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SPECIAL ISSUE: *Mycotoxins in Latin America*

Foreword – special issue Mycotoxins in Latin America

Latin America with its considerable North-South extent is subject to climate that varies from tropical, subtropical and warm temperate to temperate. Different agricultural products are produced in the area including cereals, oilseeds, beans, fruits and nuts together with animal production including cattle for beef and milk, pigs, poultry and fish. The heterogeneity of agriculture in Latin America is reflected in the diversity of the region's farm structures. While agriculture in the Southern Cone is dominated by large, commercial and export-oriented farms, particularly in Argentina and Brazil, besides increasingly in other countries like Uruguay, much of the rest of the region is characterised by smallholder and family agriculture. The contamination of agricultural products with mycotoxins has impact both human and animal health, as well as the economy due to losses related to rejections of agricultural products and by-products during trade. The economic burden related to the consumption of mycotoxins by animals is especially important, causing productivity losses up to the death of animals. The relevant mycotoxins are fumonisins, deoxynivalenol (DON) and zearalenone (ZEN) in cereals and cereal-based products, aflatoxins in cereals, oily seeds and nuts, aflatoxin M_1 in milk and dairy products as well as ochratoxin A (OTA) in coffee, grapes and raisins. Co-occurrence of mycotoxins has also been observed mainly with aflatoxins and fumonisins in different Latin American countries (Torres *et al.*, 2015). Advances on legislation in different countries including Argentina, Brazil, Chile, Mexico and Uruguay have been done to establish maximum limits for mycotoxins including aflatoxins, DON, ZEN, OTA, patulin and ergot alkaloids (ANVISA, 2011/2017; CAA, 2019/2021, Norma Oficial Mexicana, N.-243-S., 2010/2010; Reglamento Sanitario de los Alimentos, 2013).

The main aspects covered in this special issue can be classified into the following research areas:

Occurrence of mycotoxins

Maize (*Zea mays* L.) is one of the main cereals produced in the world, with Brazil, Argentina and Mexico being the largest producers worldwide. This cereal is the main staple food for many Latin American populations. Also, it is used as an ingredient in animal feedstuffs and for bioethanol production. Grain used for human and animal consumption, as well the by-products of the bioethanol industry – distillers´ dried grains with solubles (DDGS) – can be contaminated with mycotoxins. Also, co-occurrence of mycotoxins, such as fumonisins and aflatoxins have been observed. Ponce Garcia *et al.* (2021) reviewed the impact of aflatoxin occurrence in maize and their implications on health in Latin America. Data on occurrence of mycotoxins in different Latin American countries together with the adverse effects of the consumption of contaminated foods and the associated health consequences for Latin American consumers are presented. Regulations aimed to mitigate aflatoxin exposure to consumers are also reviewed and needs for further research in the maize food and feed chains are identified.

The importance to continue the efforts on research activities regarding to the development of new tools to reduce the mycotoxins in the maize food and feed chains will be crucial in the Latin American countries. This is due to the importance of this crop for the producers and exporter countries, but also due to the use of maize-based food and feed for human and animal diets. Also, continuation of the monitoring of mycotoxins in maize and maize based food and feedstuffs is crucial.

The presence of mycotoxins in by-products of bioethanol industry, such as DDGS, is of concern due to their use as ingredients in animal feed. Mallmann *et al.* (2021) surveyed DDGS samples produced in Brazil for aflatoxins, fumonisins, ZEN, DON and OTA. The study showed that about 99% of the samples were contaminated, 59.9% of which were contaminated with a single mycotoxin, 29.9% with two mycotoxins and 9.1% more than two mycotoxins. Since the production of bioethanol based on maize is increasing in Latin America, monitoring the occurrence of mycotoxins in DDGS is relevant to mitigate the impact of these ingredients in animal mycotoxicoses.

The ingestion of dairy cattle with AFB_1 through the consumption of contaminated feed causes a portion of this mycotoxin to be degraded in the rumen by resident microorganisms resulting in the formation of aflatoxicol. The remaining AFB_1 is absorbed in the digestive tract by passive diffusion and undergoes hepatic biotransformation to aflatoxin M_1 (AFM_1), a hydroxylated form of AFB_1 which is excreted in milk, tissues and biological fluids of these animals. Regarding identification and quantification of AFM_1, chromatographic and immunochemical methods are generally used. Jimenez Perez *et al.* (2021) reviewed the occurrence of AFM_1 in milk and artisanal and industrially cheese produced in Mexico. The analysed samples showed levels higher that 0.5 μg/kg – the maximum limit set in the regulations in Mexico. Other studies also showed occurrence of AFM_1 in milk samples from Peru. These studies emphasise the need to control the presence of mycotoxins in the ingredients of feedstuffs devoted to dairy cows (Salazar *et al.*, 2021).

Strategies to reduce the entry of mycotoxins in the food and feed chains

Aflatoxins are mycotoxins produced by *Aspergillus* section *Flavi*, mainly *Aspergillus flavus* and *Aspergillus parasiticus* in different crops, including nuts and cereals These species can colonise the crops at preharvest and postharvest stages. Several approaches have been evaluated to mitigate aflatoxin contamination, including physical, chemical and biological strategies. Gibellato *et al.* (2021) described the advantages and disadvantages of different strategies for prevention and reduction of aflatoxin contamination in different crops.

Toxicology and exposure to mycotoxins

Aflatoxins are the most potent naturally occurring carcinogens. Since the discovery of these mycotoxins, a remarkable spectrum of epidemiological, biochemical and molecular studies characterised the carcinogenic processes following aflatoxin exposure both in human and animals. The availably of biomarkers of exposure allowed epidemiological studies to be carried out which showed the significant risk of hepatocellular carcinoma and in specific populations a synergistic increase in risk for those infected with hepatitis B virus with potential further interactions, e.g. diabetes or obesity. Groopman *et al.* (2021) presented an interdisciplinary collaborative study to develop a long-term strategy to characterise the role of aflatoxins and other mycotoxins as health risk factors in Guatemala and neighbouring countries. The review summarised the research done to date and provides a road map of the strategies for the near term to discern the emerging aetiology of liver cancer in this region. This study will provide a base for public health based prevention strategies to mitigate the impact of mycotoxins on human health.

Brazil nuts (*Bertholletia excelsa*) are harvested in native areas of the Amazon rainforest. These nuts are exported and also consumed by local populations. A pilot study was done to evaluate the occurrence of aflatoxins in the human diets and their presence in urine as a metabolite (AFM_1). The volunteers were evaluated before and after the consumption of two Brazil nuts/day during 30 days. At the end of 30 days without the consumption of Brazil nuts, 9 samples (30%) were positive for AFM1. After 30 days consuming 2 Brazil nuts per day, there was a reduction to 2 positive samples (7%). Further studies are needed to analyse the nutrient levels in the diet, e.g. for selenium that could provide some protection to human aflatoxicosis (Higashioka *et al.,* 2021).

Cervical cancer (CC) is one of the most serious threats to the lives of women. In Mexico women are exposed to AFB_1 through their diet, and this toxin can be a cofactor in inducing progression of CC. Diaz de León-Martinez *et al.* (2021) detected AFB_1 adducts and genomic concentrations and showed correlation with the detection of two oncogenic types of HPV 16 and 18. A possible interaction with the NRF2 pathway was also proposed.

Analytical methods

Methods for detection of mycotoxins are heterogeneous and depending on the country. Nonetheless, some improvement has been made in recent years regarding sampling methods and detection methodologies (HPLC-UV, -FD, -MS/MS, near infrared spectroscopy (NIR)), as well as laboratory facilities in Latin America. Extraction procedures based on QuEChERS were validated for different matrices, mainly those based on vegetable proteins (e.g. vegetable milks) which have raw material susceptible of mycotoxin contamination. Pinto *et al.* (2021) developed and validated an analytical methodology based on QuEChERS and LC-MS/MS for the simultaneous determination of nine mycotoxins in vegetable milks from peanuts, oats, rice, cashews, maize, soybeans and coconuts.

Control strategies to reduce the impact of mycotoxicosis

Control strategies through the food and feed chains both pre- and post-harvest employ chemical and biological control. In addition to the use of microbial cells or vegetal extracts aiming to bind and adsorb aflatoxins, studies have also been conducted on the use of sorbents, such as bentonite clay materials to reduce aflatoxins. These materials can reduce the toxins´ bioavailability by entero-adsorption, avoiding aflatoxin adsorption in the gastrointestinal tract and preventing its distribution to the target organ (liver). Two studies showed the effect of adding a Brazilian bentonite, a new modified bentonite and an anti-mycotoxin additive to reduce the toxicity of ZEN *in vitro* in cell cultures and *in vivo* in heifers. The former study showed that the two bentonites were able to reduce the ZEN induced cytotoxicity both in Caco-2 and PHP 1 cells (Nones *et al.*, 2021). The *in vivo* study showed that β-zearalanol can be used as a biomarker of ZEN exposure via diet to evaluate anti-mycotoxin additives (Tonini *et al.*, 2021).

A study showed the efficacy of vegetable biocholine to improve the health of laying hens and the quality of eggs of the laying hens feed with a diet contaminated with AFB_1 (Dazuk *et al.*, 2021). The use of *Saccharomyces cerevisiae* as probiotic in pig diets was effective to reduce the toxic effects of AFB_1 in intestines. This strategy is promising for the production of feed additives since the yeast has shown probiotic action and decontamination of mycotoxin (Poloni *et al.,* 2021). Another study (Pinheiro *et al.*, 2021) showed the effect of *S. cerevisiae* to feed contaminated with AFB_1 improving the performance indices of tambaqui (*Colosoma macropomum*).

Sabini *et al.* (2021) showed the efficacy of aqueous extracts of *Achyrocline satureioides,* a medicinal plant belonging to the *Asteraceae* family traditional from South America, which contain flavonoids that prevents the multi-target toxicity induced by ZEN.

Toxic effects on animals

Toxicological effects of mycotoxins on (production) animals, including fishes, have been evaluated, and biomarkers of exposure to different mycotoxins have been measured.

In the last decades the global demand of protein derived from fish has steadily increased. Pacu (*Piaratus mesopotamicus*) is produced in South American countries, such as Brazil, Paraguay, Bolivia and Argentina. Michelin *et al.* (2021a) showed that the long-term exposure to AFB_1 has a negative influence on weight and length, causing losses in production. Another study evaluated the effect of AFB_1 on the biochemical parameters and liver damage in two fish species, pacu and matriñxa (*Brycon cepahlus*), and demonstrated that long-term AFB_1 in the diet caused liver damage as well as cell death, fatty and hydropic degeneration in both studied fish species (Michelin *et al.*, 2021b).

DON reduces reproductive performance in males and females of several species. A study demonstrated that peripubertal rats exposed to DON have compromised their testicular structure and changes in the dynamics of spermatogenesis (Gerez *et al.*, 2021). Phytic acid was used as a modulator of the immunological response of porcine intestinal mucosa exposed to DON and fumonisin B_1 resulting in beneficial effects on intestinal homeostasis and health (Olegario da Silva *et al.*, 2021).

The Latin-American Society for Mycotoxicology (SLAM)

During the IUPAC congress held in Mexico in 1992 by the initiative of a group of Latin American researchers – including chemists, microbiologists, agronomists, and veterinarians – aroused the need to establish the Latin American Society of Mycotoxicology (SLAM). The main objectives of the Society are:

- to promote scientific research on mycotoxicology in Latin America;
- to organise congresses, workshop seminars;
- to disseminate the knowledge about mycotoxins at government level and also among farmers and consumers;
- to exchange information on mycotoxins and maintain collaboration with similar societies in other countries.

Since 1994, several congresses have been organised by SLAM every 3 years in different Latin American countries, such as Brazil, Argentina and Mexico.

Also, MYTOX South consolidated the scientific cooperation between partners from the Southern hemisphere, including Latin America. During 2021, a webinar was organised on Mycotoxin Legislation in Latin America. Many Latin American partners are also members of the International Society for Mycotoxicology (ISM). Scientific cooperation among partners from Latin America, Europe and USA is ongoing to improve food security and food safety through the food and feed chains.

Future challenges to mitigate the impact of mycotoxins in Latin American countries

Under a scenario of climate change it is necessary to continue studies in Latin American countries. Changes on the biodiversity of toxigenic species and changes in the risk maps can already be observed. Rising awareness of consumers and among stakeholders, including policy makers to mitigate the effect of mycotoxins in Latin American countries is encouraging.

Considering a global economy and a post COVID-19 situation the world will require healthy and safe foods. Mycotoxins are natural contaminants; it will be necessary to continue research activities on different areas of the biology and toxicology of mycotoxins to reduce the entry of these contaminants into the food and feed chains.

To continue the good collaborations among Latin American researchers and from other continents also the possibility to obtain grants from international bodies will be relevant to stimulate the research in the mycotoxicological area in Latin America.

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