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Comparison of multiple mycotoxins in harvested maize samples in three years (2018-2020) in four continents

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Abstract

This study has examined the pattern of mycotoxin contamination of maize destined for animal feed in different global regions over a period of three years (2018-2020) with up to 1000+ samples analysed in each year. Overall, >75% of samples in each of the survey years were contaminated with multiple mycotoxins regardless of the global region (Europe, Africa, Asia, South Americas countries. Using LC-MS/MS, it was possible to quantify the relative contamination with 8 different mycotoxins present in the samples in each year from the different regions including Aflatoxin B_1 (AFB_1), ochratoxin A (OTA) Deoxynivalenol (DON), Fumonisin B_1 (FB_1) and B_2, Zearalenone (ZEA), T-2 and HT-2 toxins. The trends in mycotoxin contamination showed that there was a consistent contamination in all four regions with DON in the three sampling years in all four regions. Interestingly, AFB_1 contamination was prevalent in all regions in 2018, but more predominant in Europe and in 2019. In contrast, in 2020 it was found to be the major contaminant in Africa only. However, FB_1 contamination of maize which was prevalent in Europe in 2018, became more prevalent in Asia and LATAM countries in 2019 and even in African maize in 2020. Comparisons of contamination with different mycotoxin in each of the years globally showed significant differences for AFB_1, FB_1, DON and ZEA between the different years. These results are discussed in relation to the trends on contamination of maize with mixtures of mycotoxins and the implication for their control in this key commodity used and an important ingredient in animal feed.

Keywords: multiple mycotoxins, survey, maize, regional contamination, global trends

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Introduction

Livestock production has significantly increased in the last decade, especially in Asia where the demand for animal-based protein has increased significantly. The feed production chain requires raw commodities of a high quality to ensure that feed safety protocols can be maintained. In addition, it is critical that contaminants are minimized to ensure that animal health and such protein sources destined for human consumption are safe (Bryden, 2012).

The contaminants of most interest in feed raw materials and compound feeds are chemical residues including dioxins, heavy metals and mycotoxins. Biological contaminants, especially spoilage micro-organisms are also important. Mycotoxin contamination in both feed and food chains have received particular attention driven mainly by the legislative limits on maximum allowable contamination in many countries world-wide. Thus, there has bene a focus on understanding the trends in mycotoxin contamination in different regions on a global scale to understand the relative risks of mycotoxins entering the feed, and ultimately the human food chain. Mycotoxin contamination of animal feeds reduces animal growth rates and can have a significant spectrum of toxic effects on different groups of animals.

There have been excellent recent surveys of the mycotoxin contamination levels in raw commodities (wheat, maize, soybeans) and compound mixed feeds (Rodrigues and Naehrer, 2012; Gruber-Dorninger et al., 2019). These have shown that weather conditions in different regions of the world has influenced the trends in trends in the predominant mycotoxins present in these types of feed samples. Of particular importance is the harvesting, drying and storage phases for these raw commodities destined for feed use because some are very hygroscopic and can re-adsorb moisture exacerbating mycotoxin contamination levels post-harvest (Magan et al., 2020). Indeed, in lower middle income countries (LMICs) it has been suggested that up to 25% of raw feed/food commodities are lost due to spoilage and mycotoxin contamination, although these losses may be much greater (Eskola et al., 2020). This has had significant implications for export/import in such commodities because of the strict maximum enforced limits for different mycotoxins world-wide, especially in Europe which has strict maiximum levels for aflatoxin B_1 (AFB_1) and total aflatoxins, fumonisins, Zearalenone, deoxynivalenol and ochartoxin A (European Union, 2011, 2013).

In last decade it has been shown that because raw staple commodities for both the food and feed chains are colonized by a mixed community of mycotoxigenic fungi, contamination with multiple mycotoxins occurs (Smith et al., 2016). This has implications for the overall level of risks associated with feed raw commodities and mixed feeds and there overall preservation (Magan and Medina, 2020). Co-occurrence creates concerns as to whether the combined toxic effect may be additive, antagonistic or synergistic and have implications for animal husbandry (Grenier, B.; Oswald, 2011; Alassane-Kpembi et al., 2017).

The objectives of the present survey was focused specifically on maize (corn) as a raw commodity for feed use and examine the changes in the predominant and co-occurrence of mycotoxin in this commodity. The survey was focused on different regions of the world including parts of Europe (Serbia, Bosnia, Spain, Croatia, Italy, and Russia), LATAM countries in South America (Dominican Republic, Peru, Argentina and Colombia), Asia (Vietnam, Malaysia, Turkey, and Thailand) and Africa (Algeria, Morocco, Ghana, Ivory Coast, Kenya and Cameroon). The trends observed in the co-occurrence of different mycotoxins in three different years were compared (2018-2020).

MATERIALS AND METHODS

Sample collection and treatment

From each country involved in this survey composite maize samples were collected and sent to the Patent Co. analytical laboratories for analyses. Overall, the total number of samples per country per annum were 50-60 samples. A total of 1000+ samples per annum were analysed. This was done in each of the survey years, 2018 2019 and 2020. It should be noted that in the LATAM countries almost all the maize samples were GM cultivars which had resistance to herbicides, pests or both.

Multi-mycotoxin analyses and quantification

The corn samples were all analyzed by LC-MS/MS triple quad (Agilent 6460 series) using a multi-mycotoxin method for quantification of all mycotoxins present. These included Aflatoxin B_1 (AFB_1), Aflatoxin B_2 (AFB_2), Aflatoxin G_1 (AFG_1) and Aflatoxin G_2 (AFG_2), Ochratoxin A (OTA), Zearalenone (ZEN), Deoxynivalenol (DON), Fumonisin B_1 and B_2 (FB_1 and FB_2), T-2 and HT-2 toxins that are all regulated in the EU in feed

by EU Directives 2002/32/EC, 2006/576/EC, and 2013/165/EU. The samples were finely grounded and thoroughly mixed using a mill and mixer before a test portion was removed for analysis. A 5.0 g sub-sample was placed in a conical tube. 20ml extraction mixture I (80% Acetonitrile:19.9% Water:0.1% Formic acid) and the lid closed. This was thoroughly mixed on an orbital shaker at 200 rpm for 1 h at room temperature.

The tube was then centrifuged at 4200xg for 5 min and the supernatant removed to another 50 ml conical tube. A 20ml aliquot of the extraction mixture II (20% Acetonitrile: 79.9% Water: 0.1% Formic acid) to the residue and the mixture again extracted by placing on an orbital shaker at 200 rpm for 30 min at room temperature. This mixture was centrifuged at 4200xg for 5min. The two supernatants of the two extraction steps were combined and again centrifuged at 4200xg for 5 min. A 500µL aliquot was prepared by filtering the extract through a membrane syringe filter into a glass vial. To compensate for the matrix effects during electrospray ionization, the extracts were mixed with [13C] labelled internal standards for each group of mycotoxins (13C AFB_1, 13C DON, 13C ZEN, 13C OTA, 13C FB_1 and 13C T-2) before injection into the LC-MS/MS system.

The method was successfully validated on maize, compound feed, wheat, barley, soya meal, wheat bran, sunflower meal and total mixed rations (TMR). The method performance parameters were obtained by in-house validation. The blank samples were spiked with a mixture of 11 mycotoxin standard at two levels (LOQ and 10 × LOQ) in 12 replicates. The Relative Standard Deviation (RSDr) of the method were between 2.5% and 13.4% and the recoveries between 62% and 115% for all analytes. The LOQs for Aflatoxin B_1, B_2, G_1 and G_2 was 0.4 ppb, for OTA was 1.6 ppb, for ZEN was 16 ppb, for DON was 64 ppb, for FB_1 and FB_2 it was 40 ppb and for T-2/HT-2 the LOQ was 9.6 (Farkas et al., 2017).

RESULTS

Summary of survey results for 2020

Overall, based on 1000+ samples in the most recent survey year showed that globally 77 % of the samples examined were contaminated with multiple-mycotoxins, only 15% had 1 mycotoxin present and 8% represented samples in which the contamination levels were below the LOQ. Figure 1a and b show examples of the predominance of samples of maize from Europe and Africa which have multiple mycotoxin

contamination. This was consistent for all regions surveyed. In addition, overall, Fumonisins occurred in more than 80% samples in most of the countries, except for Russia and Turkey. Interestingly, DON was predominant in 67% of samples originating from Croatia and Algeria, 70% of samples from Colombia and was detected in all samples from Kenya. Aflatoxin B_1 was predominantly found in maize samples from Africa and Asia. The highest number of positive samples with this toxin were from the Ivory Coast (86%), Cameroon (80%) and Thailand (70%) respectively.

Table 1 summarises on a global scale the average, median and maximum contamination with 8 different mycotoxins found in this study in 2020. It is interesting to note that Aflatoxin B_1, Zearalenone, Deoxynivalenol, Fumonisin B_1 and HT-2 toxin were found in particularly high concentrations in the samples. These results demonstrate that globally, the *Fusarium* mycotoxins (FB_1, FB_2, DON, ZEN,) were predominant, contaminating harvested maize samples destined for animal feed use. The detailed results for each country by global region is shown in Table 2.

Fumonisins were the predominant mycotoxins detected with a high average contamination level found, especially in Italy, Cameroon, Ivory Coast, Kenya, and Thailand. DON and ZEN were found to be present in much lower average contamination levels.

Global trends in mycotoxin contamination over three years (2018-2020)

It is important to consider the trends and patterns of contamination of maize with multiple mycotoxins in different countries in each global region. Thus, the trends in co-occurrence have been compared for samples of harvested maize in three different years. Figure 2 shows at in each of the three years of the survey the majority of maize samples were contaminated with multiple mycotoxins. In all three years >75% of samples exhibited the co-occurrence of mycotoxins. Only about 10-15% of samples contained a single mycotoxin contaminant on a global basis.

Figure 3 compares the average contamination levels found for all samples in each of the three sampling years. This shows the consistently high levels of FB_1 in the maize samples in each of the three years. It is worthwhile noting that AFB_1 commonly present in 2018 decreased significantly in 2019-2020, especially in the LATAM countires where maize samples were predominantly from GM cultivars. Overall, DON was consistently present in the maize samples in all three years, regardless of region.

Figure 4 shows the box plots and means for AFB_1 contamination occurred extensively in all for regions sampled, especially Africa, Europe and LATAM countries. However, in 2019 the main region with contamination were Europe and to some extent the LATAM countries, with much lower overall ranges of contamination. In the other two regions the AFB_1 contamination levels were much lower. Indeed in 2020 no comparisons could be made because of the low levels of contamination found.

In contrast, there was a marked change in the FB_1 contamination of maize samples in the different global regions (Figure 5). Thus, in 2018, FB_1 was mainly found in only European samples. However, there was a switch to Asia and LATAM countries and also Africa in 2020. The contamination levels overall were also much higher in 2019 and 2020 than 2018.

Maize samples were consistently contaminated with the type B trichothecene, DON, over the three year sampling period. This was especially the case for Asia, Europe and the LATAM countries.

The post-hoc statistical analyses initially found differences between the years using the Kruskal-Wallis test. The non-parametric analyses (Wilcoxon Method) showed the relative statistically significant differences between different sampling years (Table 3). This shows the significant changes in AFB_1 contamination, especially between 2018 and 2019/2020 sampling years for maize. The significant changes from 2018 to 2019 and 2020 for FB_1 is also clear. For the other toxins there were less effects on contamination levels in the three years of the survey.

DISCUSSION

This three year survey of maize grain samples destined for animal feed examined more than 1000+ samples per annum in four different global regions. Overall, in all three years, the survey showed that the co-occurrence with ≥1 mycotoxin was common in all of the different regions examined (>75% of samples). In the most recent sampling period (2020) fumonisins were the predominant mycotoxins present. This was the case for samples from all four global regions, followed by DON and ZEN. Only in some of the African countries (Ivory Coast, Cameroon) was AFB_1 found to be present at high contamination levels. It is important to understand the relationship between mixtures of mycotoxins because of the potential interactions between them

from a toxicological pint of view (Grenier and Oswald, 2011; Alassane-Kpembi et al., 2017).

In the present study the co-occurrence of two or more mycotoxins, and in some cases 3, could lead to potentially additive or synergistic effects when fed to sensitive animal species (e.g., swine and poultry amongst others). This suggests that technologies are required for the control of mixtures of such contaminants in feedstuffs predominantly based on maize to minimize impacts on animal development and reduce potential for consumer exposure via the animal production chain.

In terms of the pattern of contamination, it was clear that over the years 2018-2020 there was a consistent contamination of maize samples with the type B trichothecene, deoxynivalenol, over the three years in all four regions sampled. For fumonisin B_1 this toxin was especially found in samples from Europe in 2018. However, there was a significant switch in 2019 and 2020 where this toxin was present in significantly higher concentrations in all four regions, especially in Asia. Studies by Vaughan et al. (2017) suggested that episodes drought stress and elevated CO_2 can influence colonization of maize cobs during ripening and increase infection by *Fusarium verticillioides* and FB_1 contamination. This pattern was not observed in different types of individual and mixed animal feed materials (Gruber-Dorninger et. al., 2019). However, this mycotoxin may be of more importance, specifically in maize samples. It was interesting to note that AFB_1 contamination was consistently found in all four global regions in 2018, but there appeared to be a switch with a significant increase in contamination of samples of maize in Europe in 2019. In contrast, in 2020, the contamination of maize was predominantly found in African samples with practically no contamination of samples in the other regions. There was however a decrease in contamination with AFB_1 and OTA when compared to previous years. In addition, the trend of maize feed samples being contaminated with mixtures of at least two mycotoxins increased over the three year period.

The LATAM countries samples were predominantly GM cultivars. Studies of maize grain from GM cultivars for herbicide/pest or stacked resistance for both and non-GM isogenic cultivars showed that the mycotoxin and associated toxic secondary metabolite profiles were relative similar (Gasperini et al., 2021a). Indeed, recent studies of the colonization of GM and non-GM based matrices and aflatoxin B1 contamination were relatively similar (Gasperini et al., 2021b). However, less is known about the relative resistance to infection by *Fusarium* section *Liseola* species (*F.*

verticillioides, *F. proliferatum*) and fumonisins contamination of GM and non-GM maize cultivars.

Maize is prone to drought stress and there can be significant impacts on colonization by drought tolerant species such as *Aspergillus flavus* during silking and predispose the ripening cobs to aflatoxin contamination. However, under climate change-related abiotic factors where wet/dry episodes have become more common then the milky ripe stages during silking can be extended allowing *Fusaria* to become more predominant and the contamination with fumonisins, ZEA and DON to occur (Medina et al., 2017; Gilbert et al., 2018; Gasperini et al., 2019).

Harvesting, drying and storage systems varies significantly in the different global regions. While relatively efficient systems are used in developed regions such as Europe and parts of S. America, in Asian and African countries efficient drying and storage, especially for maize destined for animal feed may not be as effective (Magan et al., 2020). Thus the trends and changes in contamination of maize, especially with AFB_1, with the predominance in Africa in 2020, and the increasing trend in contamination with FB_1 in African and Asian regions may be partially due to local maize chain processing factors in conjunction with climate-related factors.

For the production of animal feeds it is critical that the ingredients used, especially in the production of mixed feeds, are of the right quality. In addition, often preservatives may be required to ensure the right shelf-life and to minimize animal exposure to multiple mycotoxins which may act synergistically in impacting on animal productivity. In the context of animal feeds the preservation of maize is critical and it has been demonstrated that effective preservative mixing and coverage of the commodity is critical for effective minimization of mycotoxin contamination (Magan and Medina, 2020). Under climate change-related abiotic factors the diversity of mycotoxigenic moulds present in harvested maize may change because of the patterns of insect behavior. This can result in more damage to ripening and harvested maize cobs and grains allowing mycotoxigenic fungi to become more prevalent because of their resilience to climatic abiotic interacting factors (Patterson and Lima, 2010; Bebber et al., 2013, 2014; Medina et al., 2015, 2017).

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References

Alassane-Kpembi, I.; Schatzmayr, G.; Taranu, I.; Marin, D.; Puel, O. and Oswald, I.P. 2017. Mycotoxins co-contamination: Methodological aspects and biological relevance of combined toxicity studies. Crit. Rev. Food Sci. Nutr. 57: 3489–3507.

Bebber, D.P., Ramotowski, M.A.T. and Gurr, S.J., 2013. Crop pests and pathogens move poleward in a warming world. Nature Climate Change 3: 985-988.

Bebber, D.P., Holmes, T. and Gurr, S.J., 2014. The global spread of crop pests and pathogens. Global Ecol. Biogeo. 23: 1398–1407.

Becker-Algeri, T.A.; Castagnaro, D.; de Bortoli, K.; de Souza, C.; Drunkler, D.A.; and Badiale-Furlong, E. 2016. Mycotoxins in bovine milk and dairy products: A review. J. Food Sci. 81: 544–552.

Bhatnagar, D., Rajasekaran, K., Gilbert, M., Cary, J.W. and Magan, N. 2018. Research Advances to Safeguard Food and Feed Supply from Aflatoxin Contamination. World Mycotoxin J. 11: 47-72.

Bryden, W.L. 2012. Mycotoxin contamination of the feed supply chain: Implications for animal productivity and feed security. Anim. Feed Sci. Technol. 173: 134–158.

European Commission. Commission regulation (EU) No 574/2011 of 16 June 2011 amending Annex I to Directive 2002/32/EC of the European Parliament and of the Council as regards maximum levels for nitrite, melamine, Ambrosia spp. and carry-over of certain coccidiostats and histomonostats and consolidating Annexes I and II thereto. Off. J. Eur. Union 2011, L 159, 7–24.

European Commission. Commission recommendation of 27 March 2013 on the presence of T-2 and HT-2 toxin in cereals and cereal products. Off. J. Eur. Union 2013, L 91, 12–15.

Gilbert, M.K., Medina, A. Mack, B.M., Lebar, M., Rodriguez, A., Bhatnagar, D., Magan, N., Obrian, G. and Payne, G. 2018. Carbon dioxide mediates the response to temperature and water activity levels in *Aspergillus flavus* during infection of maize kernels. *Toxins 10, 5. Doi:10.3390/toxins10010005*

Gasperini, A.M., Rodriguez-Sixtos, A., Verheecke-Vaessen, C., Garcia-Cela, E., Medina, A. and Magan, N. 2019. Resilience of biocontrol for aflatoxin minimisation strategies: climate change abiotic factors may affect control in non-GM and GM-maize cultivars. Front. Microbiol. 10**,** doi: 10.3389/fmicb.2019.02525

Gasperini, A.M., Garcia-Cela, E., Sulyok, M., Medina, A., Magan, N. (2021a). Fungal diversity and metabolomic profiles in GM and isogenic non-GM maize cultivars from Brazil. Mycotoxin Research 37:39-48. DOI:10.1007/s12550-020-00414-8

Gasperini, A.M., Medina, A. & Magan, N. (2021b). Comparison of growth and aflatoxin B_1 production profiles of *Aspergillus flavus* strains on conventional and isogenic GM-maize-based nutritional matrices. *Fungal Biology***.** https://doi.org/10.1016/j.funbio.2021.10.006

Gruber-Dorninger C, Jenkins T. and Schatzmayr G. 2019. Global Mycotoxin Occurrence in Feed: A Ten-Year Survey. *Toxins*. 11:375. https://doi.org/10.3390/toxins11070375

Garcia-Cela, E., Verheecke-Vaessen, C., Gutierrez-Pozo, M., Kiaitsi, E., Gasperini, A.M., Magan, N. and Medina, A. 2020. Unveiling the effect of interacting forecasted abiotic factors on growth and Aflatoxin B_1 production kinetics by *Aspergillus flavus.* Fungal Biol. *https://doi.org/10.1016/j.funbio.2020.05.003*

Grenier, B. and Oswald, I.P. 2011. Mycotoxin co-contamination of food and feed: Meta-analysis of publications describing toxicological interactions. World Mycotoxin J. 4: 285–313.

Jouany, J.P. 2007. Methods for preventing, decontaminating and minimizing the toxicity of mycotoxins in feeds. Anim. Feed Sci. Technol. 137: 342–362.

Farkas H.; Raj J.; Vukovic G.; and Vasiljevic M. 2017. Development of a multi mycotoxins analysis method for animal feed samples using Agilent 6460 LC-MS/MS. 1st MYCOKEY International Conference, Global Mycotoxin Reduction in the Food and Feed Chain 11-14 September 2017 Ghent, Belgium (Toxins 2017, 9, 276: 76).

Magan, N., Garcia-Cela, E., Verheecke-Vaessen and Medina, A. (2020). Advances in postharvest detection and control of fungal contamination of cereals. Chapter 14 in *Advances in postharvest management of cereals and grains*, Edt. Dirk Maier. Burleigh Dodds Series in Agricultural Science: no. 88, Cambridge, U.K. pp.478.

Magan, N. and Medina, A. 2020. Feed preservatives for mould and mycotoxin control: are they resilient enough? https://mycotoxinsite.com/feed-preservatives-for-mould-and-mycotoxins-control-are-they-resilient-enough/?lang=en.

Medina, A., Rodriguez, A. and Magan, N. 2015. Changes in environmental factors driven by climate change: effects on the ecophysiology of mycotoxigenic fungi. *Climate change and Mycotoxins,* Eds. Luis M. Botana & María J. Sainz.. De Gruyter, Berlin, Germany.

Medina, A., Akbar, A., Baazeem, A., Rodriguez, A. and Magan, N. 2017. Climate change, food security and mycotoxins: do we know enough? Fungal Biol. Rev. 31: 143-154.

Paterson, R.R.M. and Lima, N. 2010. How will climate change affect mycotoxins in food? Food Res. Int. 43: 1902–1914.

Perrone, G., Ferrara, M., Medina, A., Pascale, M. and Magan, N. 2020. Toxigenic fungi and mycotoxins in a climate change scenario: ecology, genomics, distribution, prediction and prevention of the risk. Microorganisms 8*:* 1496; https://doi.org/10.3390/microorganisms8101496

Rodrigues, I. and Naehrer, K. 2012. A Three-Year Survey on the Worldwide Occurrence of Mycotoxins in Feedstuffs and Feed. Toxins 4: 663-675; doi:10.3390/toxins4090663

Smith, M.C., Madec, S., Coton, E. and Hymery, N. 2016. Natural co-occurrence of mycotoxins in foods and feeds and their in vitro combined toxicological effects. Toxins 8: 94.

Streit, E., Naehrer, K., Rodrigues, I. and Schatzmayr, G. 2013. Mycotoxin occurrence in feed and feed raw materials worldwide: long-term analysis with special focus on Europe and Asia. J. Sci. Food Agric. 93: 2892–2899.

Vaughan, M., Block, A., Christensen, S.A., Allen, L.H. and Schmelz, E.A. 2017. The effect of climate change associated abiotic stressors on phytochemical defences. Phytochem. Rev. 17: 37–49.

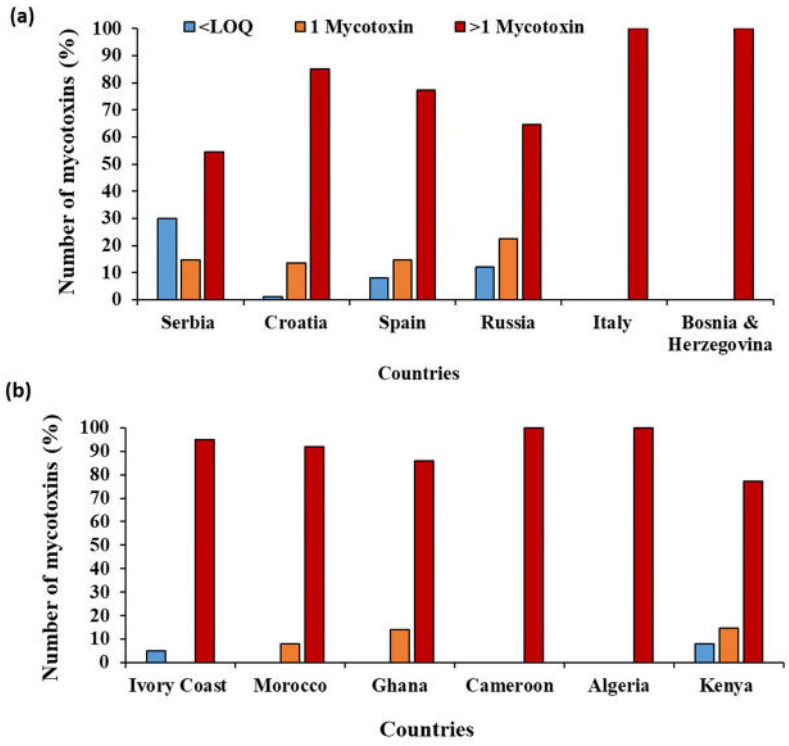


Figure 1. (a) Summary of the percentage (%) samples from different European countries contaminated with one or more mycotoxins, (b) Summary for maize samples from different African countries..

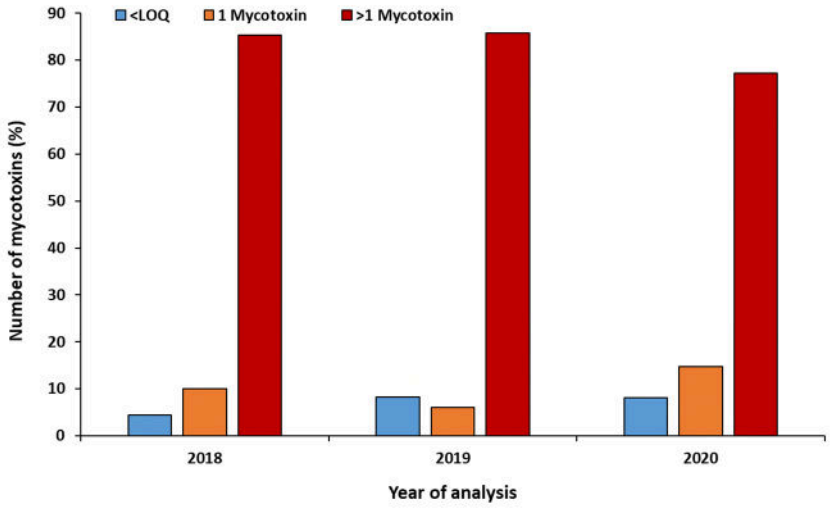


Figure 2. Comparison of the percentage of maize samples contaminated with no detectable mycotoxins, single or multiple mycotoxins globally in the three sampling years.

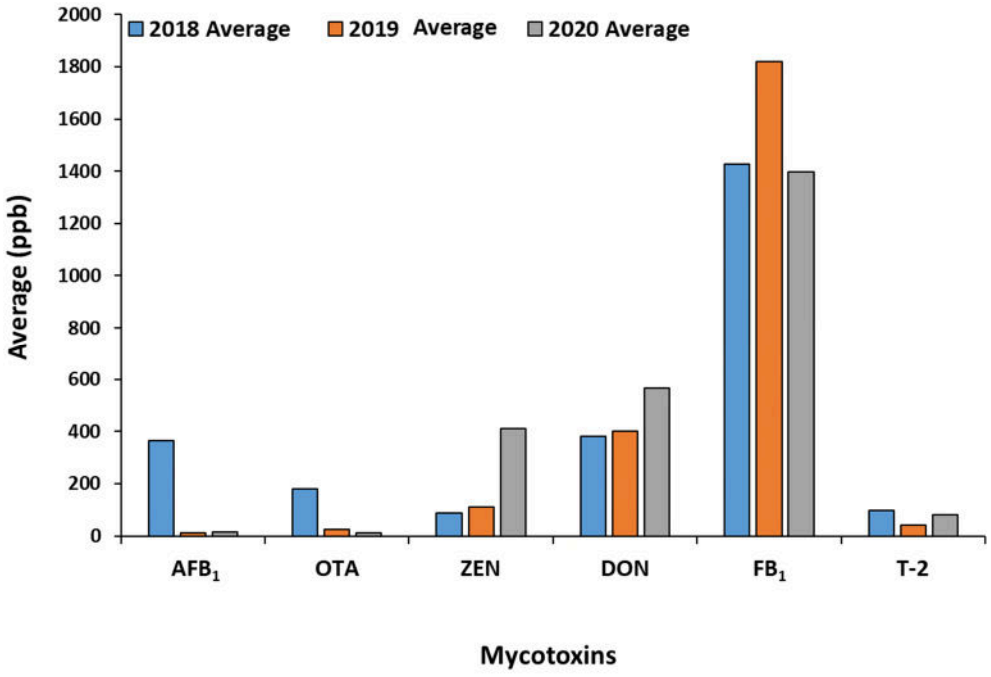


Figure 3. Comparison of the average contamination levels found for all samples in each of the three sampling years across all the four global regions.

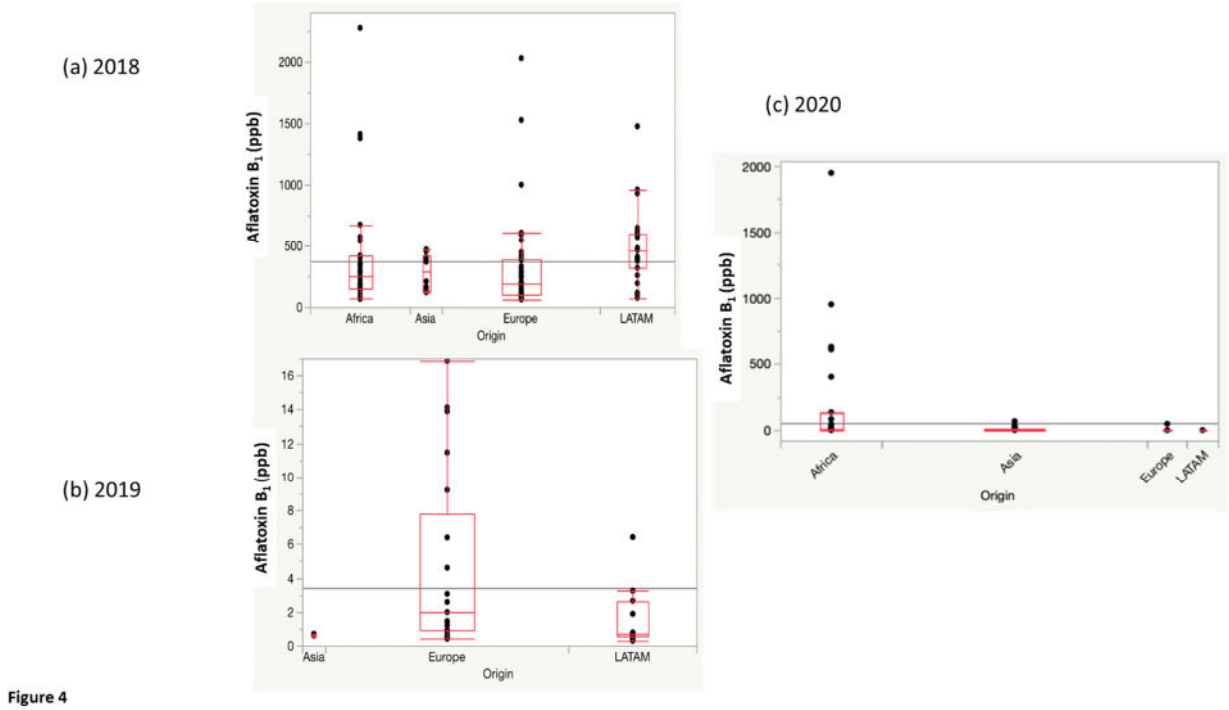


Figure 4

Figure 4. Box plots and means of the aflatoxin B_1 contamination of maize samples in four different global regions in (a) 2018, (b) 2019 and (c) 2020.

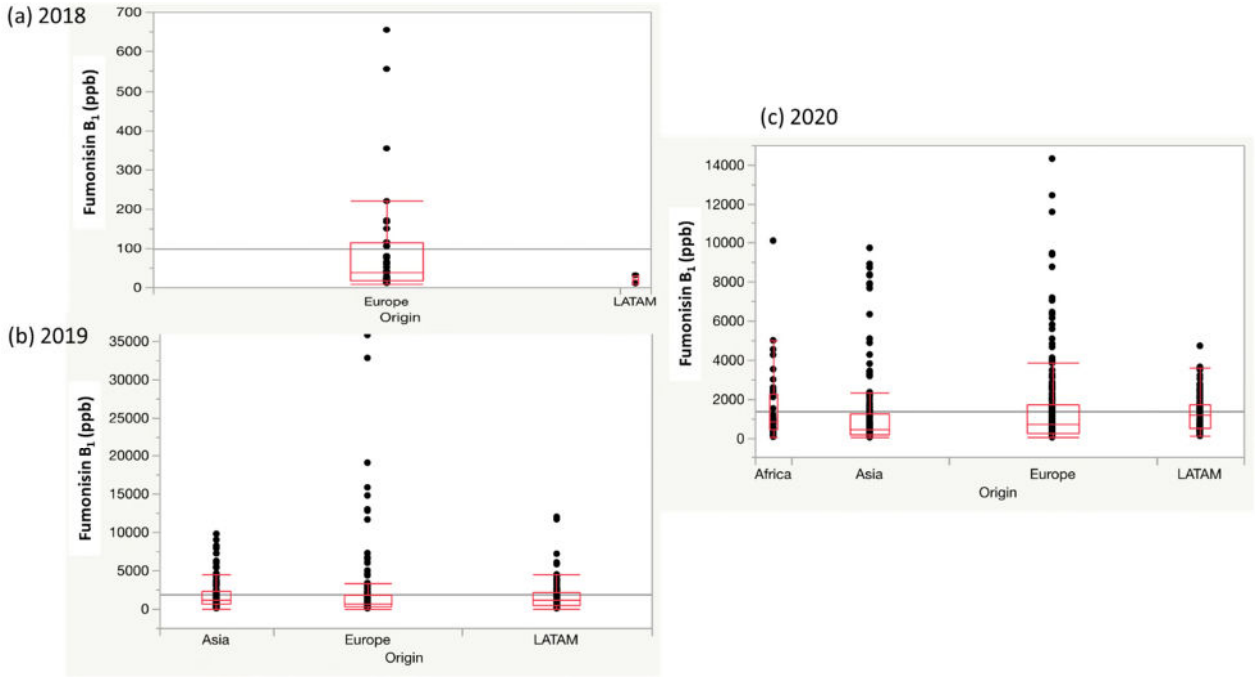


Figure 5. Box plots and means of the fumonisin B_1 contamination of maize samples in four different global regions in (a) 2018, (b) 2019 and (c) 2020.

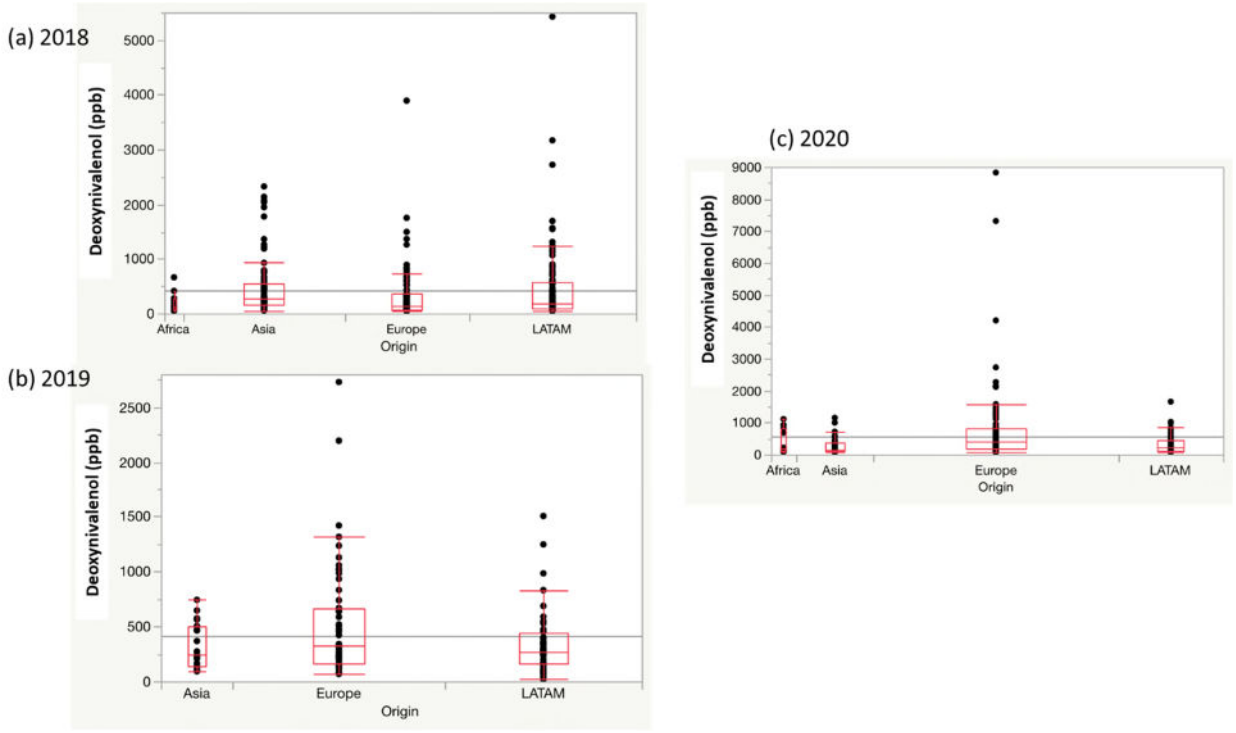


Figure 6. Box plots and means of the deoxynivalenol contamination of maize samples in up to four different global regions in (a) 2018, (b) 2019 and (c) 2020.

Table 1: Summary of the global contamination levels including the Mean, Maximum and Average contamination levels (PPB) and the relative number of positive samples based on the data from 20 countries globally in 2020.

	AFB_1	**OTA**	**ZEN**	**DON**	**FB_1**	**FB_2**	**HT-2**	**T-2**
AVG	54	11	411	566	1396	447	906	81
Max	1947	11	25731	8827	14314	4369	44303	638
Median	3	11	43	298	770	248	44	26
% of positives	16	0	16	29	85	69	9	4

Table 2: Average multi-mycotoxin contamination levels detected (ppb) in maize samples in each country and global region in 2020. Bold numbers are indicative of the highest average contamination levels found. <LOQ, Less than the Limit of Quantification.

	Countries	**AFB_1**	**OTA**	**ZEN**	**DON**	**FB_1**	**FB_2**	**HT-2**	**T-2**
Europe	Serbia	54	11	411	566	**1396**	**447**	906	81
	Croatia	4	11	968	872	**1121**	**340**	39	32
	Spain	<LOQ	<LOQ	<LOQ	<LOQ	**683**	**287**	<LOQ	<LOQ
	Russia	<LOQ	<LOQ	144	1181	**442**	**142**	109	132
	Italy	<LOQ	<LOQ	34	203	**4592**	**1015**	<LOQ	<LOQ
	Bosnia & Herzegovina	<LOQ	<LOQ	<LOQ	290	**1358**	**371**	45	68
Africa	Ivory coast	264	<LOQ	<LOQ	<LOQ	**2995**	**873**	175	<LOQ
	Morocco	<LOQ	<LOQ	58	116	**694**	**161**	10	<LOQ
	Ghana	1	<LOQ	<LOQ	<LOQ	**803**	**269**	<LOQ	<LOQ
	Cameroon	38	<LOQ	<LOQ	<LOQ	**2495**	**635**	<LOQ	<LOQ
	Algeria	<LOQ	<LOQ	<LOQ	87	**1128**	**262**	<LOQ	<LOQ
	Kenya	<LOQ	<LOQ	521	749	**2494**	**669**	<LOQ	<LOQ
LATAM	Dominican Republic	1	<LOQ	36	134	**1320**	**331**	<LOQ	<LOQ
	Colombia	<LOQ	<LOQ	31	283	**1472**	**313**	24	<LOQ
	Argentina	<LOQ	<LOQ	63	442	**1167**	**315**	<LOQ	<LOQ
	Peru	<LOQ	<LOQ	62	462	**1554**	**442**	<LOQ	<LOQ
Asia	Turkey	<LOQ	<LOQ	<LOQ	<LOQ	69	<LOQ	<LOQ	<LOQ
	Malaysia	<LOQ	<LOQ	45	184	**154**	**59**	<LOQ	<LOQ
	Vietnam	<LOQ	<LOQ	46	353	**737**	**185**	<LOQ	<LOQ
	Thailand	6	<LOQ	30	<LOQ	**2033**	**688**	22161	<LOQ



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Comparison of multiple mycotoxins in harvested maize samples in three years (2018-2020) in four continents

Raj, Jog; Farkaš, Hunor; Jakovevi, Zdenka; Medina, Angel; Magan, Naresh ...

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https://doi.org/10.1080/19440049.2021.2012600
Raj J, Farkaš H, Jakovevi Z, et al., (2022) Comparison of multiple mycotoxins in harvested maize samples in three years (2018-2020) in four continents. Food Additives and Contaminants: Part A: Chemistry, Analysis, Control, Exposure and Risk Assessment, Volume 39, Issue 3, March 2022, pp. 599-608

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