Chapter 5

Co-Occurrence of Mycotoxins and Its Detoxification Strategies

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Additional information is available at the end of the chapter

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Abstract

The contamination of foods and feeds by mycotoxins is significant problem worldwide that pose serious health hazardous effects in humans and animals. Risk arises from the fact that fungal species grow naturally in food and are difficult to eliminate. The presence of multiple mycotoxins (co-occurrence) in food products increases day by day and their natural co-occurrence is an increasing health concern due to the exposure of multiple fungal growth, which might exert greater toxicity than exposure of single mycotoxins. The presence of mycotoxins in food and feed are associated with health and reproductive issues, lower performance, and higher medical costs. Survey on co-occurrence of mycotoxins indicated that over 50% contaminated samples contained more than one mycotoxins and Asia faces a heightened risk of mycotoxins overall. There is a lack of information regarding co-occurrence of mycotoxins in food and animal feed. Face to this situation, the current chapter will be very informative to explore the incidence of multiple mycotoxins, their co-occurrence and the detoxification of mycotoxins using different techniques.

Keywords: mycotoxins, detoxification, food, feed, mitigation strategies

1. Introduction

Agricultural and Food commodities are highly susceptible to fungal growth in pre and post-harvest conditions as well as during storage. Different types of fungi especially belonging to the genus Aspergillus, Penicillium, Fusarium and Claviceps grow in crops, food and feed items throughout the world in favorable environmental conditions that ultimately produce a variety of toxins known as "Mycotoxins". The existence of more than one mycotoxin in food commodities is referred to as "Co-occurrence". Prominent mycotoxins occurring in agricultural commodities, include: aflatoxins (AFLA), ochratoxin A (OTA), zearalenone (ZEN), deoxynivalenol (DON), fumonisins (FUM) and T-toxin (T-2).

Foodstuffs are very prone to contaminants like bacteria and fungi in the pre-harvest and post-harvest stages especially, during storage when executed in poor conditions. These facts could be a cause of mycotoxins contamination in feeds and foods that pose serious health threat to animals and humans. Exposure of mycotoxins is a worldwide concern due to the globalization of food trade and its toxic nature. Some of these mycotoxins have hepatotoxic, nephrotoxic, immunosuppressive, genotoxic, teratogenic, and/or carcinogenic effects in human and animals. Consequently, mycotoxins have been a major concern of food regulatory authorities in all over the world about its exposure and hazardous nature in human and animals. Occurrence of multiple mycotoxins (co-occurrence) now gains much attention worldwide owing to its more toxic capacity (synergistic) as compared to single mycotoxin. According to the Biomin mycotoxins survey of 2015, more than 50% contaminated samples contained multiple mycotoxins in food and feed. Furthermore, co-occurrence of multiple mycotoxins increased from 2015 to 2016 and risk of mycotoxins is more heightened in Asia comparatively to other continents because of the favorable environmental conditions [1]. Frequency of mycotoxins produced by Fusarium fungal species comprising DON, FUM, ZEN are more frequent and co-occurrence of these mycotoxins can result severe detrimental impacts. The prevalence of mycotoxins in animal feed are associated with lower performance, poor growth, health and reproductive issues and higher medical costs for both animals and humans. Foods of animal origin are essential part of normal diet of everybody therefore; there is a need to assess co-occurrence of mycotoxins in animal feed and its counteracting strategies.

The worldwide contamination of agricultural commodities (crops, foods and feeds) with mycotoxins is a global concern that poses huge threat to animals and humans health. Contamination of foods by multiple mycotoxins not only has negative impact on health but also for global food security. Animal ingestion of contaminated feed with a variety of mycotoxins can result extensive damage to the liver, kidney and even induce cancer.

Mycotoxin contamination occurs widely in feedstuffs of plant origin, especially in cereals, seeds, fruits, fodder, agricultural feed or food intended for animal or human consumption [2–6]. Human beings are exposed by the effects of these toxins when used the foods of animal origin like milk, meat and eggs [7]. Furthermore, mycotoxins lead to massive economic losses, including loss of livestock production, loss of forage crops and feeds, and loss of human and animal life [8]. At the moment, different mycotoxins have been identified globally, and food regulatory authorities focused mainly on the potent and frequently present mycotoxins that have proven lethal. In continent Asia, ZEA, DON and FUM mycotoxins produced by fungal specie Fusarium are frequently present in animal feed elicit great health concerns to animals and humans due to their toxic effects [9, 10].

2. Co-occurrence of mycotoxins

Contamination of food commodities with fungus is commonly seen in every part of the world and it diverge from region to region depending upon the food products and environmental conditions like temperature & humidity. The diversity of fungi species grown on food products under various ecological conditions were observed that produce particular mycotoxins but it can occur singly or in multiple (co-occurrence). The co-occurrence of mycotoxins can affect both the production of mycotoxin and the toxicity of the contaminated material. Mycotoxins risk not only threatens the people living in tropical climate countries but it also be hazardous for people of temperate climates countries like United States of America and Europe.

During the last 10 years, incidence of multiple mycotoxins (AFLA, OTA, ZEN, DON and FUM) produced by different fungal species particularly Fusarium and Aspergillus genus have been reported in cereals from different countries [11–19]. Natural co-occurrence of mycotoxins in cereal-based infant products was also observed from Tunisia, where 32% samples were detected contaminated with multiple mycotoxins [20]. It was noticed that Fusarium fungal species can produce different mycotoxins simultaneously, and their co-occurrence became an important issue in the past years for risk assessment [21–23], these multiple toxins can have additive, antagonist or synergic effects [24, 25].

Global occurrence of mycotoxins in cereals and processed food products indicated that five major mycotoxins namely AFLA, OTA, ZEN, DON, FUM are mostly found during the past 10 years in these food stuffs. FUM mycotoxins were maximally detected (61%) in these cereals and processed foods, DON were identified in 58% samples and AFLA were noticed in 55% samples. However, contamination of ZEN and OTA in these food items were 46% and 29%, respectively [26]. It was also noticed that contamination of mycotoxins in processed food products were relatively less than the cereal grains. More than one mycotoxin can be produced by single of numerous fungal species and it may found in different combinations in food stuffs which may exert additive, antagonistic and synergistic effect in animals and humans.

Multiple occurrence (co-occurrence) of mycotoxins in European region revealed that AFLA and OTA mycotoxins were mostly found (24%) whereas the prevalence of other mycotoxins was comparatively less (Approx. 10%). Similarly, the co-occurrence of AFLA and OTA was highly detected (35%) in African countries and the occurrence of other combinations was comparatively fewer (29%). Conversely, in Asia FUM and AFLA combination was highly noticed (78%) and the prevalence of similar combination (FUM + AFLA) was found (50%) in South America, while FUM + ZEA was second most observed combination (25%) among other mycotoxins. In short, co-occurrence of AFLA and FUM mycotoxins was highly observed in Asia, Africa and South America [1, 15, 27–44].

Co-occurrence of different mycotoxins was noted in Solvak and observed the highest correlation between DON and Nivalenol toxins. On the other hand, no correlation between ZEA and DON was noticed [45].

According to the latest Biomin mycotoxin Survey (2016), DON and FUM are the most commonly found mycotoxins in feedstuffs, analyzed in 4027 animal feed samples and feed ingredients collected from >50 countries. The major food items collected in this survey include corn, wheat, barley, rice, soybean meal, corn gluten meal, dried distillers grains (DDGS) and silage, that are used in feed among others [46].

Out of all samples, DON were detected in 73%, FUM were found 64 and 53% samples were contaminated by ZEN. Whereas, contamination of AFLA were detected in 25%, T-2 toxins in 18 and 12% samples were found contaminated with OTA, shown in **Figure 1**.

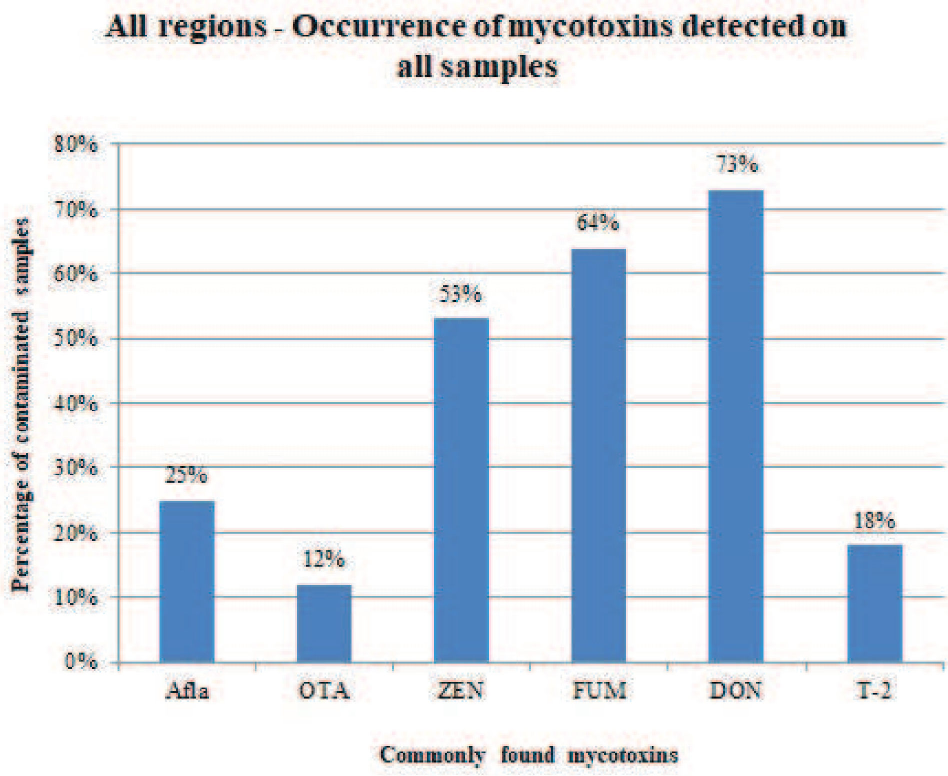

Figure 1. Worldwide occurrence of mycotoxins in food and feed surveyed in 2016.

According to the Biomin (An animal nutrition company) survey of 2017, 96% of all samples contaminated with at least one mycotoxins however, 75% samples contained two or more mycotoxins (**Figure 2**). However, survey of mycotoxins in poultry feed depicted that two-thirds (66%) poultry feed samples contained two or more mycotoxins and noted the highest mycotoxins risk (80%) in Asia comparatively to other continents [47].

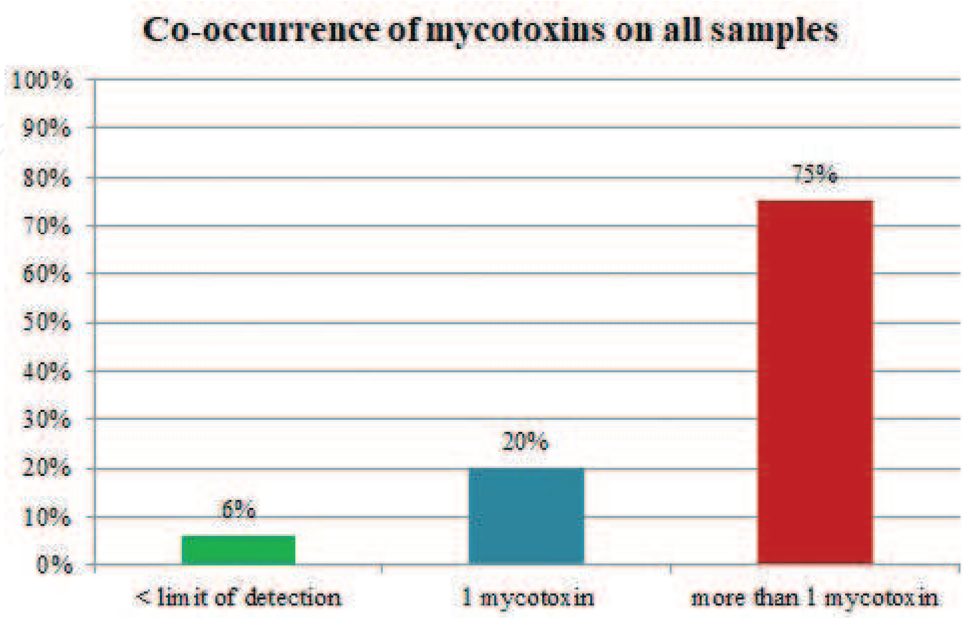

Figure 2. Co-occurrence of mycotoxins in food and feed commodities worldwide in 2017.

Worldwide contamination of mycotoxins in food commodities are represented in **Table 1** (BIOMIN World Mycotoxin survey, January to September, 2017).

It observed that, 84% of animal feed samples contaminated with single mycotoxins however more than 50% samples contaminated with several mycotoxins [1].

Multiple mycotoxin contamination may responsible of additional problems, like synergistic effects that exaggerate the more deleterious consequences for animals. The combination of DON and ZEN is reported synergistic pairing as stated by Dr. Timothy Jenkins who is product manager mycotoxins at animal nutrition company Biomin: "The effect of ZEN on reproductive systems can sometimes be worsened by the presence of DON."

2.1. Occurrence of mycotoxins in plant meals

2.1.1. Risk to aquaculture

The tendency and the economic need to replace the expensive fishmeal (an animal-derived proteins) with the cost-effective plant-based protein sources, has increased the impact of mycotoxins contamination in aquaculture feeds [48]. Mycotoxins have negative impact not only on the performance and health of terrestrial livestock species but it can also be lethal for aquaculture species [49, 50]. Mycotoxins effects even become more important in aquaculture sector due to the escalating cost of fishmeal and the necessity to pinpoint and use more cost-effective protein sources such as plant protein or other plant based products. Toxic fungal metabolites that probably affect the aquaculture species are produced mainly by Fusarium, Aspergillus and Penicillium species. Toxins produce by these fungal species are known to be carcinogenic (e.g., AFLA, OTA, FUM), hepatotoxic (e.g., AFLA), nephrotoxic (e.g., OTA), estrogenic (e.g., ZEN), dermatotoxic (e.g., trichothecenes) and immunosuppressive (e.g., AFLA, OTA and T-2 toxin).

According to the latest Biomin survey of 2107, it was found that Fusarium mycotoxins were the most prevalent mycotoxin worldwide among the other mycotoxins (AFLA, OTA, ZEN, DON, FUM and T-2 toxins) followed by AFLA. Analysis were performed in 8345 plant meal samples including corn, corn DDGS, corn gluten meal, wheat, wheat bran, rice, rice bran and soybean meal for detection of mycotoxins collected from different regions all over the world [47, 51, 52]. Corn gluten meal and corn DDGS which are commonly used in aquaculture feed were found highly contaminated with DON and FUM.

Some marine species (especially rainbow trout and *Litopenaeus vannamei*) are known to be sensitive for FUM that may cause variation in sphingolipid metabolism and inducing cancer [53–55]. FUM obstruct the sphinganine (sphingosine) N-acyl transferase (ceramide synthase), a key enzyme in lipid metabolism, resulting in the disruption of this pathway. DON, was particularly found most prevalent mycotoxins in rainbow trout (*Oncorhynchus mykiss*) responsible for decreases in growth, feed intake, feed efficiency and energy utilization [56].

Co-occurrence of mycotoxin was also noted in plant meals commonly used in aquaculture potentially leading to synergistic or additive effects. Approximately, 74% samples were contaminated with two or more mycotoxins as depicted by latest Biomin survey (2017) that can lead to significant economic impacts in the aquaculture sector [47].

Continents	Occurrence of Mycotoxins											
	AFLA		ZEN		DON		T-2		FUM		OTA	
	% contaminated samples	Average of positives (ppb)	% contaminated samples	Average of positives (ppb)	% contaminated samples	Average of positives (ppb)	% contaminated samples	Average of positives (ppb)	% contaminated samples	Average of positives (ppb)	% contaminated samples	Average of positives (ppb)
South and Central America	25	8	49	118	84	898	26	39	77	3227	4	3
North America	4	19	51	226	78	1112	3	41	60	1829	7	5
Europe	18	4	52	54	72	448	35	37	50	582	27	9
Asia	34	63	48	202	78	788	3	55	82	1026	27	8
Middle East	13	4	53	134	69	719	11	25	68	873	30	2
Africa	12	19	38	130	71	510	1	26	66	1221	14	4

Table 1. Worldwide contamination of mycotoxins in food commodities (2017).

2.2. Mycotoxin's effect in poultry

Prevalence of coccidiosis is common disease in broilers responsible for big loss (US$5–6 billion) globally each year. Coccidiosis is a renowned influencing factor for necrotic enteritis and predicted to cost poultry sector US$3 billion per annum. Existence of mycotoxins in poultry feeds aggravates coccidiosis in poultry; even its small amount can increase Eimeria infection and disease sternness in Poultry. Stakeholders in poultry sector always looking to minimize the effect of coccidiosis on their flocks.

Factors responsible for mycotoxins' intensification of coccidiosis include mycotoxin contamination in feed, higher immunosuppressive effects on broilers, and the possible synergistic effects between mycotoxins.

Aftereffects of FUM and DON toxins can be worse even if present in small concentration allowed by US and European guidelines. Permissible levels set by US FDA for FUM and DON are 30 and 10 ppm for poultry feed, respectively. However, allowed limits adapted by European regulations for FUM (20 ppm) and DON (5 ppm) toxins in poultry feeds are somewhat more stringent relatively to American regulations. FUM and DON may have some synergistic effects known to inhibit some vital functions of cells, interrupt intestinal cells that work as a barrier between pathogen and bodies of bird [57].

2.3. Impact of mycotoxins in livestock

Mycotoxins residues in food of animal origin like milk, meat (tissues) and eggs are frequently reported in every region. AFLA not only evidenced as hepato-toxic but it also have some other toxic effects like carcinogenic, mutagenic and teratogenic properties for humans as well as animals. Evidence of AFLA residues has been found so far in milk, meat tissue and eggs. Most importantly AFLA residues frequently found in milk as AFLA M1 and M2, which are the metabolites of AFLA B1 and B2. These toxic metabolites are produced when dairy animals fed on AFLA contaminated feed. It was noticed that concentrated animal feed (e.g., cotton seed cake, maize oil cake) was mostly found contaminated with huge level of mycotoxins. Conversion of AFLA B1 and B2 into the AFLA M1 and M2 in dairy animals are linearly dependent on the intake of contaminated feed and the toxin elimination totally from animal body usually finished 3 days after withdrawal of contaminated feed. The ratio between ingested and excreted AFLA is usually 1–3%, but it can be 6% presuming worst case scenarios [58–60]. Carry-over (or residues) of mycotoxins especially AFLA in milk is highly focused as it's routinely used by everyone in every part of the world especially children's and infants [61].

According to the latest mycotoxin survey it was noted that the risk levels are certainly elevated in many regions of the world. Globally, the average risk level was 62%, ranged from 46% (in Middle East) to 80% (in Asia). In light of the latest mycotoxin results, Dr. Timothy Jenkins, Mycotoxin Risk Management Product Manager at Biomin states that "livestock producers and stakeholders should be vigilant in monitoring their feed and feed ingredients for mycotoxins," [62].

Approximately, two-thirds contaminated samples contained more than one mycotoxins in animal feed and it observed that particular type of mycotoxins and its concentration vary due to climate, weather patterns and seasonal shifts, etc."

2.4. Climate change and its impact on mycotoxins

Temperature and humidity are two main factors that boost up the fungal growth and production of mycotoxins. As the world climate fluctuating, the pattern of mycotoxins contamination also vicissitudes, accordingly. The Intergovernmental Panel on Climate Change (IPCC) reported (2014) the different global warming projections and predict that global temperatures may increase by up to 4.8°C in the year 2100. Climate change will definitely affect the agriculture sector, variations in temperature and humidity may affect the efficacy of pesticide and fungicide applications, life-cycle of insects that promote fungal infections of crops may alter as well. On the other hand, fungal species may displace by other more aggressive or virulent fungi due to change in climate. If temperature begins to rise in upcoming years then the highest mycotoxin risks will be observed not only in countries with tropical climates but also in countries with temperate climates, such as parts of Europe and the United States of America [63–65].

3. Counteracting strategies

Dr. Timothy Jenkins stated that "Avoidance of contaminated food & feed and attention to storage conditions are logical approaches to reducing the mycotoxin risk."

Prevention and detection is the reliable approach with regular application of mycotoxin absorbents to minimize its lethal effects [62].

3.1. Decontamination or detoxification of mycotoxins

To minimize the level of mycotoxins in food and feed, several efforts have been made both In-vitro (in raw material and processed food) and In-vivo (within animal body). Generally, mycotoxin removal strategies can be divided in two phases, pre-harvest treatment to control or inhibit the growth of fungus and post-harvest remediation of contaminated commodities. However, preventive approaches such as plant disease management, good agricultural practices and adequate storage conditions might control the mycotoxin levels in food commodities but are not always sufficient to eradicate mycotoxins completely. Therefore, economically suitable and practically applicable approaches are required to decontaminate or detoxify the mycotoxins in food chain [66–68].

Ideally, the detoxification strategy should have the following properties: (1) inactivate, destroy or remove mycotoxin, (2) non-toxic, (3) easy or handy, (4) economical, (5) retain the nutritive value. In addition to these properties, the process should be field oriented and inexpensive.

Degradation or detoxification of toxic fungal metabolites may be an ideal approach to remove or decontaminate the toxins form food and feed products if the process not alters its nutritional composition. As most mycotoxins exhibit a high chemical stability, development of degradation or decontamination methods compatible with food quality standards is a challenging task and researchers still working to optimize the more efficient and appropriate process. Over the last decades biological, chemical and physical strategies for the degradation and decontamination of mycotoxins were investigated extensively [67, 69, 70]. Physical tactics mainly include washing, heating and irradiation were studied. Different mycotoxin binders (organic and mineral) were tried for the removal of toxic metabolites and considered the more effective removal process of mycotoxins from foodstuffs. More recently biological, enzymatic and chemical degradation procedures were also investigated and found effective. Chemical degradation processes comprise, application of acids, bases, chlorinating agents, oxidizing agents, formaldehyde and ammoniation were studied in food commodities [67, 70].

3.2. Physical methods of degradation

Removal of mycotoxins by physical approaches comprised sorting, dehulling, cleaning, milling, heating and irradiation or combinatorial methods. Organic, inorganic or mineral binders are also being tried for the decontamination of mycotoxins, although these adsorbing binders have some promising features, some may have adverse nutritional effects due to binding capacity of minerals and vitamins [71–82].

Technical plasma is a latest and innovative physical approach for the removal of mycotoxins from food and feed. Latest application of cold atmospheric pressure plasma (CAPP) in demolition of plant pathogens indicated that the process is appropriate for sensitive biological stuffs. Different types of plasma were used effectively for inhibition of fungal growth and for the decontamination of mycotoxins [83–88]. Recently, studies indicated that CAPP capable to degrade the mycotoxins in cereals and grains very efficiently [89].

3.3. Chemical methods of degradation

Degradation of mycotoxins can also be attained via chemical reactions. Different chemicals processes like hydrolysis, ammoniation, ozonation, peroxidation, and the use of hydrochloric acid, ascorbic acid, sodium bisulfite, hydrogen peroxide, formaldehyde, ammonia, ammonium hydroxide and are reported in different studies to decontaminate the mycotoxins in food [90]. However, chemical degradation does not fulfill the recommended criteria of FAO because some chemicals produce toxic metabolites and reduce the nutritional values of foodstuffs [91–93].

3.4. Biological degradation

Physical and chemical degradation methods have some confines such as losses in the nutritional value, limited efficacy and safety issues, in addition of these shortcomings costly equipment required to accomplish these techniques. Biological degradations are considered superb as it works under environment friendly conditions. Microbial degradations of mycotoxins are also preferred, since it can be a specific, efficient, environment friendly, irreversible and non-toxic. Degradation of mycotoxins using fungi are not considered a best choice because of its complicated procedures and long incubation time. However, bacterial degradation of mycotoxins has promising applications due to the high degradation rate and wide reaction conditions. Detoxification process using probiotic bacteria is also trying, which can be directly applied in the foodstuffs. Furthermore, the use of enzymes appears to be an auspicious choice for detoxification of mycotoxins [94, 95].

4. Conclusions

The current chapter contributes to increase the knowledge concerning the co-occurrence of mycotoxins in food commodities. It was noticed that co-occurrence of mycotoxins were exist in food and feed items of almost every country however, the occurrence vary from region to region. Prevalence and frequency of the mycotoxins are correlated with the locality and weather parameters (rainfall, humidity and temperatures). It would be more important that legislation of respective countries should be more stringent to protect the consumers from the lethal effects of mycotoxins.

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Conflict of interest

The author declares that there is no conflict of interest.

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