DIOXINS IN MEAT: FROM ENVIRONMENTAL POLLUTANTS TO HUMAN EXPOSURE

Ivica Kos[1] – Miroslav Jůzl[2] – Ivan Vnučec[1] – Jelka Pleadin[3] – Darija Bendelja Ljoljić[1] Paweł Konieczka[4] – Tamara Stamenić[5] – Viktorija Pralas[1]

[1]Division of Animal Science, Faculty of Agriculture, University of Zagreb, Svetošimunska 25, 10 000 Zagreb, Croatia

[2]Department of Food Technology, Faculty of Agrisciences, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

[3]Croatian Veterinary Institute, Savska cesta 143, 10 000 Zagreb, Croatia

[4]Faculty of Bioengineering, University of Warmia and Mazury in Olsztyn, Michała Oczapowskiego 2, 10-719 Olsztyn, Poland

[5]Institute for Animal Husbandry, Autoput Beograd - Zagreb 16, 11080 Belgrade, Serbia

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ABSTRACT

Dioxins are highly toxic, persistent pollutants that mainly originate from industrial processes. As they are lipophilic (fat-soluble), these compounds accumulate in the fatty tissue of both animals and humans. Meat, especially if it has a high fat content, serves as a primary channel for the transfer of dioxins in the food chain. Livestock ingest dioxins via contaminated feed, soil and water, and grazing animals are particularly susceptible. Exposure level can vary depending on the composition of the feed, the contamination of the feed and the duration of exposure, all of which influence dioxin levels in muscle tissue, fat and organs. After consumption, dioxins concentrate in fatty tissue and the liver. When people consume meat from contaminated animals, they are exposed to potential health risks, including carcinogenic, reproductive and developmental problems. Food processing, such as cooking at high temperatures and trimming visible fat, can reduce dioxin levels in meat products to some extent. However, some dioxin congeners remain relatively stable under typical cooking conditions. This resilience underscores the importance of tackling dioxins at their source, including the implementation of appropriate feed safety measures and regulation of industrial emissions. Despite regulatory efforts to limit dioxin contamination in animal feed and food, bioaccumulation remains a challenge due to the environmental persistence of these compounds.

Keywords: dioxins, bioaccumulation, health impact, meat safety, animal fat

INTRODUCTION

Persistent organic pollutants (POPs) are hazardous organic contaminants that are difficult to degrade (Kanan and Samara, 2018). Among the most toxic are dioxins, a group of 210 chlorinated compounds divided into polychlorinated dibenzo-p-dioxins (PCDDs, 75 congeners) and polychlorinated dibenzofurans (PCDFs, 135 congeners) (Knežević et al., 2011). Seventeen congeners with chlorine at positions 2, 3, 7 and 8 are particularly resistant to metabolism (Hoogenboom et al., 2015). In addition, twelve dioxin-like polychlorinated biphenyls (DL-PCBs) exhibit similar persistence and toxicity. Of the 419 known dioxin-related compounds, about 30 have significant toxicity, with 2,3,7,8-tetrachloro-dibenzo-para-dioxin (TCDD) being the most toxic (FAO, 2008).

Industrial sources of dioxins date back to the early 1900s, when large-scale contamination with organochlorine compounds occurred (Weber et al., 2008). In the 1930s, Monsanto's PCB and pesticide production caused health risks to workers, including chloracne (Institute of Medicine, 2005). Dioxins were first identified as food contaminants in the 1950s when chickens in the USA died after eating fat contaminated with chlorophenol-treated cow hides (Firestone, 1973). The Yusho incident in Japan (1968) provided further evidence of the health effects of dioxins, as PCB- and PCDF-contaminated rice oil caused widespread poisoning and highlighted the long-term persistence of dioxins in human tissues (Masuda and Schecter, 2012).

The aim of this paper is to review recent findings on dioxin sources, bioaccumulation and health risks, with a focus on how these contaminants enter the human body through meat-based foods.

SOURCES OF DIOXIN CONTAMINATION

Dioxins are colorless, odorless, fat-soluble compounds that contain carbon, hydrogen, oxygen and chlorine (Rose, 2014). They occur in nature (e.g. forest fires, volcanic eruptions, certain kaolin clays) (Reiner et al., 2006), but are mainly attributable to anthropogenic sources (Webber et al., 2008). Major contributors include industrial incineration, chlorine chemical production and paper bleaching (Duan et al., 2011; Rathna et al., 2018) as well as pesticide and herbicide production, cement production and metallurgical activities (Kirkok et al., 2020). Although emissions have been reduced by regulation (White and Birnbaum, 2009), dioxins persist in the environment and accumulate in living organisms (Weber et al., 2008). Their hydrophobic nature promotes adsorption in soil (Rose, 2014) and resists degradation (Kulkarni et al., 2008). Effective controls include high temperature incineration, extended pyrolysis time, flue gas filtration and modern incinerators (Pan et al., 2013; Zhang et al., 2017). However, solid waste incineration, forest fires, medical waste incineration and the uncontrolled recycling of e-waste remain problematic (Zhang et al., 2010).

DIOXIN BIOACCUMULATION MECHANISMS IN LIVESTOCK AND HUMAN FOOD CHAINS

Dioxins accumulate in soil, water and vegetation, especially in the vicinity of industrial sites, incineration plants or areas where chemicals are heavily used (Hoogenboom et al., 2015). Grazing animals ingest dioxins via contaminated soil or feed, which leads to increased levels in meat, milk and eggs (Rathna et al., 2018). Dioxins are lipophilic (fat-soluble) and accumulate in the fatty tissue of both animals and humans. After ingestion, dioxins are bioconcentrated and biomagnified in fat and liver and are difficult to degrade (Schecter et al., 2006). Dairy products account for up to 44 % of daily intake, meat for 25 %, fish for 10 % and plants and eggs for smaller amounts (Zennegg, 2018). While partial metabolism can occur via cytochrome P450 enzymes, dioxins remain in the body for years to decades (Toyoshiba et al., 2004), underlining the need for strict emission control and safe feed practices (Pralas et al., 2024).

HEALTH IMPACTS OF HUMAN EXPOSURE TO DIOXINS

Livestock meat can account for up to 33.8 % of dioxin exposure in older adults, with total exposure also depending on the frequency of consumption (EFSA, 2018). Global surveys show regional differences, with the highest PCDD/F levels in India, Europe and Africa and the highest PCB levels in Eastern and Western Europe (Van den Berg, 2016). Dioxins are carcinogenic and exert a variety of toxic effects even at relatively low doses - immunosuppression, endocrine disruption and effects on reproduction, neurological development and development (Kerkvliet, 1995; Ten Tusscher et al, 2014). They increase the risk of various types of cancer in humans and cause endocrine, reproductive and developmental problems in animals (Kogevinas, 2001). In populations with significant exposure, clinical studies have found a higher incidence of chloracne, sexual impotence and sensory neuropathy associated with PCDD levels (Thömke et al., 1999).

IMPLICATIONS OF DIOXIN EXPOSURE FOR THE SAFETY AND USE OF MEAT

The dioxin content in meat varies depending on the animal species, feed and regional factors, often correlates with the fat content and can be exacerbated by local industrial pollution (Weber et al., 2018). Fat and meat generally have comparable dioxin levels, although liver often has higher contamination (Hoogenboom et al., 2021). In some areas, meat can exceed the EU limits (Weber et al., 2018). For example, extensively reared calves can reach or exceed the legal limits for dioxins within a few months, mainly due to contaminated feed and milk (Zennegg, 2018). Cattle ingest dioxins via the soil in their feed, with higher chlorinated congeners accumulating particularly in the liver (Thorpe et al., 2001). Sheep and goats grazing near the soil surface can ingest up to 20 % soil in their diet, leading to elevated dioxin levels in liver and fat; however, contamination decreases when animals are switched to clean feed (Hoogenboom et al., 2015; EFSA, 2018). In pigs, intake depends on feed contamination, duration of exposure and growth rate. While dioxin levels in muscle and fat can decrease when switching to uncontaminated feed, higher levels are often maintained in the liver (EFSA, 2018). Although organ tissues generally accumulate most dioxins, muscles may contain higher concentrations than previously thought (Thorpe et al., 2001; Hoogenboom et al., 2021).

Despite the potential contamination of fresh meat, the processing of food can reduce the dioxin and DL-PCB content. Cooking at high temperatures releases fewer chlorinated congeners, and trimming fat further minimizes dioxin uptake. However, if contaminated cooking oil is used, processed products can have higher dioxin levels (EFSA, 2018). Planche et al. (2017) reported 18–48 % PCB losses in meat during pan cooking, especially at high heat, although no significant reduction in PCDD or PCDF levels was observed.

CONCLUSIONS

Dioxins are among the most toxic persistent pollutants, largely generated by activities such as incineration and chemical production. Despite regulations to reduce emissions, these compounds persist in the environment, accumulate in animal fat and enter the human food chain. Long-term exposure can lead to various health problems, including cancers, reproductive disorders and developmental problems.

Meat, dairy products and fish are the main sources of human exposure, highlighting the need for continuous monitoring, strict regulations and safe handling practices.

In livestock, dioxin contamination depends on the species, feed and regional factors, often exacerbated by industrial pollution and associated with higher fat content. Calves, sheep, goats and pigs can rapidly accumulate dioxins in both muscle and liver tissue, sometimes exceeding safety limits. Switching to uncontaminated feed can reduce levels in muscle and fat, but liver concentrations often remain higher. Cooking methods such as high temperature processing and trimming of fat can further reduce dioxin content, although the use of contaminated cooking oil can negate these benefits. Overall, strict control of feed quality, avoidance of contaminated pastures and proper cooking procedures are critical to minimizing dioxin levels in meat and protecting public health.

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Contact Information: Prof. Ivica Kos, PhD, University of Zagreb Faculty of Agriculture, Division of Animal Science, Svetošimunska 25, 10 000 Zagreb, Croatia, e-mail: ikos@agr.hr