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Effective approaches for early identification and proactive mitigation of aflatoxins in peanuts: An EU–China perspective

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Abstract
Nearly 700,000 tonnes of peanuts are consumed annually in Europe. In the last 5 years, peanuts imported from China exceeded legal European Union (EU) aflatoxin limits more than 180 times. To prevent and mitigate aflatoxin contamination, the stages of the peanut chain most vulnerable to contamination must be assessed to determine how to interrupt the movement of contaminated produce. This paper discusses effective approaches for early identification and proactive mitigation of aflatoxins in peanuts to reduce a contaminant that is an impediment to trade. We consider (i) the results of the EU Commission's Directorate-General (DG) for Health and Food Safety review, (ii) the Code of Practice for the prevention and reduction of aflatoxins in peanuts issued by Food and Agriculture Organization/World Health Organization, (iii) the results from previous EU–China efforts, and (iv) the latest state-of-the-art technology in pre- and postharvest methods as essential elements of a sustainable program for integrated disease and aflatoxin management. These include preharvest use of biocontrol, biofertilizers, improved tillage, forecasting, and risk monitoring based on analysis of big data obtained by remote sensing. At the postharvest level, we consider rapid testing methods along the supply chain, Decision Support Systems for effective silo management, and effective risk monitoring during drying, storage, and transport. Available guidance and current recommendations are provided for successful practical implementation. Food safety standards also influence stakeholder and consumer trust and confidence, so we also consider the results of multiactor stakeholder group discussions.

KEYWORDS
aflatoxin, food safety, mycotoxins
1 | INTRODUCTION

Maize, peanuts, and wheat are commonly used for human food and animal feed. China is one of the world’s largest producers of these crops. Mycotoxin-producing fungi can colonize these products and contaminate them with mycotoxins. Such contamination is common, with up to 80% of foods from plants globally estimated to be contaminated (Eskola et al., 2020). More specifically, >20% of feed samples from China, Japan, and South Korea exceeded European Union (EU) guidance levels for deoxynivalenol and zearalenone (Gruber-Dorninger et al., 2019). Hence, finding maize, wheat, and peanuts in the Chinese market contaminated with mycotoxins at levels higher than EU guidelines is expected.

China is the third largest supplier of peanuts to the EU. In recent years, China has become the leading supplier of peanuts globally, producing 17 million metric tonnes and claiming a 41% share of the global market. More than 180 alerts of aflatoxin levels in peanuts imported from China exceeding EU limits were noted in the EU’s Rapid Alert System for Food and Feed (RASFF) over the last 5 years (RASFF, 2017). Aspergillus parasiticus and Aspergillus flavus are the pathogens most commonly associated with aflatoxin accumulation in peanuts. These fungi are ubiquitous in soils in temperate, tropical, and subtropical regions of the world. Aflatoxins are carcinogenic, mutagenic, and toxicogenic compounds (Lien et al., 2019; Liu et al., 2019). Fourteen types of aflatoxins occur naturally and six are of major concern: aflatoxin B1 (AFB1), AFB2, AFG1, AFG2, AFM1, and AFM2 (Lien et al., 2019). Aflatoxins B1, B2, G1, and G2 are commonly found in tree nuts, peanuts, and maize, while AFM1 and AFM2 are primarily and commonly found in dairy products, usually in areas with high aflatoxin incidence. Although aflatoxins in peanuts are limited primarily to preharvest infections, postharvest contamination may occur if fungal propagules are present and the crop is not dried or stored properly (World Health Organization [WHO], 2018).

The WHO raised concerns that aflatoxins pose a significant economic burden that leads to annual destruction of an estimated 25% of the world’s total food (WHO, 2018). The presence of aflatoxins in the peanut supply chain, particularly the potent liver carcinogen AFB1, poses clear health risks for consumers in both the EU (Eskola et al., 2020) and in China. Hence, the European Commission’s DG Health and Food Safety conducted an audit in China in 2017 to evaluate the official Chinese control systems for preventing/reducing aflatoxin contamination in peanuts to be exported to the EU (European Commission, 2017). The objective of the audit was to verify that the existing control systems limited aflatoxin contamination in peanuts exported to the EU to levels below EU contamination regulations, and that the control systems in place comply with or are equivalent to Commission Regulation (EC) No. 1881/2006. This audit found that official controls of good hygiene practices and prevention of aflatoxin contamination were not functional for all categories of operators in the peanut supply chain. Sampling and analysis procedures followed the European regulation, but some weaknesses were found in their implementation. Chinese controls were limited to the steps from the receipt of raw materials to the loading of containers at processor level. However, no comments or evaluations were included about the shipping and transportation conditions, for example, timing, loading locations in transport ships, and temperature monitoring or control while in transit. Hence, considerable risk of failure to prevent or detect aflatoxin contamination remained.

Based on these findings, this paper uses aflatoxins in peanuts to discuss effective approaches for early identification and proactive mitigation of divergent food safety measures likely to cause impediments to trade. The results of the DG Health and Food Safety Review, the Code of Practice for the prevention and reduction of aflatoxins in peanuts issued by FAO/WHO, the results obtained in previous EU–China efforts, and the latest state-of-the-art pre- and postharvest methods all have a role in reducing aflatoxin contamination.

As noted above, up to 80% of global plant-based foods may be contaminated with detectable amounts of mycotoxins (Eskola et al., 2020). Thus, both acute and subacute exposure to mycotoxins may threaten the health and productivity of humans and domesticated animals (Cimbal et al., 2020; Edite Bezerra da Rocha et al., 2014; Leslie et al., 2020). Many countries regulate the level of mycotoxins in imports, which means mycotoxins are not only health hazards but also are important phytosanitary (non-tariff) trade barriers (van Egmond, 2002). With climate change, mycotoxin-producing fungi, including Aspergillus and Fusarium spp., will become more widespread as hot, dry conditions that intensify plant stress will enable more widespread mycotoxin contamination of human foods and animal feeds (Medina et al., 2017). Reducing mycotoxin exposure through targeted management of their hosts’ production chains thus becomes critical. Mitigation strategies developed in many parts of the world, including Europe and China, have helped reduce the amount of contaminated food and feed available in Europe (Eskola et al., 2020).

China has detailed regulations limiting contamination in food and feed by the major known mycotoxins (Zhang et al., 2013). The National Food Safety Standard for Maximum Levels of AFB1, AFM1, deoxynivalenol, patulin, ochratoxin A, and zearalenone in foods (GB 2761-2017) was released in China in 2017 as an update of the previous...
standard GB2761-2011 (United States Department of Agriculture, 2018). The pervasiveness of the problem necessitates a well-implemented strategy at strategic locations along the peanut value chain to mitigate the risks of contamination, to reach the regulatory limits, and to keep mycotoxin levels as low as reasonably achievable (ALARA). The EU and China have pooled expertise to enable sharing of experiences, expansion of scientific interaction networks, and synergistic solutions to mycotoxin contamination problems of mutual interest. Joint EU–China projects, such as EU–CHINA-SAFE and its predecessors MyToolBox (Krska et al., 2016) and MycoKey (MycoKey.eu, 2021), focused on pre- and postharvest measures to reduce aflatoxin contamination in maize and peanuts in southeast Europe and China. Postharvest studies included the evaluation of improved storage conditions. For example, wheat silo management in Italy and peanut silo management in China have benefitted from novel CO2 respiration models and development of new, improved sensors for silo monitoring (Garcia-Cela et al., 2020).

2 | THE EU—THE LARGEST IMPORTER OF PEANUTS

Other than Bulgaria, Greece, Spain, and Portugal, the climate in EU countries is not suitable for peanut production (Gribben, 2020; Prusak et al., 2014). The EU imported more than $2 billion worth of peanuts in 2017, and is the world’s largest importer of the crop (AgriXchange, 2018; CBI Ministry of Foreign Affairs, 2020). Once in the EU, these peanuts may be roasted peanuts or processed into peanut butter and then re-exported, for example, to Russia (CBI Ministry of Foreign Affairs, 2020). Germany, the United Kingdom, and The Netherlands account for 60% of total EU peanut imports, although former Eastern European countries also have been increasing the amount of this crop that they import (CBI Ministry of Foreign Affairs, 2020). The Netherlands is the largest single importer and processor of peanuts in the EU and produces more peanut butter than any other country in the EU. The United States and China are the dominant exporters of peanuts to the EU (Adams & Whitaker, 2004; European Commission, 2017).

European consumption of peanuts is estimated at nearly 700,000 tonnes per year, and recently it has been increasing at a rate of approximately 2% per year (CBI Ministry of Foreign Affairs, 2020). The largest increases have been for in-shell and dry-roasted peanuts (CBI Ministry of Foreign Affairs, 2020). These increases likely result from changes in the diets of European consumers and may include increased demand for plant-based protein sources. Recently, peanut imports from China to Europe have, however, decreased. This decrease is probably due to China’s increased domestic peanut consumption and aflatoxin contamination in Chinese peanuts that has led European buyers to look for alternative suppliers.

EC regulation No. 1881/2006 (European Commission, 2006a) sets limits for AFB1 and the sum of AFB1 + AFB2 + AFG1 + AFG2 for groundnuts (peanuts). Competent Authorities of the Member States check peanuts imported into the EU (European Commission, 2017) for compliance with Article 15 (1) of Regulation (EC) No 882/2004 (European Commission, 2004). Regulation (EC) No 1152/2009 (European Commission, 2009) governs peanuts imported from China. These imports also are subject to mandatory pre-export certification by the Competent Authorities in China and to additional physical inspections at EU borders (20% of all imported peanuts). For peanuts from China intended for food, whether in shell, shelled, or as peanut butter, additional special conditions (Regulation [EU] No. 884/2014 of 13 August 2014) (European Commission, 2014a) were imposed following aflatoxin detection in multiple lots of imported peanuts from China. Peanuts from China now must be analyzed by the Competent Authorities and these authorities must issue a health certificate that the peanuts are within specified EU contamination limits.

3 | CHINA—THE LARGEST EXPORTER OF PEANUTS

China was the third largest supplier of peanuts (sum of in shell and shelled) to the EU, behind Argentina and the United States (Eurostat, 2016). Within China, the following are seven major peanut-producing provinces: Jilin, Liaoning, Hebei, Shandong, Henan, Sichuan, and Guangdong (Yang & Zheng, 2016). In addition to meeting the large domestic demand for peanuts, China also is the world’s fourth largest exporter of the crop with large exports to Japan, Australia, New Zealand, and the EU, amongst others (AgriXchange, 2018). Aflatoxins in the peanut supply chain were a major contamination concern.

The China National Centre for Food Safety Risk Assessment (CFSA) was established in 2009 following enactment of the Food Safety Law of the People’s Republic of China. The Chinese government has made ongoing efforts to improve risk assessment and management as part of the risk analysis framework (Wu et al., 2018). The Chinese Ministry of Agriculture and Rural Affairs agreed that increased efforts were required to prevent and limit foodborne contaminants to reduce risk alerts and border rejections of foods coming from China at the EU borders (Wu et al., 2018). Since Europe is a big consumer of peanuts, the risk that aflatoxins in peanuts pose warrants the
intervention of regulatory agencies and the enforcement of food safety measures.

4 INTEGRATED DISEASE AND AFLATOXIN MANAGEMENT

Identifying stages of the peanut chain that are most vulnerable to aflatoxin contamination is important to prevent or mitigate contamination in peanuts and to interrupt the continued movement of contaminated crop. Good disease management combines sustainable preharvest and postharvest practices.

During plant growth in the field, preharvest crop management practices can reduce the accumulation of contaminants produced by plant pathogens. However, once harvested, postharvest spoilage organisms may grow and proliferate if conditions are favorable (Gerez et al., 2013). Postharvest spoilage organisms require temperate or tropical conditions and do best when the moisture content is high and carbohydrate/nutritive sources are available (Reddy et al., 2009). For peanuts, and other crops with high nutrient profiles, spoilage can occur easily during transit from the field to storage (Ren et al., 2020).

Integrated approaches to fungal disease and mycotoxin management are usually the most effective (Sangmanee & Hongpattarakere, 2014). These management plans require the development and utilization of forecasting and remote sensing data to inform tillage practices, and preharvest biocontrol and biofertilizer applications. Postharvest management utilizes proper sampling and analysis and decision support systems (DSSs) in silo management to monitor relevant parameters during drying, transport, and storage.

Integrated disease management is by definition a multifaceted strategy in which crop yield and quality serve as indicators of stress or disease. Good soil quality is imperative for a healthy plant and thus a good harvest. Peanuts grown in different soil types may differ significantly in the level of Aspergillus infection. For example, light sandy soils, particularly under dry conditions, favor rapid fungal proliferation, while heavier soils retain more water and have a lower likelihood of drought stress. Thus, peanuts grown in heavier soils tend to have lower than average levels of aflatoxin contamination (FAO/WHO Joint Publications, 2004).

A stakeholder-based EU–China approach to mitigate and control mycotoxins through the enhancement of existing tools and the development of new ones was an important objective for MyToolBox (Krska et al., 2016) — a 4-year EU-project with EU and Chinese partners with collaborative research projects and goals. Identifying future directions in mycotoxin research and the management of these contaminants in China as well as their role in China-EU relations were the subject of multiple joint conferences. A stakeholder workshop in Beijing in 2019 (Leslie et al., 2020) included group discussions of six topics: biocontrol, forecasting, sampling and analysis, silo management, detoxification, and the development of safe use options for contaminated materials. These discussions reinforced known needs for smart, integrated strategies that address mycotoxin issues and increase food and feed safety while simultaneously minimizing losses and export rejections.

In China, managing data on mycotoxin contamination events — when, where, and their size — as well as identifying the institution(s) to manage them is a complex issue. Resolving these issues is essential for effective mycotoxin risk assessment in the country. Studies of microbes and of novel, including genetically modified versions, enzymes to minimize preharvest contamination, to reduce postharvest product contamination, and to develop safe uses of contaminated materials are all at early stages in China. Results from these studies could provide new research and economic opportunities for EU scientists and their Chinese counterparts. Further efforts in both the EU and China are needed to communicate the importance of mycotoxin problems with those outside the scientific and research communities. Increased visibility is particularly important to meet potential climate change challenges. The more extreme weather events anticipated in many regions, especially increased heat and droughts, will increase stress on plants that host mycotoxin-producing fungi. Predicted climate changes in the EU and China will increase the area in which aflatoxin contamination may occur as well as intensify the problem in areas where it already occurs (Leslie et al., 2020).

5 PREHARVEST MANAGEMENT

Effective preharvest measures include crop rotation, optimized tilling, and the use of biocontrol agents such as environmentally safe pest-control and antimicrobial treatments. Monitoring crops in the field requires imaging tools that collect both visual and physicochemical data that are indicative of plant stress, plant disease, and/or toxin contamination.

The increased use of synthetic chemical fertilizers and fungicides in agriculture, as a human activity, has contributed significantly to chemical pollutants in the environment (Vejan et al., 2016). These chemicals may harm the environment and pose health risks for humans and livestock (Burdman et al., 2000; Vejan et al., 2016). The economic impacts of remediating land over time and the associated health risks are driving stakeholders toward the use of environmentally safer practices to manage pests and disease (US EPA., 2014).
5.1 | Biocontrol

Biological control, or biocontrol, is the reduction or prevention of invasive pests on plants using natural means and organisms (Gallo et al., 2016; University of Idaho, n.d.). Invasive pests may include insects, predators, weeds, mites, and pathogenic microorganisms (Gallo et al., 2016). Pathogenic microorganisms, both bacteria and fungi, have a well-documented role in food spoilage (Gallo et al., 2016; Ren et al., 2020; Vejan et al., 2016).

Chinese researchers are pursuing a process similar to one used in Africa, the United States, and the EU to develop atoxigenic strains of *A. flavus* for use as biocontrol agents on maize and peanuts in China. By using local strains, this process complies with the Nagoya protocol on biodiversity and limits the spread of introduced strains of *Aspergillus*. Chinese demand for a sustainable preharvest method that reduces or eliminates aflatoxin contamination is quite strong. Follow-up issues include (i) developing commercial application methods for biocontrol agents, (ii) identifying microorganisms that can degrade mycotoxins, and (iii) developing a standardized process that continues the introduction of novel biocontrol agents in China. Continuing current and developing further EU–China collaborations on biocontrol agents that could be used in various regions of the world and that would maintain and update current control methods are of great interest to stakeholders (Leslie et al., 2020).

Returning to the three themes identified at the 2019 Beijing Workshop (Leslie et al., 2020), the primary issues with the application and commercial use of biocontrol agents are safety, cost, and how to evaluate efficacy. Determining if/how Chinese conditions differ from those found elsewhere will be critical to determining whether existing methods can be adapted to Chinese situations or whether unique methods should be developed to solve Chinese problems. Such studies could lead to better fundamental understanding of parameters that limit successful application of biocontrols and would be fertile ground for future international collaborations.

Competitive exclusion of toxic strains by an atoxic strain at the population level is the basis for one biocontrol strategy, and the direct degradation of toxins by a biocontrol organism(s) is an important alternative. Research in this area is limited, even though microorganisms must be degrading mycotoxins under field conditions (Vanhoutte et al., 2016). Successfully harnessing these microbes to ensure breakdown products are less toxic than their precursors and to thereby increase food and feed safety is in the early stages. Finally, efforts are continuing to develop new biocontrol agents. These efforts include (i) identifying novel species and protocols for use under Chinese conditions, (ii) determining how to recover and manipulate potential biocontrol agents, and (iii) designing criteria to determine when and where to apply an emerging technology.

Based on a literature search, research on biocontrol appears to be ongoing in China to control aflatoxin production through the presence of non-aflatoxin-producing strains of *A. flavus* strains at the preharvest level. Such strains have been proposed as biocontrol agents to reduce aflatoxin contamination on peanuts (Wei et al., 2014; Zhang et al., 2013; Zhou et al., 2015) as have other bacteria and enzymes (Kong et al., 2010; Shakeel et al., 2018). Thus, while biocontrol of aflatoxin due to *A. flavus* in peanuts is still at the research level, its movement to commercial application is occurring elsewhere in the world and provides a clear path for Chinese scientists to follow.

The EU and China need to continue to share experiences with the production, formulation, application, standardization, and long-term monitoring of biocontrol agents for peanuts, expanding the collaborative effort to include information on the varieties of peanuts grown, where and how biocontrol is being employed, and the degree to which biocontrol has contributed to mitigate aflatoxin contamination in peanuts produced in China.

Key factors restricting *Aspergillus* growth and aflatoxin biosynthesis in storage are temperature and the water activity (*a*<sub>w</sub>) (Mousa et al., 2016). The combined effects of incubation period, temperature, *a*<sub>w</sub>, pH, and CO<sub>2</sub> levels relative to growth of *A. flavus* have been evaluated (Abdel-Hadi et al., 2010; Gallo et al., 2016; Schmidt-Heydt et al., 2009) along with the effects of nutritional sources. Collectively these variables have a significant effect on the growth rate of aflatoxigenic fungi and aflatoxin biosynthesis. Changes to *a*<sub>w</sub> and temperature also alter the expression of aflatoxin-biosynthesis genes (Gallo et al., 2016; Gerez et al., 2013; Mousa et al., 2016).

Protease P6281 activity in *Trichoderma harzianum* most effectively inhibits the growth of *A. flavus* at 40°C (Deng et al., 2018). The optimal temperature for the inhibition of *A. flavus* growth and the accumulation of AF2 by *Kluyveromyces* spp. is 45°C after a 60-min incubation period at an *a*<sub>w</sub> of 0.95 (Montemarani et al., 2014), although positive results can be obtained if the *a*<sub>w</sub> is between 0.93 and 0.99. In some cases, isolates of *Kluyveromyces* exhibited inhibitory and anti-aflatoxigenic activity across an even broader range of *a*<sub>w</sub> values (La Penna et al., 2004). *Debaryomyces Hansenii*, a yeast, can stimulate aflatoxin accumulation by *A. parasiticus* at an *a*<sub>w</sub> of 0.99, but reduce it at an *a*<sub>w</sub> of 0.92 (Peromingo et al., 2019). Thus, both *a*<sub>w</sub> and temperature have a significant impact on fungal growth and mycotoxin accumulation (Mousa et al., 2016).

Antifungal activities of biocontrol organisms can be influenced by factors other than temperature and *a*<sub>w</sub>. The biocontrol activity of *Lactobacillus plantarum*, for
5.2 Biofertilizers

Biofertilizers are formulations containing living microorganisms that can colonize a plant’s rhizosphere or its interior (Podile & Kishore, 2007). They enable plant growth by increasing the supply and bioavailability of critical nutrients required by the plant. Biofertilizer products commonly contain one or more plant growth-promoting microorganisms (PGPMs) that usually belong to one of three major groups: (i) arbuscular mycorrhizal fungi (AMF) (Jeffries et al., 2003), (ii) plant growth-promoting Rhizobacteria (PGPR) (Vessey, n.d.), and (iii) nitrogen-fixing rhizobia (Franche et al., 2009; Figure 1). PGPR have been used globally in biofertilizers and are the best documented of these PGPMs.

The use of PGPR is well known to increase yields and soil fertility and is a component of sustainable agriculture and forestry. Biofertilizers with PGPR are beneficial to plant growth and contribute to biocontrol of plant pathogens (Khalid et al., 2009). Coupling nanoencapsulation technology with appropriate microbial formulations should make biofertilizers more stable and effective, which would increase their utilization and help make agricultural activities more sustainable (UC Sustainable Agriculture Research and Education Program, 2017; Vejan et al., 2016). Reducing the rate limiting factors that impede the adoption of biofertilizers is important for creating more sustainable agricultural practices (Choudhary et al., 2011; Vejan et al., 2016).

5.3 Tillage practices

Good-quality soil has sufficient bulk density, porosity, water-holding capacity, filtration rate, organic matter content and beneficial soil organisms (European Space Agency, n.d.) is the mechanical disturbance of the topsoil layer. Initially, tilling allowed farmers to prepare the seedbed prior to planting, improve soil aeration, turn over cover crops, bury heavy crop residues, incorporate soil additives (e.g., manure or fertilizers), and activate pesticides (Al-Kaisi, 2004; European Space Agency, n.d.). Unfortunately, however, traditional tilling practices can be destructive to overall soil quality.

Reduced and minimum tillage are now viable approaches to crop management as a consequence of their economic and ecological benefits. Improper implementation of these tillage practices, however, also can result in losses of either profitability or productivity (Sorensen et al., 2010).

Reducing tillage often increases the occurrence of pests, rodents, and pathogenic microorganisms, since more crop residue remains on the soil surface. Mechanical weed tillage is practiced by some growers to reduce weeds and
5.4  |  Forecasting

Forecasting disease occurrence and mycotoxin production has become much more prominent now that multiple forecasting models are available for multiple toxins in several crops (Liu et al., 2018). Some models incorporate only weather information, while others also include farm-specific agronomic and geographic information. Some models are empirical and are defined by relationships between input and output data. Other models are mechanistic in nature as they are based on the growth patterns of toxin-producing fungi under particular conditions. While existing models are not perfect, several are 80% or more accurate in locations where they have been adapted (de Wolf & Paul, 2014; Liu et al., 2018). Chinese stakeholders are very interested in developing and implementing mycotoxin forecasting models, and especially in using machine learning in combination with big data (Leslie et al., 2020). Transforming analytical and field survey data and model predictions into usable information for farmers and researchers remains a major challenge. Future EU–China collaborations should focus on the accuracy and cost-effectiveness of forecasting models/DSSs, models tailored for Chinese end users, and EU–China data sharing for supply chain analysis (Leslie et al., 2020).

In China, there are three current issues with mycotoxin forecasts: (i) implementing forecasting technology, (ii) developing new and improving existing forecasting technology, and (iii) ensuring that participants in the peanut chain from farmers to end users can understand the identified risks in terms of both likelihood and potential severity. Implementation of any forecasting system in China faces challenges even after accurate, timely forecasts become available (Leslie et al., 2020). The roles and interests of government, universities, research institutes, and the private sector in developing forecasts and determining when and how potential warnings are distributed currently are undefined and might even be in conflict. Similarly, the responsibility for recommending responses to particular forecast problems remains unassigned as well. Educating farmers and other participants in the peanut food chain of the value, interpretation, and utility of model forecasts will be critical if the forecasts are to have long-term success as a tool for crop management.

Upgrading technology and developing infrastructure to obtain the data necessary for forecasting models requires careful design and attention to numerous details. Which production chains? How much of the chain? Who has access to and is allowed to interpret the data? Are answers to questions that go beyond science required for success? Avoiding stigmatization of individual farms, crops, and production regions is essential while implementing protocols that enable data collection, disclosure, and sharing. These systems require big data concepts and technologies for successful implementation and to overcome problems related to pollution and imperfections in the data (Leslie et al., 2020). A fundamental understanding by farmers, traders, and others with roles in the various food chains of the risks posed by mycotoxin contamination is required before the forecasts will have any practical use.

5.5  |  Big data-based risk monitoring by means of remote sensing and satellite imagery

Since 2009, the Chinese Ministry of Agriculture (MoA) has monitored risk to crops, including the detection of aflatoxin contamination at multiple locations. In 2016, 2.4% of the samples tested after harvest were contaminated. This monitoring, when combined with other indicators, enabled MoA to identify high-risk regions for AFB1 contamination. These regions were identified primarily based on specific agro-environmental conditions.

China is a large, climatically diverse country whose latitude and longitude span more than 20°. There are four main peanut-producing areas in China, with the highest aflatoxin contamination occurring in the Yangtze River Area (Ding et al., 2015). The relationship between pre-harvest weather data and aflatoxin content of preharvest peanuts was first evaluated in China in 2010–2013 (Wu et al., 2016), and further development of predictive methods specific for China was recommended. These methods would enable local governments and farmers to proactively take appropriate precautions to reduce aflatoxin contamination of crops, for example, by adjusting planting or harvesting dates or by using irrigation to reduce drought-related plant stress that can result in severe aflatoxin contamination (Wu et al., 2016). Potential impacts of climate change on peanut yield in China have been generated with multimodel ensemble projections. Thus, research to link aflatoxin production in peanuts with Chinese-specific climate data is already underway. Specific information on Chinese remote sensing technology as applied to aflatoxin contamination in peanuts is not currently in the public domain, but satellite imagery has been used for peanuts to assess the relationship between environmental conditions and aflatoxin production in Australia in 2004.
(Robson, 2007) and in Mali (Waliyar et al., 2010). In the United States, farmers have used remote sensing technology to improve peanut yields (Martin, 2009). In China, remote sensing also has been used to monitor peanut fields and the impact of climate on peanut yield (Zhou & Li, 2017).

In 2015, the EU’s Joint Research Centre and the Chinese Academy of Sciences’ Institute of Remote Sensing and Digital Earth (CASRADI) signed a collaborative research agreement to develop and exchange scientific and technological information in the areas of climate change, sustainable development, and disaster risk reduction. Research areas covered include monitoring air and agricultural quality, human settlement detection and characterization, mapping soil and land cover, and furthering digital earth sciences. Mycotoxins were not specifically identified as a subject area for research in this agreement between the Joint Research Centre (JRC) and China.

Future projects will incorporate data from multiple sources, for example, satellite images, field and weather records, and thermal and hyperspectral imagery, together with ground truth data, for example, planting dates, genotypes, aflatoxin measurements, harvest dates, and georeferenced data, into a big data model. State-of-the-art algorithms for machine learning techniques remain to be developed and implemented to extract hidden dependencies between these diverse data sources and the presence of AFB1 in peanuts. Both the EU and China can use the freely available Sentinel-2 satellite images and satellite images owned by the Chinese Academy of Sciences (Institute of Remote Sensing) to develop improved models for aflatoxin risk mapping in peanut-producing provinces. Farmers from peanut growing provinces should be involved in these studies to ensure constant feedback input from and education of end users. Farmers and other local personnel are essential for gathering ground truth data, for example, aflatoxin levels, genotype, and crop growth stage, for model development and testing, and to help determine what data need to be considered when the models are implemented on a wider scale.

Based on ground truth data, image processing algorithms need to be developed to segment the satellite images, that is, to map the affected areas. Historic ground truth, weather, and satellite data available for peanut fields can be used to test and refine forecasting models that identify risk zones for aflatoxin contamination. Quantifying drought conditions at preharvest stages from satellite data and derived vegetation indices is needed before satellite-based variables can be identified that are linked to aflatoxin contamination of peanuts. Additional entries evaluating other crops surrounding the peanut fields will help resolve issues with intercropping of peanuts with other crops.

Ideally, an integrated big data-based management approach that uses satellite images, weather records, and localized data for early warning and DSSs for management should be combined with a real-time postharvest monitoring system for storage and transport of peanuts. The existing risk monitoring program run by the Chinese Ministry of Agriculture and Rural Affairs could be significantly improved through the development of a big data-based preharvest aflatoxin forecasting system for peanuts grown in China. Such a system (Figure 2) would merge data from multiple sources into a big data model with algorithms that identify critical variables within the input data that correlate with the presence of aflatoxins in Chinese peanuts. This big data approach would provide a firm scientific foundation for a digital platform used for preharvest management of this hazard through early warning and DSSs. Prototype prediction models for aflatoxin biosynthesis during transport and storage in large peanut silos based on real-time postharvest environmental monitoring systems have been developed within the EU-funded MyToolBox project and should be extended and validated. Thus, a combination of hazard monitoring and control options for specific stages of the peanut chain should be pursued, as recommended in the recent DG Health and Food Safety report (European Commission, 2017) and to generate the largest impact.

Satellite images that can indicate when aflatoxin contamination has occurred. Additionally climate data should also be analyzed to identify favorable conditions for toxin contamination in the field. Critical parameters include the number of growing degree days and the number of consecutive days with tropical temperatures and high dew points. These values, along with the raw daily data, can be integrated into the big data models along with historic information to develop the most robust models possible. The models would function in real time and adjust themselves to new batches of climate and satellite data to dynamically refine the model’s accuracy throughout the growing season. Special attention is needed to understand why the models work, as the machine learning models are essentially black boxes that can potentially identify extremely complex relationships between inputs and outputs.

6 | POSTHARVEST MANAGEMENT

Postharvest management practices increasingly rely on well-planned and coordinated tracking and tracing efforts that use sophisticated information technology tools during storage, drying, and transport of the food crops. Early warning systems, such as RASFF take advantage of highly refined databases to monitor and store information in real-time. Further efforts require new policies to govern the
safe movement of foods between borders and good coordination between stakeholders along the peanut chain to ensure enforcement of food safety regulations and to create awareness of pertinent safety issues surrounding the sale and consumption of peanuts and other nuts.

6.1 Sampling and analysis including rapid testing along the supply chain

Appropriate sampling and analysis protocols are crucial for effective, accurate, and reliable risk estimation and enforcement of phytosanitary and food safety regulations. Obtaining a representative sample of mycotoxins from a food lot is difficult because of the irregular distribution of mycotoxins within the lot. In the EU, sampling and analysis for regulatory purposes is governed by Regulations (EC) No. 401/2006 (European Commission, 2006b) and 519/2014 (European Commission, 2014b), which specify the method’s precision, repeatability, and reproducibility for different foods.

The most recent audit of aflatoxins in Chinese peanuts by DG Health and Food Safety (European Commission, 2017) recommended that official evaluations of peanuts be made at all stages of production, processing, and export. However, the analytical methods used are tedious and a typical analysis usually takes 3–5 days. These assays usually are based on High-Performance Liquid Chromatography (using UV post-column derivatization with fluorescence detection) with LC–MS-MS (Krska et al., 2017) as a confirmatory method. The EC report concluded that the current risks are (i) for failure to prevent and/or detect aflatoxin contamination, and (ii) for detecting fraud in a timely manner. Thus, there remains a great need for reliable, rapid, accurate, and cost-effective on-site tests of peanuts for aflatoxin contamination at all stages of production and processing up to export at the border. The heterogeneity of aflatoxin contamination of peanuts and the biosynthesis of aflatoxins during transport or storage are considered the major reasons for the high level of noncompliance observed at the border. In this context, cost-effective rapid strategies for efficient sampling and subsequent routine screening for enforcing legislation have recently been identified (Focker et al., 2019).

In the context of further EU–China efforts, all rapid test methods must meet the requirements for semiquantitative screening methods for the analysis of mycotoxins in food (Point 4.3.2 of Annex II of Regulation [EC] 401/2006), which also are applicable to self-controls and official controls. Rapid analytical solutions would enhance the monitoring capacity at all stages in the peanut supply chain and would provide the information needed for quicker and better decisions. Identification of the individual aflatoxins, rather than just the routine total aflatoxin and AFB₁ tests, is required to assess the combined toxicity of these toxins to peanut consumers. Chinese processor’s self-checks of peanuts for export to the EU also must follow Regulation (EC) No. 401/2006 methodology (European Commission, 2017). In peanut-producing provinces in China, these self-checks typically are done on samples taken at the end of

FIGURE 2 High-level concept diagram of an aflatoxin contamination in peanuts case study (©IRIS)
the production line, while the official sampling is done on consignments at a dedicated place in the processor’s warehouse (European Commission, 2017).

In Shandong province, due to the importance of peanut production and the number of RASFF notifications, the Competent Authorities (CAs) required processors to conduct systematic aflatoxin testing on incoming raw material and the final products to be exported to the EU. Analyses must be performed by a laboratory accredited to the ISO/IEC 17025:2005 standard or which participates in proficiency tests (PTs) organized by the reference laboratory of the provincial CIQ.

Several days or weeks may elapse between official sampling and the loading and shipping of containers. Most exports are packaged in big plastic bags (1 tonne) or in smaller bags or cartons with plastic bags (40 kg). Sample preservation is ensured by storing at temperatures <10°C and avoiding sunlight both during and after analysis. The remaining replicate samples are retained for 3 months. The moisture of the peanuts sampled is not measured by the CAs to verify the stability of the products during subsequent storage and transport. All annual z-scores in PTs were satisfactory (European Commission, 2017).

Forty-seven laboratories in China are accredited to ISO/IEC 17025:2005 by the Chinese National Accreditation Service (CNAS) for the analysis of AFB1 and total aflatoxins. About 20 laboratories regularly perform such analyses with peanuts. The Technology Centre of Shandong CIQ also is accredited to ISO/IEC 17043 for the organization of PTs. Due to the variety of mycotoxins analyzed and the multiplicity of matrices involved, dedicated PTs for aflatoxins on peanuts products are not regularly organized at the Shandong CIQ, with the last one offered in 2013 (European Commission, 2017). The frequency of participation in PTs specific to aflatoxin in peanuts by official Chinese laboratories is inadequate. The precision of the measurements is not monitored as part of the quality control (QC) checks for each analytical run performed, as recommended by points 41 and 42 of the Codex Alimentarius Guidelines CAC/GL 26–1997 (Codex, 2010) and related point 3 of CAC/GL 27/1997. The lack of adequate QC weakens confidence in the results provided (European Commission, 2017).

6.2 Recent trends in notifications for aflatoxins and other mycotoxins through RASFF

The RASFF was introduced following a case of mercury poisoning in oranges in Germany and the Netherlands in 1978 (European Commission, 2019). RASFF marked its 40th anniversary in 2019 with a conference “All you need is RASFF” on the eve of the implementation of a new amended regulation—(EC) No. 178/2002 of the European Parliament and the European Council. This new amendment merged the Administrative Assistance and Cooperation network (AAC) with the RASFF network. Between 2000 and 2019, RASFF notifications most commonly originated from the EU followed by Asia (European Commission, 2020). RASFF notifications increased significantly in the EU from 2016 to 2019 (European Commission, 2020).

RASFF promotes regulatory compliance since when one country encounters a food safety risk, it alerts the other participating member countries of the problem and the steps taken to address it. Actions taken following a safety alert may include withholding, recalling, seizing, or rejecting products. The rapid dissemination of standard alerts allows RASFF members to determine, in real time, if they are affected and the level of attention that the identified problem will require. Authorities of RASFF member countries often must take predetermined actions in response to an alert (RASFF, 2017). These actions may include directly informing the public, and recalling products, and other appropriate actions to limit exposure along the value chain.

RASFF reported 5045 and 439 notifications for mycotoxin contamination in food and feed products, respectively, imported by EU countries from 2010 to 2019 (Aishannaq et al., 2021). Of the notifications for mycotoxin contamination in food, 89% (n = 4487) were attributed to aflatoxins. Aflatoxins also were the most commonly detected mycotoxin in fruits and vegetables, and to a lesser extent in herbs, spices, cereals, and confectionery (European Commission, 2020). The second most commonly reported mycotoxin was ochratoxin A with 10% (n = 507) of the RASFF notifications. Deoxynivalenol, fumonisins, zearalenone, and patulin were reported in 1.01% (n = 51), 0.71% (n = 36), 0.23% (n = 36), and 0.09% (n = 5) of the RASFF notifications, respectively. The top 10 countries were linked to 80% of RASFF mycotoxin notifications on food products and included both Turkey with 33% of the notifications and China with 15%.

AFBI is a particularly significant risk with the lowest acceptable limit for consumption of 1 or 2 μg/kg in most countries that have regulations that regulate it (USDA Foreign Agriculture Service, 2018). However, the carcinogenic and toxigenic nature of aflatoxins means that there is no safe level of intake (European Commission, 2020). Thus, aflatoxins are subject to the ALARA principle whereby the legal limit enforced is “As Low as Reasonably Achievable”. Recently, excessively high levels of aflatoxins were found in peanuts, nut-contact foods, and seeds destined for the EU from developing countries and nonmember states. Developing countries must establish programs to assist nonmembers and developing countries mitigate food safety impediments to trade and their associated economic
impacts. These programs must ensure that safer food and feed are imported into developed countries (European Commission, 2020). However, it also is important that the “trickle up” regulatory process does not result in the poorest consumers in developing countries, whose diet is of very limited scope and who do not consume an extraordinarily large amount of mycotoxins on a daily basis are impacted. Food insecurity issues in many developing countries guarantee that all food, regardless of mycotoxin contamination levels, will be consumed and that little or no food will be discarded. Pathogenic microorganisms, pesticides, and mycotoxins far outnumber all other hazard notifications with 968, 690, and 422 notifications, respectively (Figure 3a). Of the 399 mycotoxin notifications reported in food in 2020, 343 were for aflatoxin contamination (Figure 3b). By product, contamination of peanuts with aflatoxin in 2020 was quite high with 134 of 234 notifications in the category nuts, nut-contact, and seed products. Of the 422 total notifications for mycotoxins, 407 were for serious hazards with 134 of these related to peanut products (Figure 3c,d).

### 6.3 | DSSs for effective silo management

Based on the stakeholder interviews performed as part of the MyToolBox project (Krska et al., 2016; Leslie et al., 2020) with stakeholders from the peanut industry, the need remains for improved (in-silo) monitoring and field-to-fork approaches for the Chinese peanut supply chain. Beginning in early September each year, peanuts are hand-picked by farmers and dried under the sun, usually on the roof of the farmer’s houses. Peanut-producing companies in Rushan county, Shandong province, for example, begin buying peanuts in November. They limit moisture content to less than 8%, and acid, AFB₁, and peroxide levels as well. Those peanuts usually are sold as kernels that were shelled at the farmers’ union, but with about one-eighth of the final product consisting of hulls since a portion of the company’s final products are in the form of with hulls. All peanut kernels are packed at 25 kg/bag in woven polypropylene or jute bags, stored in a shelter (10,000 m² with a capacity of 20,000–30,000 t) ventilated with ambient air, until April of the following year. Since the temperature is quite low during this time, it generally is safe and energy efficient to store peanuts this way. The peanuts are transferred to cool rooms (10,000 t) where the temperature is kept under 10°C until the end of the spring. The cool rooms are fumigated with aluminum phosphide and sealed for at least a week. Peanuts are protected from insects until processed. Machine and human sorting and QC are done right before processing. Aflatoxin contamination remains a major challenge for peanut exporters. In recent years, multiple shipments of processed and

**FIGURE 3** RASFF notifications for mycotoxins in food and nuts, nut-contacts, and seed products downloaded from the RASFF portal for 2020: (a) notifications by hazard; (b) mycotoxin notifications recorded in feed and food; (c) notifications by product category; and (d) mycotoxin specific notifications
unprocessed peanuts to Japan and the EU have been rejected due to excessive aflatoxin contamination. Stakeholders also agreed that it is very important to build up the monitoring, preventive, and control capacities for mycotoxin management from the field to the final products. Initial limited efforts were made as part of the MyToolBox project, but more resources are needed to develop an integrated approach in China from planting to postharvest management. Moreover, novel monitoring devices are needed to rapidly and accurately monitor peanuts in bags.

Future EU–China collaborations can build on the work carried out in previously funded EU–China flagship projects, such as MyToolBox and MycoKey. These projects integrated infrared (IR) CO$_2$ sensors, temperature (T) sensors, and relative humidity (RH) sensors into a device for real-time monitoring of key abiotic parameters, primarily in grain silos and peanut sacks. The CO$_2$/RH/T sensors refined and applied within MyToolBox (Krska et al., 2016) now need to be scaled up and installed in peanut silos, where peanuts are stored both in sacks and as bulk, to monitor temperature, moisture, and CO$_2$ levels as early indicators for the growth of A. flavus and the biosynthesis of AFB$_1$. Access to large storage facilities for peanuts is a prerequisite for the implementation, refinement, and deployment of these sensors and monitoring systems.

Chinese stakeholders also were interested in postharvest management of staple foodstuffs, especially rice, maize, wheat, and peanuts, to minimize direct losses from and export rejections due to mycotoxin contamination (Leslie et al., 2020). Generic approaches to these problems are not possible due to regional differences in the quality of harvested products and silo design and management strategies. Short-term sensing systems for critical abiotic factors, that is, RH, T, and CO$_2$, are currently used in Chinese storage facilities. Development of improved permanent sensors and more sophisticated models that use the data from these sensors is a critical step forward. As part of the MyToolBox EU–China efforts, a real-time DSS was successfully developed that can be used together with models for fungal growth and aflatoxin biosynthesis on stored peanuts under abiotic conditions. CO$_2$ production is the earliest indicator of A. flavus colonization and aflatoxin biosynthesis in stored, shelled peanuts (Garcia-Cela et al., 2020). Once localized changes in CO$_2$ levels within a silo could be visualized, areas where fungal/insect respiration was occurring could be readily identified. These areas are those most likely to be contaminated with aflatoxins. Scientists from China and the United Kingdom worked together at Chinese storage facilities using trial versions of the DSS to improve postharvest management by executing remedial actions such as aeration or the removal of potentially contaminated material from the silo.

Postharvest issues, including silo management, are critical for reducing losses of food after it has been produced. Moving materials from farm gate to storage and the processing of crops after harvest but prior to storage can significantly alter the length of time for which a crop can be stored and the quality of the material that is taken from storage. The single most important step is to reduce moisture content below the critical threshold that is specific for the target crop. China has a range of postharvest practices and numerous storage facilities that are being modernized rapidly and that now require sophisticated, trained managers. The design of these storage structures often is uniquely Chinese and practical management solutions may also be unique, even if the underlying problems to be solved are the same as those encountered elsewhere.

### 6.4 Postharvest risk monitoring during drying, storage, and transport

In the establishments visited by DG Health and Food Safety (European Commission, 2017), risks related to aflatoxin contamination of incoming raw materials and synthesized during storage of raw materials were systematically included in the hazard analysis. In several cases, however, the risk of fungal growth and aflatoxin biosynthesis was not considered for the storage of intermediate or final products, or for the transport of materials to the final client.

Incoming materials are subject to quality checks upon receipt for kernels that are broken, moldy, discolored, decayed, shriveled, and rancid. Sorting during processing also is intended to reduce aflatoxin contamination. All the processors visited by DG Health and Food Safety combined manual sorting with electronic color sorting equipment.

All Chinese processors visited by DG Health and Food Safety also limited moisture content at reception to a maximum of 10% for unshelled and 8.5% for shelled peanuts. Incoming peanuts with moisture levels exceeding those allowed are sun dried or blanched for faster processing. The national standards of China, GB 2761-2011, set the standards for AFB1 at 20 µg/kg in peanuts and associated products for local consumption. The code of practices for the prevention and reduction of aflatoxin contamination in peanuts, NY/T 2308-2013, sets guidelines for peanut operators. This code of practice includes recommendations for moisture levels (unshelled, 9%–10%; shelled, 8%–9%) and storage conditions (temperature < 15°C and RH < 70%). The recommended temperature is not consistent with the recommendation of 6 to <10°C found in point 39 of the Codex Code of Practice (FAO/WHO Joint Publications, 2004).
Most peanut growers are small farmers in agricultural cooperatives. Recently, some larger Chinese peanut processors have begun to contract with multiple farmers to manage the entire peanut cultivation cycle more effectively and to create larger plots of land that are amenable to irrigation and mechanization. After harvest, peanut plants are dried in the field. After separating kernels from shells, the kernels may be sun-dried further on the farm before being packed into 40 kg bags. The evaluation of the level of moisture levels on farm usually is based on touch or the sound made by the peanuts when shaken in the bag.

During storage of peanuts in large silos, postharvest environmental real-time monitoring is made of key abiotic parameters in grain silos and peanut sacks. For risk monitoring during transport, sensors should be packaged in sacks and bulk consignments to record temperature, moisture, and CO₂ levels. Existing models should be employed, and in some cases improved, for predictive purposes based on recorded outcomes with peanuts, which usually are shipped in containers. Unshelled peanuts usually are packaged in polythene sacks containing 25–30 kg of peanuts or in cartons containing 10 kg. Shelled peanuts usually are transported loose in bulk. Blanched peanut kernels commonly are packaged in 50-kg polythene sacks.

The transportation of peanuts should be evaluated by collecting relevant data for different lots of peanuts being exported from China. The lots should be representative of different ages of peanuts and different modes of packaging and handling. Data collected should include not only the aflatoxin levels in the peanuts but also the extent of fungal colonization prior to transport and values of risk factors such as α₉₀, as well as details of the transportation arrangements. The same parameters should be measured again after the consignment is received in the EU. In some shipments, sensors may be packaged in sacks and bulk consignments to record temperature, moisture, and CO₂ levels. Recently developed models (Garcia-Cela et al., 2020) can then be used for predictive purposes in conjunction with the recorded outcomes for the transported peanuts. Understanding changes that occur when crops are transported has been neglected, and this significant link in the agri-food chain requires more attention. The identification of risk factors that accompany peanuts as they are transported would contribute to standard setting and regulatory cooperation between the EU and China.

A notice was issued by the Shandong CIQ on May 1, 2017 recommending that if sea vessels going to the EU are passing through a tropical zone, then containers with peanuts must be loaded either below deck or at water level. This recommendation has not yet systematically implemented by Food Business Operators (FBOs) and the information is not always included on the shipping documents (European Commission, 2017).

The DG’s conclusions on procedures for exporting to the EU were that although the CAs conduct competent inspections and analyses of export shipments, the lack of supervision after final testing and of storage, loading, and transport to Europe weakens the reliability of the official controls (European Commission, 2017). The European Commission concluded that since its last audit, improvements have been made with regard to the development of Good Agricultural Practices (GAPs), self-checks, Good Storage Practices, and the implementation of the Hazard Analysis and Critical Control Point (HACCP) principles at the processor level. However, a lack of supervision of the preprocessing stages, in addition to problems with trade and transport to the EU (European Commission, 2017), still persists.

6.5 Detoxification

Mycotoxins in animal feeds can be detoxified by adding substances that either bind mycotoxins so they are no longer bioavailable or act as bio-transforming agents and convert the toxins to biologically less active products. The mycotoxin detoxification in animal feed literature base is large, and numerous substances have been promoted as physical or biological adsorbents, or as microbiological/enzymatic transformation agents. The 2009 EFSA report exhaustively reviewed mycotoxin-detoxifying agents used as feed additives and their mode of action, efficacy, and feed/food safety (BOUDERGUE et al., 2009).

Previous studies with Brazil nuts using low ozone concentrations of 14 and 32.5 ppm were found to completely inhibit AFBI production, but the treatment was applied for 24 h, which also completely inhibited aflatoxicogenic fungal growth (Giordano et al., 2012). Ozone is a strong oxidizer and reacts with the 8,9 double bond of the terminal furan ring in aflatoxin through an electrophilic attack mechanism. In peanuts, a more recent study (Chen et al., 2014) describes optimized conditions for ozonation to detoxify aflatoxins in peanuts. In peanuts with a moisture content of 5% (w/w), ozone readily degraded aflatoxins when the peanuts were exposed to 6 mg/L of ozone for 30 min at room temperature. The detoxification rates of the total aflatoxins and AFBI were each 66%. When the quality of peanuts samples was evaluated, there were no significant differences (p > .05) in polyphenols, resveratrol, acid value, and peroxide value between treated and untreated samples. Ozone also inhibits the growth of A. flavus and A. parasiticus, which prevents additional aflatoxin biosynthesis in the treated peanuts. Current research focuses on improved detoxification with combinations of ozonation and a catalyst or UV irradiation. The mechanism by which
the aflatoxins are detoxified, especially the identification of the end products, also remains to be fully elucidated. Despite its limitations (ozone is not very user friendly and requires effective safety protocols and equipment that will not degrade during use), these results suggest that ozonation is an alternate potential method for detoxification of aflatoxins in peanuts.

7 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

To prevent and mitigate aflatoxin contamination in peanuts, the stages of the peanut chain that are most susceptible to contamination need to be identified, and mechanisms to interrupt the continued movement of infested crop need to be developed and implemented. There are several interventions that, when used in combination, can reduce predation and fungal infection of the crop and improve the quality or yield of the harvested peanuts. In this paper, we emphasized an integrated disease management strategy that combines sustainable preharvest and postharvest practices ranging from biocontrol measures and big data-based remote sensing at the preharvest level to smart DSSs for silo management and risk monitoring during storage and transport at the postharvest level. Available guidance and current recommendations are provided to assist with the successful practical implementation of the identified procedures. As food safety standards may influence stakeholder and consumer trust and confidence, we also incorporated the results of group discussions with stakeholders from both industry and academia all along the peanut supply chain.

A major conclusion of the European Commission’s audit of Relevant National Legislation in China was that the lack of supervision of some links in the supply chain for peanuts probably is preventing full compliance with good hygiene practices at every stage of the peanut supply chain. This lack of supervision makes issuing health certificates difficult and renders their reliability problematic. The report issued by the DG for Health and Food Safety (European Commission, 2017) recommends that official controls of peanuts be conducted at all stages of production, processing, and export, and conform to the requirements detailed in point 21 of the Codex Alimentarius Guidelines for the Design, Operation, Assessment, and Accreditation of Food Import and Export Inspection and Certification Systems (CAC/GL 26–1997; 66). These guidelines require quick and reliable analytical methods. The DG for Health and Food Safety also recommended that storage and transport conditions follow the good hygiene practices described in point 58 of the Codex Code of Practice CAC/RCP 55–2004 (FAO/WHO Joint Publications, 2004) and that sampling and analyses are performed as described in Regulation (EC) No. 401/2006.

The Code of Practice for the Prevention and Reduction of Aflatoxin Contamination in Peanuts is intended as a guide to all parties interested in producing and handling peanuts sold in international trade for human consumption. Major peanut-producing companies follow this Code of Practice (Refix Commodities, n.d.). We recommend that resources be devoted to developing and implementing GAPs at the preharvest level and to improving drying, storage, and Good Manufacturing Practices (GMPs) for the distribution and processing of peanut products. An HACCP system is needed and could be based on established GAPs and GMPs. Integrated mycotoxin control programs should incorporate HACCP principles to reduce risks associated with mycotoxin contamination of foods and feeds. Implementation of the HACCP principles will minimize aflatoxin contamination of peanuts via preventive controls implemented to the greatest extent possible during the production, handling, storage, and processing of peanuts worldwide.

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AUTHOR CONTRIBUTIONS


CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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