International Food Research Journal 30(6): 1370 - 1391 (December 2023)
Journal homepage: *http://www.ifrj.upm.edu.my*

Review

Mycotoxin mitigation approaches in selected developed and developing countries

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Article history

Received:
16 February 2022

Received in revised form:
7 February 2023

Accepted:
28 August 2023

Keywords

mycotoxin,
food safety,
foodstuff,
feedstuff,
mitigation approach

Abstract

Rapid population growth leading to increased demand for poultry has intensified poultry production over the years. However, research has detected the presence of mycotoxin contaminations, such as aflatoxins, ochratoxin A, zearalenone, *etc*. in foodstuffs for human consumption and poultry feed. Mycotoxin contamination in feedstuffs might ultimately have adverse impacts on human health. As it is vital to mitigate mycotoxin at the national level, this study reviews the mycotoxin mitigation approaches for foodstuffs and feedstuffs in selected developed and developing countries, namely the United Kingdom, Singapore, Taiwan, and Malaysia. The present review focuses on the legislative frameworks, relevant national authorities, mycotoxin determination analyses, and other initiatives related to mycotoxin management. Analysis indicated that every selected country has respective national authorities and stipulated regulations for regulating mycotoxin levels in foodstuffs. However, not all mycotoxin types and foodstuffs are covered. Furthermore, not all countries have regulatory frameworks to control the mycotoxin levels in feedstuffs. Hence, it is still a challenge because of the inevitable impact on human health.

DOI
https://doi.org/10.47836/ifrj.30.6.02

Introduction

Over the years, the world's population has grown rapidly, from 600 million in 1700 to 7.7 billion in 2019 (Max *et al*., 2020). As the population increases, the quantity, quality, and diversity of foods also increase and are enhanced to accommodate global population needs. This includes production and demand for livestock products, such as meats, eggs, and milks, as the nutrition in these livestock products is essential for the development and maintenance of well-being and good health of humans. Therefore, the global volume of livestock production, such as poultry production, has been intensified to meet the demand (Martinez *et al*., 2009).

Although livestock products are one of the vital protein sources needed for human growth and development, there might be potential risks in the consumption of livestock products. For example, it has been found that some chicken meats were contaminated with mycotoxins, such as aflatoxins (AFs), ochratoxin A (OTA), and zearalenone (ZEN), and when people consume these contaminated chicken meats, they could develop certain diseases like aflatoxicosis and liver cancer such as hepatobiliary carcinoma (Bbosa *et al*., 2013; Iqbal *et al*., 2014). As far as aflatoxin B_1 (AFB_1) is concerned, it is converted into a reactive form that will alter DNA conformation after it is metabolised by a microsomal enzyme known as cytochrome P450 (CYP450), thus causing carcinogenicity (Bbosa *et al*., 2013). Therefore, there is a need to regulate the level or residue of mycotoxin in livestock products in order to reduce and eliminate the risks of consuming contaminated livestock products.

Mycotoxin contamination in poultry is often caused by toxin-producing fungi in animal feeds. For example, chicken feeds that are contaminated by mycotoxins are the cause of mycotoxin contamination in chicken meat. Mycotoxins can accumulate in the body of chicken through long-term consumption of mycotoxin-contaminated feeds such as wheat, grain, and other ingredients (Greco *et al*., 2014). Therefore, as part of the initiatives to ensure food safety, determining and regulating levels of

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mycotoxin in foodstuffs and feedstuffs are crucial since they could be highly toxic even when the concentration is relatively low (Zain, 2011). According to the World Health Organization (WHO), the implementation of food safety standards and effective inspection is necessary at the national, regional, and international levels. The monitoring and inspection systems have to be affordable and practical so that they are applicable for both large and small agricultural production (King *et al*., 2017). These systems should be applied to different stages of feed and foodstuff production so that appropriate actions can be taken to minimise the loss of products. Such efforts will also be contributing to Goal 3 of the Sustainable Development Goals (SDGs), particularly indicator 3.9.3, which aims to reduce mortality rates from unintentional poisoning (DSDG, 2021).

Mycotoxin concerns over food security and food safety

Food security is a condition where safe and nutritious food is accessible to everyone that meets the dietary needs and food preferences in order to achieve an active and healthy life (WFS, 1996). The four major problems considered in food security are non-availability, access difficulty, improper utilisation, and instability of food (Napoli *et al*., 2011). Among the dimensions of food security, physical availability of food is tightly related to food safety. Food safety aims to ensure the continual availability of food by maintaining food quality as well as avoiding contamination and foodborne diseases.

According to the WHO, one of the major causes of death in developing countries might be due to highly detrimental diarrhoeal diseases resulting from foodborne and waterborne contaminations (WHO, 2017). Other than that, poor food safety may also result in severe health impact. For instance, in 1961, many turkeys were found dead due to feedstuff contamination of aflatoxin in England (Peng *et al*., 2018). The virus that caused the avian influenza A (H7N9) outbreak in 2013 infected poultry and the environment (Andreas, 2017), resulting in a total of 1,557 people from China, Hong Kong, Macao, and Taiwan getting infected with H7N9. About 90% of the victims were infected through poultry exposure (Kile *et al*., 2017). As for mycotoxin diseases, the first case of severe acute aflatoxicosis was reported in 1974, causing the death of 106 citizens of Western India (Kachapulula *et al*., 2017). It is also known that contamination of AFB_1 in animal feeds is responsible for the presence of aflatoxin M_1 (AFM_1) in dairy milk intended for human consumption. AFM_1 is a metabolite of AFB_1, thus they are quantitatively correlated (EFSA, 2004).

Generally, the production of poultry feeds includes growing, pre-harvesting, post-harvesting, and storing. Three levels of preventive actions mitigate mycotoxin production based on the severity of mycotoxin contamination. The primary prevention is designed for pre- or post-harvest feedstuffs, such as creating conditions and an environment that discourage fungal growth. Meanwhile, the secondary prevention is to eliminate fungi and prevent further decay of poultry feeds when they are already affected by fungi during storage. When poultry feeds are severely contaminated and contain high concentrations of mycotoxin, tertiary prevention is employed by diluting the concentration of mycotoxin by mixing with poultry feeds consisting of low mycotoxin levels so that it is below the maximum level (ML) determined by the authority (Ravindran, 2013).

Many research studies on mycotoxin determination and management have been conducted, particularly on the establishment of advanced technologies and methods to prevent the occurrence of mycotoxins, and reduce the severity of contaminated foods and feeds. For instance, detection techniques such as chromatographic and sensor-based techniques like monitoring and prevention action are used to promote food safety (Mahato *et al*., 2019). Various methods for treatment of contaminated food, such as biological detoxification, genetic improvement, and the application of nanotechnology are discussed in a recent review (Haque *et al*., 2020). The prevention, detoxification, and decontamination methods for foods and feeds during pre- and post-harvest management have also been reviewed recently (Ndemera *et al*., 2018; Peng *et al*., 2018; Agriopoulou *et al*., 2020). The management of mycotoxins using feed additives to prevent their contamination in poultry and livestock feed has also been studied (Tilley *et al*., 2017; Gallo *et al*., 2020). Furthermore, the integrated management of mycotoxins for stored grain by using the five-stage system from prevention to monitoring, reduction, treatment, and the research of bio-competitive strains against mycotoxigenic fungi has also been updated (Fleurat-Lessard, 2017).

The review of previous studies, however, revealed the absence of studies comparing the management of mycotoxins at the national level. It is vital to compare national mycotoxin mitigation approaches in order to manage mycotoxin in foodstuffs and feedstuffs. Hence, the present review aims to analyse and compare mycotoxin mitigation approaches in four countries, namely the United Kingdom, Taiwan, Singapore, and Malaysia.

Methodology

For the purpose of analysing and comparing mycotoxin mitigation approaches in the United Kingdom, Taiwan, Singapore, and Malaysia, four aspects were emphasised as justified in Table 1. The four aspects were reviewed and analysed based on existing approaches, information in the legal documents, and relevant initiatives obtained from their respective official websites.

Table 1. Justifications of the four main aspects of the present review.

Aspect	Justification
Legislative framework	Based on the conclusion by Sachin *et al*. (2021), the elements of government and policy are the top-ranked challenges in food safety. It is crucial to understand the backbone structure of food safety management in each country before proceeding with an in-depth study regarding its implementation by national authorities. Therefore, the legislative framework for food safety is the foremost aspect to be analysed.
National authority	National authorities executing and sustaining food safety are important since countries with different legislative frameworks require different organisational structures to accomplish and enable efficient food safety.
Mycotoxin analysis method	In general, contaminants in foodstuffs and feedstuffs are prevented by monitoring and analysing the samples with analytical techniques. Analytical techniques are constantly improved, and new techniques are developed to increase the overall performance during analysis. Therefore, it is valuable to explore different mycotoxin analysis methods in the selected countries.
Other initiative	Other initiatives involving governmental and non-governmental organisations, as well as stakeholders in the food industry, are also explored to gain a broader understanding of the approach taken in each selected country to attain food safety.

United Kingdom (UK)

Since the UK was one of the 28 European Union (EU) members, the food safety in the UK was enforced and managed through cooperation with the authority in the EU, namely the European Food Safety Authority (EFSA). However, the UK formally left the EU on 31 January 2020. According to the European Union (Withdrawal) Act 2018, although the UK has left the union, the EU legislation regarding food and feed safety and hygiene is still available for adoption as, or adaptation to, UK law (FSA, 2021a). Therefore, the following discussion includes elements from both the EU and the UK.

In order to address the problem of mycotoxin in foodstuffs, the Food Standards Agency (FSA) provides guidance based on two EU regulations, namely Commission Regulation (EC) No. 1881/2006 and Commission Regulation (EC) No. 401/2006. Commission Regulation (EC) No. 1881/2006 has determined the MLs for certain contaminants (including mycotoxins) in foodstuffs. The ML is the maximum allowable concentration of a contaminant that can be safely present in food. Comprehensive guidance with respect to the MLs in foodstuffs is stipulated in Commission Regulation (EC) No. 1881/2006. In the UK, the FSA monitors the MLs of mycotoxins in foods; whereas in the EU, the responsibilities are with the EFSA and the Food and Drug Administration (FDA) (Ksenija, 2018). Commission Regulation (EC) No. 401/2006 established the methods of sampling and analysis for the official control of mycotoxins in foodstuffs (EC, 2006b).

The degree of toxicity varies among different types of mycotoxins. Therefore, the MLs for AFs were the lowest as compared to OTA, ZEN, patulin (PAT), and others. The MLs for foodstuffs are considerable in detail and specific, as different types and stages of foods are considered. For instance, the ML of ZEN for unprocessed cereal is 100 μg/kg, while processed cereals intended for direct human consumption have a lower ML, *i.e.*, 75 μg/kg. The mixing of foodstuffs containing contaminants lower than the ML and those that exceed the ML for the purpose of complying with the ML is prohibited. Other than that, foodstuff products with extremely low MLs are specially made for young children and infants since they are highly vulnerable to toxins (EC, 2006a). All of the MLs for foodstuffs implemented in the UK are simplified and summarised (EC, 2006a; 2007), and compared with those of other countries in Table 2.

Apart from mycotoxins in foodstuffs, mycotoxins in feedstuffs are also a concern due to the toxicity of mycotoxins spread *via* the food chain. Aflatoxins are common contaminants for poultry feeds like cottonseed, groundnuts, wheat, legumes, and corn, and produced by *Aspergillus flavus* and *A. parasiticus*, which grow easily on the feeds due to environmental factors such as temperature, humidity, and pH (Yin *et al*., 2015). Although the MLs of mycotoxins for animal feeds are absent from the regulations provided by the FSA, they are stated in Commission Recommendation 2006/576/EC and Directive 2002/32/EC. Table 3 shows the MLs for animal feeds (with a moisture content of feedstuffs of 12%) enforced in the UK (EC, 2006c; 2006d). It is noted that the range of ML of AFB_1 in feedstuffs (Table 3) is relatively higher than the ML of AFB_1 in foodstuffs (Table 2). This is because AFB_1 is metabolised by poultry, leaving only some toxic residues in poultry meat or products for human consumption (Haque *et al*., 2011). Low concentrations of toxic residues will also have fewer harmful effects on human health. Any violation of MLs will incur a penalty by paying extra based on the function of the batch of feeds (Siegel and Babuscio, 2011).

The concentration of mycotoxins is measured using validated analytical methods such as thin-layer chromatography (TLC), high-performance liquid chromatography (HPLC), gas chromatography (GC), and enzyme-linked immunosorbent assay (ELISA) (Van Egmond, 2004; Siegel and Babuscio, 2011). All samples for mycotoxin analysis in the UK must be sent to laboratories accredited by the United Kingdom Accreditation Service (UKAS), a reputable national accreditation body in the UK (UKAS, 2019). Accredited laboratories will utilise certified reference materials and validated methods for mycotoxin analysis to obtain reliable and accurate results (EFSA, 2004).

Besides the legislative framework and analysis methods, the UK has also taken other initiatives to mitigate the formation and content of mycotoxins in poultry feeds. These initiatives include the quality management systems that are implemented during the planting stage of feed materials in order to effectively prevent the formation of mycotoxin. Generally, there are four types of quality management systems: Good Manufacturing Practice (GMP), Good Hygienic Practice (GHP), Good Agricultural Practice (GAP), and Good Storage Practice (GSP), which are utilised in controlling food safety (FAO, 2001). The FSA has adopted several quality management systems in the UK, namely the GAP and GSP. However, currently only the code of practice for cereals has been established. This code of practice is intended to reduce *Fusarium* mycotoxins (DON, ZEN, HT-2, and T-2) in cereals during planting and OTA during storage (FSA, 2021b).

Among the GAP recommendations are the practice of crop rotation, the use of multiple resistances, ear spraying to mitigate ear blight, crop debris reduction, and timely harvesting (FSA, 2021b). Crop rotation is crucial for eliminating the accumulation of *Fusarium* fungi inoculum from being transmitted to the next crop. Different crop types vary in their resistance to mycotoxin contamination; thus, crop species with higher resistance are preferred. Furthermore, when cereals are at the flowering stage, fungicide in the form of ear spray is required to control the fungal disease known as ear blight. Another important factor in decreasing mycotoxin contamination is eliminating crop debris before planting new crops. The methods introduced for removing crop debris from the soil surface are straw removal and soil cultivation. Besides, the schedule for harvesting a crop is important since *Fusarium* fungi produce mycotoxins at a higher rate after ripening; thus, delayed harvesting would lead to heavily polluted cereals. After grain harvesting, it will be cooled and dried to retain 18 and 15% moisture content for short- and long-term storage, respectively. Therefore, the GAP is crucial in mitigating mycotoxin contamination (FSA, 2021b).

On the other hand, the strategies for the GSP only aim to reduce OTA since this particular mycotoxin is produced during storage. OTA is often produced by fungi such as *Aspergillus* species and

Table 2. Maximum levels of various mycotoxins in foodstuffs in the UK, Taiwan, Singapore, and Malaysia.

Group	Mycotoxin	Foodstuff	Maximum level (μg/kg)			
			UK	Taiwan	Singapore	Malaysia
1	Sum of AFs (B_1, B_2, G_1, and G_2)	Nuts	4.0 - 15.0	4.0 - 15.0	5.0	10.0 - 15.0
		Others	-	10.0	-	5.0
2	AFB_1	Grains, nuts, dried fruits, and spices	2.0 - 8.0	2.0 - 12.0	5.0	-
		Cereal-based, baby, and dietary foods for special medical purposes	0.10	0.10	0.10	0.10
3	AFM_1	Milk	0.05	0.50	0.50	0.50
		Baby, follow-up, and baby milk for special medical purposes	0.025	0.025	0.025	0.025
4	Ochratoxin A (OTA)	Coffee	5.0 - 10.0	5.0 - 10.0	5.0 - 10.0	5.0 - 10.0
		Cereal-based and baby foods, and baby milk for special medical purposes	0.50	0.50	0.50	0.50
5	Patulin (PAT)	Fruit beverages	50.0	50.0	50.0	50.0
		Apples (products and beverages) for infants and young children, and baby foods	10.0	10.0	10.0	-
6	Citrinin (CIT)	Red yeast (rice, complex foods, food supplements)	-	2000.0 - 5000.0	-	-
		Monascus food colour	-	200.0	-	-
7	Fumonisins (FUMs)	Grains (unprocessed/products)	800.0 - 4000.0	800.0 - 4000.0	800.0 - 4000.0	-
		Maize-based foods for infants and young children, and baby foods	200.0	200.0	200.0	-
8	Deoxynivalenol (DON)	Cereals and oats (unprocessed/products), pasta, breads, biscuits, and pastries	500.0 - 1750.0	500.0 - 1750.0	500.0 - 1750.0	-
		Cereal-based foods for infants and young children, and baby foods	200.0	200.0	200.0	-
9	Zearalenone (ZEN)	Grains (unprocessed/products), breads, biscuits, and pastries	50.0 - 400.0	50.0 - 400.0	50.0 - 400.0	-
		Cereal-based foods for infants and young children, and baby foods	20.0	20.0	20.0	-

Table 3. Maximum levels of various mycotoxins in animal feeds enforced in the UK.

Mycotoxin	Feedstuff	Maximum level (µg/kg)
Aflatoxin B_1 (AFB_1)	Feed materials: Cereals, Cereal products, Maize by-products, Complementary and complete feedstuffs	5 - 20
Ochratoxin A (OTA)		100 - 250
Deoxynivalenol (DON)		800 - 12000
Zearalenone (ZEN)		200 - 300
Fumonisins B_1 + B_2 (FUMs)		20000 - 60000

Penicillium verrucosum. These fungi are present in dirt, such as old grains and dust attached to stores and machinery that have not been cleaned periodically. Therefore, these fungi may be transmitted to freshly harvested crops, leading to OTA contamination in the crops. The strategy provided by GSP to overcome this problem is to ensure the hygiene of machinery and storage areas for the crops. Since the growth of fungi is highly dependent on environmental factors such as temperature and humidity, the moisture content of crops has to be maintained at 15%. Therefore, prior to the storage of grain, cool air with a temperature of 5°C and an airflow of 10 m^3/hour/tonne is used to lower its temperature after reducing the moisture content of grains with hot air. During storage, good ventilation and sufficient headspace are recommended to prevent the re-absorption of moisture in the grain in order to avoid fungal growth. Other than that, the condition of the grain will also be monitored by a calculation model based on data on the temperature and moisture content of the grain recorded over a period of time (FSA, 2021b).

Besides these mitigation and managerial methods, the FSA conducted a 4-year surveillance programme from 2010 to 2015 to inspect the mycotoxin in a wide range of foods such as nuts, cereal, spices, fruit, oil, and others (FSA, 2018). The aim was to generate an in-depth survey of the actual condition of mycotoxin contamination in foods, which could indicate the need to amend the ML values for mycotoxin stipulated in legislation. Moreover, the data serves as a reference for the FSA to advise the public on the consumption of the foods selected in the surveillance programme. The results of the surveillance programme showed low mycotoxin content among the 400 food samples analysed, indicating that the selected food types were safe for consumption (FSA, 2018). Before the FSA's surveillance programme, a study was conducted by Edwards (2009) that analysed 300 samples of wheat in the UK from 2001 to 2005 to determine the levels of 11 mycotoxin types (10 types of trichothecenes and ZEN). The results indicated a percentage range from 0.4 to 11.3% of the wheat samples with mycotoxin levels higher than the ML (Edwards, 2009). While this percentage was obtained over a 5-year period and is not critical, the surveillance of mycotoxin content is crucial to ensure its level is within safe limits.

In summary, the UK employs comprehensive food safety and food security systems for preventing mycotoxin contamination in foodstuffs and feedstuffs, using the regulatory framework adopted from the EU. Several legislations and regulations related to mycotoxin contaminants have been updated and amended over the years to improve the management of mycotoxin, especially when new scientific evidence is made available. The UK has also introduced quality management systems, such as the GAP and GSP, to further prevent contamination with mycotoxins.

Taiwan

The agriculture sector in Taiwan has grown rapidly from involving only 0.07 hectares in 1968 to 797,000 hectares in 2015 (Christensen, 1968; Wan, 2018). In Taiwan, chicken has the highest consumption record among different types of poultry meat, such as geese, ducks, and turkeys. Almost 50% of chicken is domestically farmed for meat and egg production (Lee, 2006). Thus, poultry meat production is strictly regulated by several government agencies, such as the Ministry of Health and Welfare (MOHW) and the Council of Agriculture (COA), which are responsible for ensuring food safety.

The Department of Health (DOH) has been responsible for the health and medical development of Taiwan since 1967, and its organisational structure was reformed during 2003 and 2004 to reach the international level in ensuring the good health of its citizens (DOH, 2018). Under the DOH, the Food and Drug Division is responsible for ensuring food safety. In 2013, with some welfare agencies, DOH was transformed into the MOHW (MOHW, 2014). Since then, the MOHW has become the main agency to regulate and enforce food safety-related acts and regulations and is also responsible for the food safety management system and certification.

The Act Governing Food Safety and Sanitation by MOHW consists of the Enforcement Rules and Sanitation Standards for Contaminants and Toxins in Food in order to implement a thorough food safety system (Republic of China, 2017; 2019a; 2021). The MLs for mycotoxins in foodstuffs are comprehensively stipulated in the second appendix of the Sanitation Standard for Contaminants and Toxins in Food (Republic of China, 2021), and the MLs are simplified and summarised in Table 2. The ML for mycotoxin is very detailed, covering most of the common potential mycotoxins in foodstuffs, and it is similar to the regulations enforced in the UK. However, no ML of mycotoxin is provided for feedstuffs.

The management of food safety hazards is also regulated by the Act Governing Food Safety and Sanitation through the Regulations on Food Safety Control System, which were gazetted in 2014. A professional team with the knowledge of the Hazard Analysis Critical Control Point (HACCP) is required to identify and avoid any potential hazards to the food. Although many regulations and enforcement rules had been implemented by MOHW, many incidents associated with food safety still occurred from 2003 to 2011, as summarised by Li *et al*. (2012). Thus, the Taiwan Food and Drug Administration (TFDA) was established in 2010 after a severe incident of adulterated milk products with melamine, leading to six deaths and impacting around 300,000 infants and young children in 2008 (Li *et al*., 2012). The TFDA enhances food safety by implementing the Health Food Control Act and its Enforcement Rules (Shen, 2020). Furthermore, food safety in Taiwan has been enhanced since the TFDA adopted the international risk analysis system from the Codex Alimentarius Commission (CAC), a joint enterprise of the Food and Agriculture Organization (FAO) and WHO for food safety, in 2012 (Kang *et al*., 2014). Currently, the TFDA is part of MOHW since joining forces in 2013 due to the reformation and restructuring of Taiwan's administration (Shen, 2020).

In the effort to enhance food safety and mitigate mycotoxin contaminants, the source of mycotoxin should be prevented. Thus, the mycotoxin mitigation actions begin with the cultivation of crops and livestock. In Taiwan, the safety of agricultural products is managed by the COA, which comprises two commissions, namely the Council for Agricultural Planning and Development (CAPD) and the Agricultural Bureau of the Ministry of Economic Affairs (MOEA) (COA, 2020a). The Feed Control Act, established by the COA, is to ensure the quality of feedstuffs for livestock, poultry, and aquatic animals. Although the Feed Control Act does not specifically mention mycotoxin, it is described as a "hazardous substance" in Section 20.1 of Article 20 (Republic of China, 2015). Thus, the quality of domestic, imported, and even exported animal feeds are regulated under this Act.

It is difficult for the COA to manage the huge agriculture sector alone. Thus, two major agencies, namely the Agriculture and Food Agency (AFA) and the National Animal Industry Foundation (NAIF), assist the COA. The AFA specialises in cultivating healthy crops by designing, guiding, and executing development plans based on the optimum conditions suggested by research (AFA, 2018). The NAIF is supervised by the COA to facilitate the production and sale of livestock products (NAIF, 2000). In order to ensure the safety of poultry and livestock products, the NAIF is entrusted by the COA's Bureau of Animal and Plant Health Inspection and Quarantine (BAPHIQ) to employ professional meat inspectors (BAPHIQ, 2021). A meat inspector is a qualified veterinarian that performs meat inspection services for the slaughterhouses of livestock (pigs, cattle, buffalo, sheep, and goats) and poultry (chickens, ducks, and geese). The scope of meat inspection services includes infrastructure requirements, inspection standards and procedures, HACCP, and pathogen reduction programmes, respectively (Du, 2002). The meat inspection result is crucial since it determines the approval or disposal of the meat before and after slaughtering in order to ensure it is safe for consumption (Du, 2002). Currently, about 653 meat inspectors are in charge of a total of 54 slaughterhouses (livestock and poultry) in accordance with the Requirements for Slaughter Operation and Rules for Meat Inspection (BAPHIQ, 2021).

A huge advantage of Taiwan's food safety system is its agricultural products' transparency to the consumer. The COA has implemented a third-party accredited certification system known as the Traceable Agricultural Product (TAP) system to enable consumers to trace the source of agricultural products from farm to table. Only those agricultural product operators legally permitted to produce, process, package, distribute, and sell agricultural products that successfully fulfil the requirements of Taiwan's Good Agricultural Practice (TGAP) can obtain the TAP Certificate from Taiwan's Agriculture and Food Traceability System (TAFTS) (Republic of China, 2019b; TAFTS, 2019). The products with the TAP certification are preferred by consumers because of the quality assurance that the products meet the standards for production (TGAP) and processing (ISO 22000). Based on the study by Suhandoko *et al*. (2021), 80% of the 1420 responses collected from consumers in a traditional market are willing to spend more for TAP-certified pork products. Therefore, the number of TAP-certified operators has been increasing gradually since 2013, with consumers becoming more concerned about food safety (TAFTS, 2019). Additionally, a quality management system like GAP is implemented by the TGAP by incorporating GLOBAL G.A.P. Certification standards (MOA, 2018a). Besides the production of agriculture, livestock, aquaculture, and horticulture, it covers the supply chain and Compound Feed Manufacturing (AGFOCERT, 2011). Therefore, it can also help reduce mycotoxin contaminants in foodstuffs with the implementation of GAP.

Mycotoxin mitigation in Taiwan is comprehensive, involving the sharing of professional knowledge and real case scenarios among the governmental sectors and stakeholders. Formal meetings such as congresses or conferences are held to improve agricultural development by employing more smart technologies while maintaining environmental sustainability. For instance, the 6th National Agriculture Congress focused on the 123 key issues revolving around agriproduct safety, environment and resource sustainability, smart technology prospects, and farmers' happiness (MOA, 2018b). A total of 73 conclusions were tabled from the discussions among more than 300 experts from the industry, government, and academia that would be converted into practicable policies (MOA, 2018a). Another formal meeting involving the stakeholders was held recently as a virtual meeting due to restrictions imposed on account of the COVID-19 pandemic. The formal meeting of the 2020 International Conference on Smart Agriculture, attended by Taiwanese stakeholders from various countries such as the UK, the Netherlands, and Japan, was held to solve problems such as climate change and population structure, trade liberalisation, food safety, and the environment with the help of agricultural technologies (COA, 2020b). Thus, Taiwan is actively developing its agriculture sector to overcome existing problems and progress towards sustainable agricultural development.

Recently, a new rapid analytical technique was developed by Taiwan's Agricultural Chemicals and Toxic Substances Research Institute (TACTRI) of the COA for the analysis of pesticide residues in pre-harvested fruits and vegetables by using mass spectrometry (MS) (COA, 2020c). However, the analytical method recommended by the MOHW for mycotoxin detection is still valid, using HPLC with a fluorescence detector for both foodstuffs and feedstuffs (The Executive Yuan Gazette Online, 2020). During the inspection of commercial foodstuffs, such as peanut products, spices, wheat, roasted coffee, rice, *etc*. for mycotoxin (AFs, OTA, and CIT) contaminations by the TFDA, analyses were conducted using the HPLC method incorporated with tandem mass spectrometry (HPLC-MS/MS) (Chen *et al*., 2016). Therefore, the fluorescence detector and tandem MS are effective in mycotoxin detection.

The TFDA pays attention to mycotoxin issues by monitoring, assessing risk upon exposure, and researching analytical methods for mycotoxin in foodstuffs and feedstuffs. For instance, the mycotoxin contaminations in various commercial foodstuffs, such as peanut products, tree nuts, spices, Coix seeds, wheat, roasted coffee, rice, and red yeast rice products, were monitored for a year to determine the degree of compliance with the regulation. It was found that 96.8% of the total food products of the commercial foodstuffs (712 samples) from 2012 to 2013 were below the regulated ML stipulated by the MOWH (Chen *et al*., 2016). However, since the incident of the contamination of red yeast rice, where most of the raw materials (62.7%) were contaminated with CIT in 2009, it has been altered, and inspection has to proceed immediately upon import (Chen *et al*., 2016). Another inspection by the TFDA was performed with 1089 samples of peanut products collected from 2011 to 2017. Unlike the previous research, the Margin of Exposure (MOE) was used instead of the ML during evaluation. The MOE was determined using the ratio of the benchmark dose and the estimated AFs intake by humans. The TFDA agreed to the use of MOE for the safety assessment of genotoxic and carcinogenic components such as mycotoxin, as suggested by the EFSA Scientific Committee (Lien *et al*., 2019). Therefore, mycotoxin mitigation can be achieved by measuring the MOE and ML of the mycotoxin. Furthermore, the TFDA has cooperated with two laboratories from the FDA of the United States and the Overseas Merchandise Inspection Company USA Inc. in validating the analytical method of using a stable isotope dilution and liquid chromatography-tandem mass spectrometry (LC-MS/MS) to quantify AFB_1, aflatoxin B_2 (AFB_2), aflatoxin G_1 (AFG_1), aflatoxin G_2 (AFG_2), and AFM_1 in milk, milk-based infant formula, and animal feed (Zhang *et al*., 2018). The use of the carbon-13 isotope simplifies the sample preparation and calibration steps due to its ability to reduce the unfavourable matrix effects that suppress or enhance the resulting signal. Only extraction, centrifugation, and filtration of samples are required during preparation, while calibration standards of the solvent are sufficient, unlike the conventional LC-MS/MS methods that demand matrix-matched calibration standards (Zhang *et al*., 2018).

In summary, the mycotoxin mitigation approach in Taiwan is largely based on the acts enforced by the MOWH for foodstuffs, while the COA regulates feedstuffs. The TFDA also plays a huge role in the execution of research and analyses of mycotoxin contaminants in foodstuffs and feedstuffs. Food safety is further enhanced by implementing the TAP system, which enables a higher rate of product transparency and disclosure to society. Therefore, the food safety management in Taiwan, including mycotoxin mitigation, is well established and is expected to improve over the years as it moves towards a sustainable agricultural system.

Singapore

Due to the limited land area in Singapore, 90% of its food supplies are imported from over 170 different countries and regions. Various technologies and methods such as vertical farming, aquaponics, reusing food waste, having alternative protein sources such as insects, microalgae, and cultivated meat, and multi-functional urban land use were practised to produce 30% of its nutritional requirements by 2030 (Diehl *et al*., 2020; Mok *et al*., 2020; SFA, 2020; 2021a).

The management of food safety and food security in Singapore is mainly the responsibility of the Singapore Food Agency (SFA), a statutory body of the Ministry of Sustainability and the Environment (MSE) (SFA, 2019). Therefore, mycotoxin mitigation is the responsibility of the SFA, particularly in imported or locally manufactured and processed foodstuffs and feedstuffs. The Sale of Food Act is strictly enforced in regulating food safety. The mycotoxin mitigation is evident in the Food Regulations, Section 56 of the Sale of Food Act, where the MLs of mycotoxins are stipulated (Singapore, 2002; 2005). However, the MLs of only a few major mycotoxins like AFs, AFB_1, AFM_1, and PAT are provided in the regulations. The SFA provides a more inclusive list of regulatory MLs for mycotoxin in foodstuffs, as summarised in Table 2. Although the list of MLs for mycotoxins is not comprehensive (for example, the CIT is not mentioned), the maximum residue limits from the CAC are adapted for those contaminants without MLs stated in the regulatory instruments (SFA, 2021b). On the other hand, as far as feedstuffs are concerned, no specific regulatory limits are stated for mycotoxin in feedstuffs since they are already covered in General Standard for Contaminants and Toxins provided by the CAC (Codex, 2019).

According to the Feeding Stuffs Act, a licence to import, manufacture, and sell animal feeds is mandatory, and the SFA is accountable for this operation (Singapore, 2000). The Animal Feed Licence is essential for a local company to produce and process livestock and aquaculture feed. It is frequently applied with the Free Sale Certificate to merchandise those feedstuffs. Besides, the Cargo Clearance Permit (CCP), which serves as the SFA import permit, is also mandatory during animal feed import to enable food traceability, withdrawal, and liability for any non-compliance (SFA, 2021d).

Since many types of animal feed in Singapore are imported from countries such as Indonesia, India, Vietnam, the United States, and Australia, their quality is ensured through international nutritional standards (SFA, 2021d; WITS, 2021). It is also one of the requirements in the Feeding Stuffs (Licensing, Analysis, and Fees) Rules regulated in the Feeding Stuffs Act (Singapore, 2000; 2009). Apart from feedstuffs, imported foodstuffs such as poultry meats and products from various countries such as Malaysia, France, Argentina, Spain, and others are strictly assessed and approved by the SFA to allow importation for only a specific period (SFA, 2021c). In 2003, the Association of Southeast Asian Nations' (ASEAN) Food Safety Network (AFSN) was established to facilitate the sharing of information regarding food safety issues such as mycotoxin, pesticide residues, veterinary drugs, heavy metals, *etc*. among ten ASEAN member states. After eight years, six laboratories, known as the ASEAN Food Reference Laboratories (AFRLs), have been built to provide technical and practical support based on various areas of proficiency to the laboratories of ASEAN member states. In Singapore, the National Centre for Food Science (NCFS) is responsible for the surveillance and analysis of foodstuffs (SFA, 2021e). Thus, one of the three ASEAN Food Reference Laboratories (AFRLs), the AFRL for Mycotoxins, is under the Research and Risk Assessment Department of the NCFS. It has 27 accredited (ISO/IEC 17025:2017 standard) analysis methods for mycotoxins and phytotoxins (ACFS, 2015; NCFS, 2020). Furthermore, a Specialist Team for Laboratory Competency Development was formed to aid in regulating the activities of all four AFRLs (NCFS, 2020).

Besides the AFRLs of the NCFS, 13 accredited private testing laboratories recognised by the SFA currently assist in food analyses in the industry through the Laboratory Recognition Programme (SFA, 2021f). The accredited analytical methods for the detection of AFB_1, AFB_2, AFG_1, and AFG_2 in flour, improvers, and related products, as well as AFM_1 in milk and dairy products, are HPLC, Ultra-HPLC (UHPLC), liquid chromatography-mass spectrometry (LCMS), and liquid chromatography-tandem mass spectrometry (LC-MS/MS) (SFA, 2021g). Mycotoxin analysis methods are constantly being explored, as some mycotoxins have been analysed *via* methods that have not been accredited. In 2017, the analyses of PAT in juices with LC-MS/MS were accredited by the Singapore Accreditation Council through the Singapore Laboratory Accreditation Scheme (AVA, 2018).

The NCFS was appointed as a World Organisation for Animal Health (OIE) Collaborating Centre for Food Safety in 2014 (WOAH, 2021). Thus, many partnerships have been formed, and many activities have been executed to mitigate mycotoxin contamination. For instance, existing multi-mycotoxin detection methods for food and cereal products were enhanced in 2017 (AVA, 2018). Practical seminars regarding the analyses of mycotoxins (AFB and AFG), pesticide residues, mercury, *etc*. were conducted as regional training during collaboration with the Global Food Safety Partnership with the aim of enhancing global cooperation in strengthening the capability of food safety (AVA, 2019).

Recently, a strong foundation for food safety was laid through the establishment of the Future Ready Food Safety Hub (FRESH) partnership among three organisations, namely the SFA, the Nanyang Technological University (NTU), and the Agency for Science, Technology, and Research (A*STAR). The purpose of this partnership was to encourage research on the sustainability, processing, and innovation of food that would ultimately establish a robust food safety capability since Singapore is moving towards producing food locally (Fu, 2021). Furthermore, the implementation of the GAP is encouraged in vegetable, fruit, and herb farming for quality assurance of the products and agricultural environment through the newly published SS675 Certification Scheme in August 2021 (SFA, 2021h). Therefore, the food safety system is expected to be enhanced by the partnership and the new certification scheme, which covers every stage of food production from farm to fork.

Some mycotoxin research has been conducted at NTU since 2014. Nasir and Pumera (2014a; 2014b) demonstrated that an edge-plane pyrolytic electrode was highly selective in detecting ZEN, CIT, PAT, and OTA using the differential pulse voltammetry (DPV) technique. ZEN and CIT could be detected simultaneously, and PAT was detected simultaneously with OTA. Although the lowest detection limits (LODs) of PAT and OTA were determined to be 10.5 and 1.38 ppm (mg/L), respectively, which were above the regulatory limits, the linearity of the voltammogram was excellent with a correlation coefficient, R, of 0.99 (Nasir and Pumera, 2014a; 2014b). A recent case study evaluating the exposure and health risk of children in Vietnam to AFB_1, OTA, and FUMs through their diet food samples using a Total Dietary Study approach discovered that rice products were the main culprits for AFB_1 and OTA. Exposure to FUMs resulted from the accumulation of numerous types of food rather than a specific type of food containing a low FUM concentration (Huong *et al*., 2019). Other than that, research has also discovered the whole genome sequence of *Aspergillus westerdijkiae*. This has enabled a better insight into the regulation of OTA biosynthesis (Chakrabortti *et al*., 2016).

In summary, mycotoxin mitigation in foodstuffs and feedstuffs is predominantly regulated by the SFA. Since most of the poultry meats and raw materials for the feedstuffs are imported, the prevention and control of mycotoxin at the point of importation are critical. Therefore, the facilities and capabilities for food safety, especially laboratories for monitoring and conducting analyses, are sophisticated. The establishment of the FRESH partnership is expected to enhance mycotoxin prevention efficiency due to the advancement in overall food safety.

Malaysia

In Malaysia, agricultural products like industrial crops, cash crops, vegetables, spices, fruits, and livestock products are produced locally (Norhayati and Noor Hasani, 2004). Generally, the food safety of foodstuffs is governed by the Ministry of Health (MOH). In contrast, the food safety of feedstuffs is regulated by the Ministry of Agriculture and Food Industries (MOA). The safety and quality of food in Malaysia have been supported by various legislations and regulations enforced by the MOH and MOA, focusing mainly on the midstream and downstream of the food supply chain, where the food is ready to be exported, imported, retailed, and for domestic food production. In order to ensure the public health and food quality, the management of food safety in Malaysia has been evolving since 1936.

In 1936, before Malaysia became independent, the food safety of citizens in British Malaya was ensured by the Municipal Ordinance of 1936. However, due to the lack of specificity of this ordinance, it was replaced by the Sale of Food and Drugs Ordinance of 1952. This transformation enhanced the level of food safety since the definition of food had become more specific and detailed, including flavourings and condiments customarily used in food composition (Chew *et al*., 2018). However, no specific legislation was enacted for mycotoxin until the first incident, when the livers of pigs from two pig farms located in Malacca were found to be severely damaged due to the presence of aflatoxin in feedstuffs during the 1960s (Mohd-Redzwan *et al*., 2013). The Food Act of 1983 was later enacted to strengthen food safety by taking into account more aspects of foods, such as the preparation, sale, and substances used in the preparation of foods. After that, the Food Regulations 1985 was gazetted with details for applying the Food Act 1983. Under the Food Regulations 1985, the ML of mycotoxin was 35 μg/kg, which was applicable for all mycological contaminants (Mohd-Redzwan *et al*., 2013). However, over the years, the Food Regulations 1985 has been revised and amended, with the latest amendment being made in March 2020. After revisions, the ML of mycotoxin is now stipulated in the Fifteenth Schedule of the Food Regulations 1985 (Malaysia, 1985), tabulated in Table 2. The Food Regulations 1985 is still the primary regulation used in Malaysia to control every type of contaminant that may be present in food.

Under the Food Regulations 1985, the MLs of aflatoxins (AFs) allowed for foodstuffs were the sum of different types of AFs such as AFB_1, AFB_2, AFG_1, and AFG_2. Although AFB_1 possesses potent toxicity, no specific ML was set for AFB_1 alone other than the ML of 0.1 μg/kg for cereals and cereal products intended for infants and children. Other than that, no ML was provided for mycotoxins such as FUMs, ZEN, and DON. Therefore, the mitigation and prevention of mycotoxins under the Food Regulations 1985 are still not comprehensive due to the exclusion of a few types of mycotoxins. It is crucial to include different types of mycotoxins in the regulation to assure good public health *via* food safety enhancement. For instance, the MLs of the European Commission are more integrated since they include FUMs, ZEN, and DON, which have higher MLs due to their lower toxicity compared to AFs.

Numerous regulatory agencies, policies, and regulations are related to food safety and security, for example, the Food Hygiene Regulation 2009, Food Analysts Act 2011, and Food Analysts Regulations 2013 (FSQD, 2021b). In order to provide the public with higher assurance of food safety from food enterprises, the Food Safety and Quality Division (FSQD) from the MOH has provided several certifications, such as Food Safety is Responsibility of the Industry (MeSTI), HACCP, and GMP (FSQD, 2021a). Other certifications are also provided by the MOA when farms implement GMP and GAP, such as the Malaysian Farm Accreditation Scheme (SALM) certificate for agricultural production farms and the Veterinary Health Mark (VHM) certificate for livestock processing plants (Norhayati and Noor Hasani, 2004). The management of food safety standards in Malaysia is comprehensive, as it involves the international food standards from CAC. In 2009, the food standards from both the Food Regulations 1985 and the CAC, which were initially managed separately, were harmonised and merged into one section, namely the Codex and International and Standards Development Section (FSQD, 2021a).

On the other hand, as far as feedstuffs are concerned, the Feed Act 2009 was enforced by the Department of Veterinary Services Malaysia to manage the importation, production, and sale of feedstuffs and feed additives (Malaysia, 2009). However, the ML of mycotoxin legislation specially designed for commonly used poultry feeds such as maize, wheat, sorghum, oilseeds, and legumes are not stipulated in the Act (Afsah-Hejri *et al*., 2013). Research shows that a portion of the feedstuffs are contaminated with mycotoxin (Reddy and Salleh, 2011; Anukul *et al*., 2013; Mohd-Redzwan *et al*., 2013). Moreover, based on the database of mycotoxin tests from the Veterinary Public Health Laboratory (VPHL) in Malaysia, the presence of aflatoxin in animal feed samples has increased by 51% from 2005 to 2009 (Suhaimi *et al*., 2014). Therefore, it is undoubtedly true that a regulatory ML for feedstuffs is crucial to ensure food safety and food security *via* the food supply chain.

Furthermore, having been a member of the Association of Southeast Asian Nations (ASEAN) since 1967, Malaysia would benefit from efforts by the association to regulate food safety and security. For instance, validated analytical methods such as liquid chromatography-fluorescence (LC-Fluorescence) and LC-MS/MS, where LC is combined with tandem mass spectrometry (MS) for mycotoxins are harmonised for ASEAN member states, including Malaysia (Lim *et al*., 2018).

Research on mycotoxin has been carried out in Malaysia since 1965 when the impact of mycotoxin in feedstuffs was realised through the outbreak in pig farms in Malacca during the 1960s (Mohd-Redzwan *et al*., 2013). Analytical methods such as TLC, mini-column, HPLC, and ELISA test kits were used by institutes such as the Malaysian Agricultural Research and Development Institute (MARDI) and the Institute for Medical Research (IMR) (Norhayati and Noor Hasani, 2004). Currently, a more advanced technique is being introduced by ASEAN in which tandem mass spectrometry is incorporated to increase the selectivity of a specific mycotoxin during identification. This method can be further enhanced when integrated with a stable isotopic dilution assay (SIDA), where chromatographic separation of analytes can be omitted. However, this method is yet to be officially validated (Lim *et al*., 2018). Although some of the feedstuffs originated in Malaysia, many of them are actually imported. Almost 100% of grain corn, one of the main ingredients in poultry feed, is imported mainly from Argentina and Brazil (Amana *et al*., 2019). Since the feedstuffs have been transported for a long time, it is important to monitor the condition of the feedstuffs before feeding the poultry.

In summary, the legal instrument for mycotoxin prevention in Malaysia is the ML for foodstuffs stipulated in the Food Regulations 1985, but this does not apply to feedstuffs. Although the ML for foodstuffs can be used as a reference during mycotoxin analyses for feedstuffs, it might not be accurate. Furthermore, not all MLs of the mycotoxins in foodstuffs are covered in the Food Regulation 1985. The regulation for the safety of feedstuffs is crucial, especially when Malaysia is striving to decrease its dependence on imported agriculture products with the development of the grain and corn industries to intensify its animal feed production in attaining the target of the National Agrofood Policy (NAP) (Rozhan, 2019). Thus, the regulation of mycotoxin contaminants in feedstuffs should not be neglected.

Comparison of mycotoxin mitigation approaches in the UK, Taiwan, Singapore, and Malaysia

The four countries in this study are found to have used several direct and indirect mycotoxin mitigation approaches, as tabulated in Table 4. At least one organisation in each country is responsible for the surveillance of mycotoxin in foodstuffs for human consumption through acts, regulations, standards, and enforcement rules.

All four countries in this study have manifested various approaches to attaining food safety decided upon by their respective national authorities. Quality management systems such as GAP, GSP, and GMP are present to mitigate mycotoxin from the cultivation stage to the storage of agriculture products. In Malaysia, GMP is introduced in the form of certification, whereas in the UK, GAP and GSP are advocated as codes of practice, acting as general principles in the approach to mitigating mycotoxin. However, the GAP is implemented through TAP certification in Taiwan since only agricultural product

Table 4. Comparison of mycotoxin mitigation approaches in the UK, Taiwan, Singapore, and Malaysia.

Country	National authority	Legislative framework	Method of analysis	Other initiative
United Kingdom	Food Standards Agency (FSA), Food Standard Scotland (FSS), United Kingdom Accreditation Service (UKAS)	Commission Regulation (EC) No. 1881/2006, Commission Recommendation 2006/576/EC, Directive 2002/32/EC, Commission Regulation (EC) No. 401/2006	TLC, HPLC, GC, ELISA	Quality Management Systems, Good Agricultural Practice (GAP), Good Storage Practice (GSP), Research, 4-year surveillance on mycotoxins
Taiwan	Ministry of Health and Welfare (MOHW), Taiwan Food and Drug Administration (TFDA), Council of Agriculture (COA), Agriculture and Food Agency (AFA), National Animal Industry Foundation (NAIF)	Act Governing Food Safety and Sanitation 1975, Regulation on Food Safety Control System 2014, Enforcement Rules for Contaminants and Toxins in Food, Sanitation Standards for Contaminants and Toxins in Food, Health Food Control Act 1999, Enforcement Rules for Health Food Control Act 1999, Feed Control Act 2015	HPLC-Fluorescence, HPLC-MS/MS	Certifications, Taiwan Agriculture and Food Traceability System (TAFTS), Traceable Agricultural Product (TAP), Research, Taiwan Agricultural Chemicals and Toxic Substances Research Institute (TACTRI), Activities, 6th National Agriculture Congress, 2020 International Conference on Smart Agriculture

Singapore	Ministry of Sustainability and the Environment (MSE), Singapore Food Agency (FSA), National Centre for Food Science (NCFS), Singapore Accreditation Council	Sale of Food Act: Food Regulation, Feeding Stuffs Act: Feeding Stuffs (Licensing, Analyses, and Fees) Rules, General Standard for Contaminations and Toxins	HPLC, UHPLC, LCMS, LC-MS/MS	Licence, Animal Feed Licence, Certificate, Free Sale Certificate, Permit, Cargo Clearance Permit (CCP), Research, Nanyang Technological University (NTU), NCFS, Partnerships, Partnership of SFA, NTU and A*STAR: Future Ready Food Safety Hub (FRESH), Activities, Seminars on mycotoxin analyses, Laboratory, ASEAN Food Reference Laboratory (AFRL) for Mycotoxins
Malaysia	Ministry of Health (MOH), Food Safety and Quality Division (FSQD), Ministry of Agriculture and Food Industries (MOA), Department of Islamic Development Malaysia (JAKIM)	Municipal Ordinance 1936, Sale of Food and Drugs Ordinance 1952, Food Act 1983, Food Regulations 1985, Food Hygiene Regulation 2009, Codex and International and Standards Development Section (in 2009), Feed Act 2009, Food Analysts Act 2011, Food Analysts Regulations 2013	Conventional methods, TLC, Mini column, HPLC, ELISA, Current methods, LC-Fluorescence, LC-MS/MS	Certifications, MeSTI, HACCP, GMP, SALM, VHM, Halal, Research, Malaysian Agricultural Research and Development Institute (MARDI), Institute for Medical Research (IMR), Veterinary Public Health Laboratory (VPHL)

operators that fulfil the requirements of the TGAP will be eligible for TAP certification, and the GAP is executed by the TGAP. Similarly, GAP is implemented through a certification scheme, namely the SS675 certification in Singapore.

Among the four countries, Singapore is the only one that manages the mycotoxin issue with one agency. Besides the provisions, the presence of mycotoxin in imported feedstuffs is strictly controlled through the Animal Feed License, Free Sale Certificate, and CCP. The approach of preventing mycotoxin at one point is more efficient than analysing the condition of feedstuffs after they are distributed to different locations. The surveillance of mycotoxin in Singapore is highly sophisticated, with the support of the AFRL for Mycotoxins. Furthermore, the capability of the laboratories is emphasised by providing seminars to laboratory practitioners on mycotoxin analysis. Although Malaysia has comprehensive legislation regulating food safety for human consumption, no specific regulation is targeted directly towards mycotoxin in feedstuffs.

Since both Singapore and Malaysia are members of ASEAN, both countries have benefited from the AFSN, where information about mycotoxin and other food safety issues is shared. For instance, LC-MS/MS is used in both countries for mycotoxin analyses. Besides, HPLC is the most common analysis method in all countries. All four countries in this study have comprehensive legislation regulating food safety for human consumption. The legislation for feedstuffs is also present in all four countries. For instance, to regulate feedstuff quality, Taiwan, Singapore, and Malaysia have the Feed Control Act, Feeding Stuffs Act, and Feed Act 2009, respectively. However, no specific MLs of mycotoxin have been specified in these legislations. In comparison, the UK legislation includes the MLs of mycotoxin for feedstuffs in Commission Recommendation 2006/576/EC and Directive 2002/32/EC.

The mitigation of mycotoxin is insufficient by relying only on the legislative framework. The four countries in this study have encouraged the participation of the stakeholders in agriculture and the livestock industry in mycotoxin mitigation by organising activities such as congresses, conferences, and shows. In Taiwan, even consumers play an important role in encouraging food safety by supporting the demand for food products with TAP certification. The certification system covers different aspects of food safety, such as the type of raw materials, the processing methods and conditions, food product quality, *etc.* that are employed in ensuring food safety from cultivation to processing and the production of final food products.

Table 2 shows the summary of the MLs of various mycotoxins in foodstuffs for all four countries. The types of foodstuffs listed in Table 2 comprise only the foods that are simultaneously included in the regulations of all four countries to enable comparison of the MLs. Most of the MLs are provided separately for foodstuffs for infants and young children since lower MLs are required. Most of the MLs among the four countries are similar except for the sum of AFs (B_1, B_2, G_1, G_2), AFB_1, PAT, and DON. For instance, there is only one ML (5.0 μg/kg) for the sum of AFs in Singapore for any food except foods for infants and young children, while the MLs for the sum of AFs in the UK, Taiwan, and Malaysia are applied to several types of foods such as dried fruit, cereal, grain, fats, and different types of nuts. Since different countries provided the ML of the same category to different types of foodstuffs, only the common foodstuff type in all four countries, such as nuts, is summarised to facilitate comparison. Other than that, the MLs for AFB_1 in the UK and Taiwan have the lowest lower limit of 2.0 μg/kg and an upper limit of 8.0 and 12.0 μg/kg, respectively, whereas Singapore only has an ML of 5.0 μg/kg for any foodstuff, which is not for infants and young children. In Malaysia, the ML of AFB_1 is only available for infants and young children. Furthermore, the MLs of DON for unprocessed cereals and oats are the same for the UK, Taiwan, and Singapore, which are 1250.0 and 1750.0 μg/kg, respectively. However, Singapore has provided an ML of 2000.0 μg/kg for unprocessed cereal grains, which is absent from the regulations for DON in the UK and Taiwan. The regulations of MLs for CIT, FUMs, DON, and ZEN in foodstuffs are absent in the regulations of Malaysia.

Based on the analysis of this study, Taiwan has the most extensive regulation of ML among the four countries. The most commonly employed analytical methods for mycotoxin detection in each country are liquid chromatography techniques with different detectors. The regulation of mycotoxin in imported feedstuffs is implemented most thoroughly in Singapore. The approaches to mitigate mycotoxin in foodstuffs in all four countries include a concrete legislative framework that comprises many aspects of food production from farm to market. These approaches include initiatives to prevent and minimise any incident of mycotoxin contamination since severely contaminated foodstuffs and feedstuffs have to be discarded. Thus, any ill effects on health and unnecessary financial loss can be avoided by ensuring that sources of foodstuffs and feedstuffs are uncontaminated.

Conclusion

In conclusion, the existing mycotoxin mitigation and management methods and provisions in the UK, Taiwan, Singapore, and Malaysia are sophisticated for foodstuffs and feedstuffs. Although Taiwan and Malaysia are classified as developing countries, the surveillance of mycotoxin in foodstuffs in both countries is comparable to that practiced in developed countries. The present review shows that the principal elements of the mycotoxin mitigation approach in a country comprise feasible provisions, advanced analytical techniques, and extensive research. Additionally, the partnerships and activities in strengthening food safety capability and sharing knowledge, information, and technology among the experts regarding mycotoxin through congresses and seminars are pivotal to improving the efficiency of mycotoxin mitigation.

The distinctive characteristic of food safety in the UK is the thorough provisions, where necessary measures are concentrated in four regulations. The food safety system in Taiwan is impressive, where the sources of contaminants are emphasised by the COA using TAP systems. The efficiency in contaminant source tracing and transparency of the food products are strengthened through TAP systems, advancing towards a smart agricultural system. Apart from the feasible provisions in Singapore, their food safety systems are constantly improving through partnerships. For Malaysia, the food safety system focuses mainly on the midstream and downstream of the food supply chain. Therefore, based on the analysis presented in this review, the extensive regulation of ML in Taiwan is preferable for adoption by other countries. The remarkable features of the food safety systems in each country can be adopted by other developing countries that are advancing their agriculture sectors.

Acknowledgement

The authors would like to thank the Malaysian Ministry of Higher Education for funding the research upon which this paper is based through the Fundamental Research Grant Scheme (FRGS/1/2019/STG01/UKM/02/4).

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