 and 10˚C
170:2016	Code of Practice for the Prevention and Reduction of Ochratoxin A Contamination in Coffee	Maximum aw of 0.67 to 0.70; MC of beans not to exceed 12%
27:2018	Code of Practice for the Prevention and Reduction of Aflatoxin Contamination in Corn	MC of corn not greater than 14%
194:2022	General Standard for Contaminants and Toxins in Food and Feed-Product Standard	Maximum allowable limits (μg/kg) for aflatoxin M1, total aflatoxins, ochratoxin A, deoxynivalenol, fumonisins (B1 + B2)
146:2019	Code of Practice for the Prevention and Reduction of Mycotoxin Contamination in Cereals	Corn MC at 14% before storage; Rice and sorghum grains MC at 14% before storage

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