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FOOD CONTAMINANTS INCIDENCE ON CEREAL VALUE CHAIN, A MINIREVIEW

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Abstract

In order to ensure effective protection of public health, it is mandatory that the level of food contaminants present in the cereal value chain to be below the maximum level established by the regulations in force, and not to be placed on the market or used as ingredients or mixed with other food products if they don't comply with these limits. Cereals can be contaminated through exposure to polluted environment, mycotoxins and heavy metals being a significant source of contamination. These contaminants are considered a public health concern, having an impact on the food security and the economy of many countries, their monitoring being important. There are certain situations in which food is contaminated with mycotoxins and heavy metals, but which can hardly be controlled at all or is only poorly controlled. Therefore, the aim of this review is to offer an update of the incidence of these contaminants on the cereal value chain, the accumulation in the cereal and cereal-based products, the mitigation of these contaminants and the impact on the human health.

Key words*: cereals, contamination, food safety, heavy metals, mycotoxins.*

INTRODUCTION

Food safety cannot become a real fact unless it constitutes a responsibility of all those involved in the food field, from professionals to consumers. Along the food chain, various procedures and control mechanisms are implemented, which ensure that the food that reaches the consumer's table is edible and that the risk of contamination is reduced to a minimum, so that the population is healthier as a result of the benefits brought by safe and healthy food.

Cereals are currently the primary source of carbohydrates in the human diet worldwide. The Food and Agriculture Organization (FAO) forecasted that world grain use in 2021/2022 will reach a record level of 2809 million tons. The FAO forecast for total wheat utilization is 777 million tons, which was 2.4% (18.5 million tons) higher than in 2020/2021 (FAO, 2021). Only three of these (rice, maize and wheat) provide about 60 percent of the world's food energy intake (FAO, 2017).

Heavy metal pollution became a global problem, degrading environment and posing a serious threat for the human health. The underlying causes of this persistent problem seem to be the increased rate of urbanization, land use changes and industrialization, especially in densely populated countries and under developed ones (Zhang et al., 2019).

Food contamination with heavy metals, including cadmium (Cd), lead (Pb) and arsenic (As), is frequent in the agricultural regions and is a major concern worldwide (Naseri et al., 2015; Wang et al., 2021). Many studies have shown that even low levels of exposure to heavy metals could lead to serious health problems (Tchounwou, 2003; Khan et al., 2015; Abtahi et al., 2017; Al-Saleh et al., 2017). Also, by eating contaminated food with heavy metals for a long period of time could lead to many types of diseases, such as cancer, leukaemia, genetic toxicity and so on (Nejabat et al., 2017). Worldwide, about 600 million people are affected annually by contaminated food with heavy metals (World Health Organization, 2015).

Mycotoxins are considered to be part of the most significant food contaminants in terms of impact on public health, food security and the economy of many countries. They are found in a wide variety of plant products before, during and after harvest. Mycotoxins naturally present in various food products constitute a serious food safety problem, especially in certain regions of the globe where climatic conditions are favorable to molding or agricultural standards are poor. Due to the toxic action on the human and animal body (De Ruyck et al., 2015), they negatively influence the quality of the food; in addition, the economic losses they generate are not negligible. Currently there are 300-400 mycotoxins. Among them, aflatoxins, ochratoxins, trichothecenes, zearalenone and fumonisins are the most studied due to their effects on the human and animal health and their special agro-economic importance.

The main genera of fungi producing mycotoxins are *Aspergillus*, *Penicillium*, *Fusarium, Alternaria* and *Claviceps*. A certain fungus can produce several mycotoxins and a given mycotoxin can be produced by several fungi; this fact can lead to the synergism phenomena and potentiation of the toxic action.

Chemical origin of mycotoxins is very diverse, some derives from amino acids (ergot alkaloids, aspartic acid, acid cyclopiazolic, slaframine, glioxin, roquefortin, sporodesin), some are polyketoacids (aflatoxins, ochratoxin, patulin, citrinin, sterigmatocystin, zeararlenona), and others are their terpens derivatives (fusar enone, deoxynivalenol varidin, T-2 toxin). Mycotoxins are formed at the end of the exponential phases and at the beginning of stagnation phases of mould growth.

RESULTS AND DISCUSSIONS

Heavy metal contamination of cereals and derivative products

Contamination of crop plants may occur either through contact with contaminated soils, or through air pollution. The soil, as the fundamental support of food cultures, can be contaminated with heavy metals from different sources, such as irrigation with waste water, industrial effluents, mining activities and poor agricultural practices, as well as incorrect waste disposal. Heavy metal levels in soil can be raised also by using certain types of fertilizers, including organic manure, pesticides and herbicides which contain such compounds.

Air can also be a source of contamination representing a vehicular path for heavy metals and their deposition on the soil or plants (eg. lead emission from automobiles). Absorption of heavy metals by plants from contaminated areas depends not only on soil properties, such as temperature, moisture content, organic matter, pH and availability nutrients, but also on plant species.

Kumar et al. (2022) investigated the level of contamination with heavy metals and metalloids in irrigation water, soil and cereal plants in the area of Lucknow city from India. The highest concentration of these compounds was found in irrigation water, while in the majority of soils the levels were close to the maximum allowed concentration. Concentration levels significantly higher than the maximum allowed limits were found in the aerial parts of the studied plants.

A study conducted by Ali & Al-Qahtani (2012) showed exceeding limits values for some heavy metals' concentration in various vegetables, including, cereals, in four areas from Saudi Arabia. The highest amounts of heavy metals were determined in leafy vegetables, mostly for those collected from middle and eastern districts.

Pirsaheb et al. (2021) conducted a study to analyse the presence of chromium (Cr), cadmium (Cd), lead (Pb), nickel (Ni), copper (Cu), zinc (Zn), mercury (Hg) and arsenic (As) in wheat, rice, peas, split peas, lentil, corn and bean, which are high consumed cereals, from the market of Kermanshah city from Iran. The results of the study showed that the overall concentration was of 27.3 μg/kg for Cr, 6.85 μg/kg for Cd, 87.7 μg/kg for Pb, 21.2 μg/kg for Ni, 147 μg/kg for Cu, 459 μg/kg for Zn, 2.03 μg/kg for Hg and 1.80 μg/kg for As, all values reported to the dry weight.

Different cereal grains from Jos market (Nigeria) were analysed by Ikem et al. (2023) in terms of elemental composition and the results showed below allowed limit values for daily (for example Zn, Cu, etc.) and weekly intakes (for example Hg, Pb, Cd, etc.). Although the hazard index showed no hazard for adult consumers, the cumulative cancer risk (because of Pb, Cr, As and Ni) presented higher values that the established standard (10^{-5}).

A study performed by Wei & Cen (2020) aimed at determining heavy metal contamination and dietary exposure in different types of legumes, cereals and their products from 16 districts in Beijing, China. The results of the study registered daily exposure doses of 0.0772 μg kg d^{-1} for Cd, 0.0051 μg kg d^{-1} for Cr, 0.3350 μg kg d^{-1} for Pb, 0.0119 mg kg d^{-1} for Cu, 0.0417 mg kg d^{-1} for Fe, 0.0367 mg kg d^{-1} for Mn and 0.0505 mg kg d^{-1} for Zn. In this study, the hazard index values showed that long term consumption could lead to non-carcinogenic adverse effects for the studied area residents.

A mining area from Nanyang Basin (Henan Province, China) was studied from heavy metal presence in soils and crops by Dong et al. (2023). Varying degrees of pollution were determined in crop roots. In maize fields, heavy metal concentration was higher compared to wheat fields and Cd gives the highest pollution in both fields.

Singh et al. (2022) investigated heavy metal concentration in vegetables and crops from an area in India where untreated wastewater has been discharged for a long period of time. The results showed exceeded safety limits in *Beta vulgaris* L. (5.35 μg/g DW for Cd and 58.41 μg/g DW for Zn) and *Triticum aestivum* L. (16.02 μg/g DW for Cr, 27.97 μg/g DW for Cu and 40.74 μg/g DW for Ni), also having the highest values.

Absorption and translocation of heavy metals in cereals

The degree of absorption of heavy metals varies between different cereal species, some crops showing a greater accumulation than others. This accumulation may have serious implications on consumers health because extended exposure to high levels of these toxic metals can lead to different health problems. The current maximum levels for heavy metals and mycotoxins in foods like cereals and derived products, are regulated according to Commission Regulation (EU) 2023/915.

The highest lead concentrations were identified in a rice sample in Thailand at 0.419 mg/kg, followed by Iran with a rice sample at 0.297 mg/kg and a sample of infant rice cereal from Spain, having a lead concentration of 0.116 mg/kg. Regarding cadmium, the highest concentration was identified in a rice sample from India with a concentration of 0.190 mg/kg, followed by a rice sample from Malaysia with a cadmium concentration of 0.160 mg/kg. For Arsenic, the highest concentration was identified in a rice sample from Nepal with a concentration of 0.180 mg/kg.

Mycotoxin contamination of cereals and derived products

Cereals along with their producs, nuts, fruits and also feed, present high risk of mycotoxin contamination, such as deoxynivalenol (DON), aflatoxin B1 (AFB1), nivalenol (NIV), zearalenone (ZEN), fumonisin Bs (FBs), ochratoxin A (OTA) and T-2 toxins, which are secondary metabolites produced by some fungi (Terzi et al., 2014; Sirbu et al., 2020; Khodaei et al., 2021; Tan et al., 2023), which are further presented.

Aspergillus genus produces aflatoxins: B1, B2, G1, G2, M1, M2, ochratoxin A, sterigmatocystins and cyclopiazonic acid.

The genus *Penicillium* produces patulin, citrinin, penitrem A, rubratoxin and other substances as well known as ochratoxin A and cyclopiazonic acid.

The genus *Fusarium* produces trichothecins and deoxynivalenol (DON, vomitoxin), 3-acetyldioxynivalenol, 15-acetyldioxynivalenol, nivalenol, zearalenone, fuminizins and moniliformin as well as other potentially toxic substances and unknown toxic substances.

The genus *Alternaria* produces a number of biologically active compounds such as tenuazoic acid, ethylmetal alternariol.

The exposure to mycotoxins can occur under different situations, such as food, working area or various environments. However, the ingestion of contaminated food (especially cereal and nut based foods) represents the main cause for mycotoxicosis (Karlovsky et al., 2016). The types and levels of mycotoxins in human diets vary depending on different factors such as geographic location, type and amount of grain and grain based products, spices and other ingredients, but also cooking or processing methods.

For example, in Africa and South America the main cereal in the human diet is maize, in North America and Europe wheat is preferred and rice in Asia. Regarding those cereals, the main mycotoxins present are aflatoxin, ochratoxin and deoxynivalenol. The level of mycotoxins can be reduced during food or feed

processing and/or cooking, resulting products that are relatively safe to eat (Paterson et al., 2010).
The contamination with mycotoxins can happen both in the field and during storage (Streit et al., 2013; Smeu et al., 2017). The climatic conditions, especially tropical and subtropical ones, are thought to be the main factors for aflatoxin occurence, above all in developing countries, where there is insufficient food and the conditions for storage are poor (Paterson et al., 2010). Aflatoxins (AF), deoxynivalenol (DON), fumonisins (FUM), ochratoxin A (OTA) represents the main identified mycotoxins, especially in maize grains (Streit et al., 2013).
The Food and Agriculture Organization of the United Nations (FAO) estimated that before 1985, about 25% of the world's food will have in its composition some form of mycotoxins (CAST. Mycotoxins, USA, 1989). An extensive review of the literature found the global prevalence of mycotoxins in food crops to be as high as 60-80%, although data vary widely, depending on a lot of factors like mycotoxin type, methods of analysis and results reporting (Eskola et al., 2020). According to this survey report, at a global level, the most frequent determined mycotoxins are deoxynivalenol (65%), fumonisins (64%) and zearalenone (48%) in the grain harvested in 2020 (Biomin World Mycotoxin Survey, 2020). Higher contents of AFB1 and OTA are often present in cereals produced in developing countries, which also have higher levels of mycotoxins, generally above regulatory limits. Some of these mycotoxins can be taken into cooked or processed food and food products when using highly contaminated cereals as ingredients, mainly due to the fact that common processing and cooking methods like sorting, cleaning, cutting, grinding, baking, etc.) can't eliminate them; however, these methods could significantly reduce their content (Karlovsky et al., 2016).
A study conducted by Andrade et al. (2020) focused on determining the probabilistic dietary risk in respect to mycotoxins for the Brazilian population. The results showed that for the general population and teenagers, safe limits were exceeded in respect to chronic exposure for fumonisins and DON.
Huang et al. (2022) performed a screening for mycotoxins in different stored cereals from Shanghai, China. The results showed the presence of 46 mycotoxins and their metabolites in 138 stored samples. Some of them were reported in cereals, fact that present a potential health risk for both humans and animals.
Quinoa and kaniwa (pseudocereals) were analysed by Ramos-Diaz et al. (2021) in comparison with cereals (wheat, oat, barley) in two areas, namely North Europe (Latvia, Finland, Denmark) and South America (Peru, Bolivia). The aim of the study was to determine mycotoxin contamination in these products. The results showed lower mycotoxin contamination in South America for the pseudocereals and higher in cereals compared to North European samples. The identified analytes presented various levels and were mainly produced by fungal strains belonging to *Aspergillus* spp., *Fusarium* spp. and *Penicillium* spp.
The toxic effects of mycotoxins can affect all humans, but infants are more susceptible to these effects, mainly due to their different physiology (lower body weight, high metabolic rate, etc.) (Piacentini et al., 2019). Ji et al. (2022) screened 820 samples of cereal-based foods for infants in China and the results showed the presence of deoxynivalenol, enniatin A, tenuazonic acid, enniatin B, enniatin B1, enniatin A1, zearalenone, alternariol, alternariol nonomethyl ether, ochratoxin A, fumonisin B1 and fumonisin B2 in low levels in the tested samples. A greater variety of mycotoxins was determined in wheat based products compared to rice based products.

CONCLUSIONS

Heavy metal contamination of cereals is a great challenge nowadays, which is extended to the entire world, having negative effects on human health and not only. Therefore, there is a need for technology development in order to remove heavy metals from food and feed, assuring this way the safety and security of all populations. Regarding mycotoxins exposure, it seems to be unavoidable. Mycotoxin contamination of grain will continue to be a major challenge for grain producers as well as for food and feed industrials as grain can be contaminated with fungi both in the field and after harvest, especially during storage. Therefore, it is very important to implement mycotoxin control strategies before and after harvest to reduce the initial degree of contamination.

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