REVIEW PAPER

Dioxins in Livestock Products: Sources, Bioaccumulation, and Health Impacts

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Abstract

Dioxins, a group of persistent organic pollutants, are highly toxic, resistant to degradation, and primarily enter the environment through industrial processes. They include polychlorinated dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs), and dioxin-like polychlorinated biphenyls (DL-PCBs). Dioxins accumulate in fatty tissues of animals and humans due to their lipophilic nature, posing significant health risks, including cancer, reproductive, and developmental issues. Contaminated food, particularly from livestock production like dairy and meat products as well as fish are the primary route of human exposure.

Studies show that dioxin levels in livestock depend on factors such as feed contamination and exposure duration. Cattle, sheep, and goats which are exposed to contaminated soil during grazing are particularly vulnerable. Studies have found that dioxins concentrate in liver and fat, with higher sequestration in the liver. Due to their lipophilic nature, dioxins bind to fat tissue and bioaccumulate in the bodies of animals and humans, leading to prolonged exposure. Human exposure is primarily through the consumption of animal products, with dietary intake accounting for 90-95 % of dioxin exposure. Food processing, particularly high-temperature cooking and fat removal can reduce dioxin content, although some congeners may persist.

Regulatory measures have significantly reduced industrial dioxin emissions, but environmental persistence and bioaccumulation remain challenges. The European Union has set strict limits on dioxin levels in food to protect public health, with ongoing research focused on reducing exposure through improved agricultural practices and food processing methods.

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

Introduction

Persistent organic pollutants (POPs) are typically defined as hazardous organic contaminants that resist metabolic, chemical, microbial, and photolytic degradation (Kanan and Samara, 2018). One of the most toxic POPs in nature are dioxins. The term "dioxins" refers to a group of 210 chlorinated compounds, divided into two subgro-

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ups: polychlorinated dibenzo-p-dioxins (PCDDs, 75 congeners) and polychlorinated dibenzofurans (PCDFs, 135 congeners) (Knežević et al., 2011). The most important of these are 17 congeners with chlorine atoms at the 2, 3, 7, and 8 positions due to their resistance to metabolic degradation (Hoogenboom et al., 2015). In addition to PCDD/Fs, 12 dioxin-like polychlorinated biphenyls (DL-PCBs), with at least 4 chlorine atoms, share similar persistence and effects. Of the 419 identified dioxin-related compounds, only about 30 have significant toxicity, with 2,3,7,8-tetrachloro-dibenzo-para-dioxin (TCDD) being the most toxic (FAO, 2008).

Dioxin production linked to industrial activities dates to the 1900s, with large-scale organochlorine contamination producing dioxins and related compounds (Weber et al., 2008). One infamous incident involved Monsanto, whereby the 1930s, the company's production of PCBs and pesticides led to health risks for workers, including skin rashes and chloracne. Products like Lysol and the herbicide Agent Orange, used in the Vietnam War, were contaminated with high levels of dioxins (Institute of Medicine, 2005).

Dioxins are widespread in the environment, found in air, water, soil, and food, especially in industrialized regions (EU Memo, 2001). They were first identified as food chain contaminants in the 1950s when U.S. chickens died from feed containing fat from chlorophenol-treated cow hides (Firestone, 1973). Another major incident occurred in Japan in 1968, known as the Yusho incident, where rice oil contaminated with PCBs and PCDFs caused widespread poisoning. High dioxin levels were later found to persist in patients' tissues for decades (Masuda and Schecter, 2012).

The aim of this paper is to give an overview of the latest findings about sources, bioaccumulation, and health impacts of dioxins which as contaminants can be introduced into the human body through the food of livestock origin.

Sources of Dioxin Contamination

Low levels of dioxins are ubiquitous in the environment through natural processes, such as forest fires and volcanic eruptions, and they can also appear under favourable natural conditions, as seen in certain kaolinic clays (Reiner et al., 2006). Although dioxins unintentionally enter the environment due to human activities, they are primarily generated from anthropogenic sources (Webber et al., 2008). Nowadays, dioxins are mostly produced by industrial processes, including the incineration of waste containing materials like polyvinyl chloride, the manufacturing of various chlorinated chemicals, and paper bleaching (Duan et al., 2011; Rathna et al., 2018). Other sources include pesticide and herbicide production, cement production, pharmaceutical processes, tanning, and metallurgical activities (Kirkok et al., 2020). PCBs, on the other hand, were widely produced and used in large quantities for transformers, heat exchange equipment, and certain paints and sealants (Hoogenboom et al., 2015). Dioxins are particularly formed as by-products during the combustion of chlorine-containing organic compounds (Kulkarni et al., 2008).

Over time, the sources of dioxins have shifted due to regulations. Industrial activities, once a major contributor to dioxin emissions, have seen a drastic reduction as governments and international organizations adhere rigorously to established regulations aimed at minimizing the release of these harmful substances (White and Birnbaum, 2009). As a result, emissions from industrial processes have considerably diminished, reflecting the effectiveness of these regulatory measures in protecting both human health and the environment. Unfortunately, the persistence of dioxins in the environment allows them to be absorbed by living organisms and enter the human food web, posing significant health risks (Weber et al., 2008). The toxicity of dioxins to humans, wildlife, and ecosystems is exacerbated by their properties, such as hydrophobicity and bioaccumulation (Tuomisto, 2011). Their hydrophobicity causes them to strongly adsorb onto the surfaces of organic materials and soil components (Rose, 2014). Additionally, dioxins are highly resistant to chemical degradation, making their removal from environmental sites a substantial challenge (Kulkarni et al., 2008).

Formation of dioxins is a proven complex reaction process involving multiple solid and gas phase reactions with dioxins formed alongside other combustion gases, fly ash and slag (Pan et al., 2013). In order to reduce emission of dioxins into the environment from thermochemical processes for instance pyrolysis and combustion processes, it has been proposed that a combination of stringent measures would be fundamentally helpful; (1) incineration activities to be conducted at a temperature in excess 1000 °C, (2) increasing the pyrolytic contact time and the total pyrolysis time, (3) use of flue gas filtration, (4) employing well-designed modern incinerators (Zhang et al., 2017). However, it has been reported that emission of dioxins from burning of solid fuel, forest fires and medical waste incinerators has become increasingly difficult to control (Tuomisto, 2011). The most recent concern regarding the formation of these pollutants arises from the recycling of electronic waste under poorly controlled conditions, which ultimately facilitates the production of dioxins (Zhang et al., 2010).

Mechanisms of Dioxin Bioaccumulation in Livestock and Humans

Dioxins are colourless, odourless organic compounds containing carbon, hydrogen, oxygen, and chlorine. They are not soluble in water but are highly soluble in fat, meaning that dioxins and dioxin-like PCBs can adsorb onto mineral or organic particles suspended in water (Rose, 2014). When dioxin emissions are transported by air and deposited on oceans and seas, they concentrate in the aquatic food chain. Soil also naturally absorbs dioxins from the atmosphere, sewage sludge, spills, and nearby contamination. Grazing animals like cattle, goats, and pigs kept outdoor ingest dioxins through soil or dust on plants. Aerial deposition contaminates leafy vegetables and pastures, which animals graze directly or consume as hay or silage. Even the use of sewage sludge on vegetation can slightly increase livestock exposure (EU Memo, 2001).

This issue is more pronounced in areas with prevalent chemical use and disposal, such as near industrial sites, waste incineration plants, and regions with heavy agricultural activity. In such areas, dioxins and similar pollutants accumulate in soil and vegetation, posing a greater risk to livestock and humans who consume animal products (Hoogenboom et al., 2015). Dioxins are not biodegradable, making them persistent in the environment (EU Memo, 2001). Additionally, dioxins bioconcentrate in organisms over time, meaning their concentrations increase within organisms compared to the environment. Their lipophilic nature allows dioxins to pass through cell membranes and accumulate in living organisms (Schecter et al., 2006), and they resist metabolism in vertebrates, allowing for biomagnification through the food chain (Van den Berg et al., 2006). As dioxins enter the food chain, they accumulate at higher levels, especially in carnivores, including humans (Schecter et al., 2006).

The longer an animal's lifespan, the greater the potential for dioxin accumulation in its adipose tissue. In general, food of animal origin contributes 90-95% of human dioxin exposure (Rathna et al., 2018; Zennegg, 2018). Contamination can vary widely depending on the origin of food. Main livestock products like meat, eggs and milk as well as farmed fish may be contaminated above background levels by dioxins from animal feed (Rathna et al., 2018; Weber et al., 2008). This contamination may result from local environmental pollution, such as emissions from waste incinerators, or from dioxins in aquatic animal by-products like fishmeal and fish oil. Wild fish from polluted areas may also be highly contaminated (EU Memo, 2001).

Human exposure to dioxins can occur through work in industries where dioxin is a by-product, industrial accidents, contaminated food, human breast milk, and drinking water, while skin contact or breathing account for very small sources of exposure (Van den Berg et al., 2006). An analysis of the main food categories contributing to the daily intake of dioxins, expressed as WHO toxicity equivalent (WHO-TEQ), was presented by Zennegg (2018). The author stated that fatty-rich food categories like dairy products and meats contribute significantly to daily dioxin intake, accounting for 44 % and 25 %, respectively. Fish and cheese each contribute 10%, while plants (8 %) and eggs (3 %) provide smaller amounts. Despite dairy products contributing the most, meat and meat products should also be recognized as major contributors.

Mudhoo et al. (2013) stated that 90 % of the daily dioxin intake comes from ingestion. When ingested via contaminated food, dioxins are absorbed through the gastrointestinal tract with an efficiency of 80-90 % (Aylward and Hays, 2002). After absorption, dioxins are distributed through the bloodstream to various tissues, accumulating in fat and the liver due to their lipophilicity, where they bind to plasma proteins or intracellular receptors like the aryl hydrocarbon receptor (AhR) (Okey, 2007).

Due to their chemical stability and resistance to metabolism, dioxins are broken down slowly in the body, with half-lives ranging from several years to decades, depending on the type of dioxin and the tissue involved (Van den Berg et al., 2006). This slow metabolism leads to cumulative accumulation, especially in fat tissue, where toxic concentrations can be reached. The liver is also a key organ for dioxin accumulation due to the high expression of AhR receptors, but fat tissue serves as the primary reservoir, slowly releasing dioxins into the bloodstream, prolonging exposure to internal organs (Schecter et al., 2006). Although dioxins are known for their stability and resistance to metabolism, some biotransformation occurs, primarily in the liver. This process involves the oxidation of dioxins by cytochrome P450 enzymes, which produce water-soluble hydroxylated metabolites. Cytochrome P450 plays a key role in converting these compounds into polar substrates, which can then be excreted from the body (Toyoshiba et al., 2004).

Health Impacts of Human Exposure to Dioxins

The EFSA evaluation (EFSA, 2018) provides a comprehensive assessment of human dietary exposure to PCDD, PCDF, and DL-PCB contaminants across various age groups. The analysis, which covered nearly 20,000 food samples, highlights that fatty fish is the dominant source of dioxin exposure across all age groups. As individuals age, the contribution of livestock meat to dioxin exposure increases, reaching up to 33.8 % in older population. However, the contribution ratio of food items to human exposure does not only depend on their contamination level, but the consumption frequency among the population is also considered an important factor (Aoudeh et al., 2022; EFSA, 2018). Additionally, regional variations must be recognized, as seen in global surveys on PCDD, PCDF, and PCB levels in human milk conducted by WHO/UNEP since 1987, which revealed significant differences. Between 2000 and 2010, PCDD and PCDF levels were highest in India, Europe, and Africa, while PCB levels peaked in East and West Europe (Van den Berg, 2016).

Regardless of the source, dioxins have a wide range of toxic effects, with some classified as known human carcinogens. In laboratory animals, they have been linked to endometriosis, developmental and neurobehavioral effects, reproductive issues such as low sperm count and genital malformations, and immunotoxic effects. These non-carcinogenic effects occur at much lower exposure levels than those needed to cause cancer (EU Memo, 2001). Dioxins are also reported as immunosuppressants (Kerkvliet, 1995) and endocrine disruptors (Costa et al., 2014), affecting cell growth and development, neurodevelopment (Ten Tusscher et al., 2014), and reproductive systems (Van Luong et al., 2018).

Kogevinas (2001) conducted a detailed review of dioxins' health effects and confirmed their carcinogenicity in both animals and humans. In humans, an increased risk of all cancers was observed, although no specific type predominated. Higher risks were noted for reproductive cancers such as female breast, endometrial, male breast, and testicular cancers, though the overall pattern remains inconsistent. In animals, endocrine, reproductive, and developmental effects are the most sensitive to dioxin exposure (Bruns-Weller et al., 2010). For instance, decreased sperm counts in rats and endometriosis in rhesus monkeys occurred at concentrations 10 times higher than current human exposure levels (Kogevinas, 2001). Everett and Thompson (2012) found that pre-diabetes with elevated glycohemoglobin (A1c) was associated with PCB 126, PCB 118, and multiple dioxin compounds. Total diabetes was linked to six of eight dioxin-based compounds tested, and the risk increased with elevated levels of four or more compounds.

It is challenging to directly link dioxin levels with specific illnesses in humans, so studies on exposed populations are crucial. Clinical and neurophysiological examinations of 156 workers exposed to dioxins in a pesticide plant showed that those with chloracne had significantly higher exposure to PCDDs and reported a higher incidence of sexual impotence (28.6% vs. 5.8% of those without chloracne). They also had more frequent sensory neuropathy in the legs, neurophysiological abnormalities, and lower mean motor compound muscle potential amplitudes in the peroneal nerve (Thömke et al., 1999).

Impact of Dioxin Exposure on Livestock Products Safety and Utilization

Meat is one of the primary sources of

dioxins in the human diet, alongside other food products of animal origin like (Mudhoo et al., 2013; Schecter et al., 2006; Zennegg, 2018). Various studies have shown that dioxins and related compounds, such as PCBs, accumulate in the fatty tissues of animals. This accumulation leads to high concentrations of dioxins in meat products, especially those from animals fed contaminated feed or exposed to environmental pollution (Van den Berg et al., 2006). As a result, the European Union has established strict regulatory limits for dioxins and dioxin-like PCBs in food, aiming to reduce health risks to consumers. These limits are based on risk assessments that consider long-term exposure to low levels of dioxins through diet (EFSA, 2018). To ensure the safe use of food, Commission Regulation (EC) No 1881/2006 was established. However, since that regulation has been amended substantially over time, a new Commission Regulation (EU) No 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food was introduced. This regulation sets maximum limits for contaminants, including dioxins and dioxin-like PCBs. To ensure efficient protection of public health, food containing contaminants above the maximum levels should not only be prohibited from entering the market but also from being used as ingredients or mixed with other food products.

Reports indicate that dioxin concentrations in meat vary depending on the type of meat and geographic region. For example, beef, pork, and poultry can contain different levels of dioxins, with higher concentrations typically found in fattier meats. Studies from Germany additionally elaborated by Zennegg (2018) show that calves from extensive production and suckler cow husbandry, slaughtered at a young age (5–6 months), tend to have higher dioxin and PCB levels than conventionally raised cattle fed with concentrated feed. This is due to the higher dioxin and PCB load in green fodder and suckler cow's milk. Contaminated green fodder, containing soil particles, increases pollutant absorption in both the suckler cow and calf. While the cow detoxifies by releasing fat-rich milk, the calves accumulate these pollutants in body fat, nearing or exceeding the maximum permitted levels within months.

Studies in Europe have shown that meat from certain regions may have significantly higher dioxin levels, often due to local pollution sources like industrial emissions and soil contamination (Weber et al., 2018). Research has also found that dioxin and PCB levels in the fat of animals grazing outdoors can be quite high, frequently exceeding EU limits. While dioxin levels in meat are generally similar to those in fat, animal liver often shows significantly higher contaminant levels, even when concentrations in fat and meat are relatively low (Hoogenboom et al., 2021).

Cattle are particularly sensitive to environmental contamination by dioxins which can enter cattle through feed, including contaminated soil particles found in grass, grass silage, or hay. During grazing, cattle are exposed to contaminated soil, with the amount of soil intake varying depending on the quality of the pasture and the availability of grass. On high-yield pastures, soil typically accounts for at least 3 % of the grass intake (EFSA, 2018). Studies on dioxin transfer and tissue accumulation in cattle for beef production are limited. Feil et al. (2000) fed steer calves with dioxins and DL-PCBs over 120 days, showing that higher chlorinated congeners accumulated in the liver. Back fat and perirenal fat reflected lipid-based levels of dioxins as in the meat. Some of the dioxins like TCDD showed higher retention rate in the body, while some like TCDF was metabolized quickly. Thorpe et al. (2001) treated steers with a dioxin mixture for 4 weeks and found similar results, with liver concentrations of dioxins being 9- to 17-fold higher than in fat. Dioxin levels in muscle were also higher than in adipose tissue, a contrast to Feil et al. (2000). After a depuration period of 14 weeks, dioxin levels in fat decreased but remained higher in muscle. Despite further weight gain, dioxin levels were stable after 27 weeks.

Sheep and goats are considered among the most sensitive animals to environmental contamination. Sheep and goats graze close to the soil surface, resulting in a high intake of soil, which can account for up to 20 % of their total feed. Sheep meat can come from both young and older animals, with particular concerns raised about the high levels of toxic equivalents found in sheep livers. An EFSA evaluation (EFSA, 2018) highlighted these risks, pointing to liver sequestration as the cause of elevated TEQ levels. A study by Hoogenboom et al. (2015) on young blackhead sheep fed contaminated grass from a floodplain revealed that PCDD/F levels in adipose tissue increased rapidly before stabilizing, while DL-PCB levels peaked at day 30 and then slightly decreased. The liver showed significantly higher TEQ levels than fat, especially for highly chlorinated congeners. Over time, dioxin levels in both liver and fat decreased, especially when clean feed was introduced. These findings align with other studies, which also noted differences in the sequestration of PCDD/Fs and DL-PCBs between liver and fat. Goats are mostly used for milk production and several studies have examined the transfer of dioxins and DL-PCBs to goat milk. Grova et al. (2002) administered a high dose of TCDD and reported that 7.8 % of the dose was excreted in milk, with levels peaking at 22 hours. Ounnas et al. (2010) observed that steady-state PCB levels in milk were reached after two weeks, with some of them (PCB-126) accumulating more in the liver than other PCBs. At the end of the study, goats showed higher bioconcentration of PCB-126 in the liver (23 %) compared to fat tissue (4 %). Across studies, transfer rates varied depending on the congener, with higher chlorinated compounds showing lower transfer rates.

Studies on pigs indicate that dioxin exposure varies based on feed contamination and fat accumulation. Pigs raised for about six months increase body fat, which slows down dioxin accumulation. Studies show that some PCDD/Fs are metabolized, with TCDF and PeCDF being examples (EFSA, 2018). Liver sequestration is common, with higher chlorinated congeners, such as PCB-126, accumulating more in the liver than in fat (Watanabe et al., 2010). Similarly, studies by Brambilla et al. (2011) and Shen et al. (2012) found that total TEQ levels were higher in the liver than in adipose tissue. Controlled studies by Hoogenboom et al. (2007) and Spitaler et al. (2005) showed that PCDD/F levels in fat decreased when pigs were switched to clean feed, but liver sequestration persisted. The toxicokinetic models (Hoogenboom et al., 2007; Adolphs et al., 2013) developed from these studies highlight that pigs' dioxin levels are affected by exposure duration, feed contamination, and growth patterns. Liver sequestration, especially at low doses, is a consistent finding, even after extended periods on clean feed (EFSA, 2018).

Although fresh meat can be contaminated with dioxins and DL-PCBs, food processing can lead to significant reductions in their content, with lower levels of PCDD/Fs and PCBs observed in processed food compared to raw food (EFSA, 2018). High-temperature cooking can release lower chlorinated congeners, and removing fat during processing further minimizes dioxin intake. However, using contaminated cooking oil can result in higher dioxin levels in processed products. Planche et al. (2017) reported PCB losses of 18-48 % in meat due to pan cooking, with greater losses under more intense cooking conditions, though no significant reductions in PCDDs or PCDFs were observed. Similarly, grilling or boiling mackerel and beef reduced PCDD/F levels by 31-42 % (Hori et al., 2005), and Domingo (2011) noted that fat removal during cooking decreases concentrations of PCDD/Fs and PCBs.

Conclusion

Dioxins, some of the most toxic persistent organic pollutants (POPs), are primarily generated through anthropogenic activities like waste incineration, chemical manufacturing, and industrial processes. Despite regulatory efforts to reduce dioxin emissions, their persistence in the environment allows them to bioaccumulate in animal fat and the human food chain, posing significant health risks. They have wide-ranging toxic effects, including carcinogenicity, reproductive issues, and developmental disorders. Human exposure to dioxins occurs mainly through consumption of contaminated livestock products like meat, dairy, and fish. The accumulation of dioxins is particularly pronounced in livestock and wildlife exposed to contaminated soil or feed. Dioxins tend to accumulate in fat and liver tissues, with higher chlorinated congeners showing more significant sequestration in the liver. Meat, milk, and other animal products are the major contributors to human dioxin exposure, especially in industrialized regions. While food processing techniques, such as high-temperature cooking and fat removal, can reduce dioxin levels, contamination remains a concern. In conclusion, long-term exposure to dioxins, even at low levels, continues to pose a public health challenge, highlighting the importance of ongoing monitoring, regulation, and safe food handling practices to minimize exposure.

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Dioksini u mesu: izvori, bioakumulacija i utjecaj na zdravlje

Sažetak

Dioksini, skupina postojanih organskih zagađivača, iznimno su toksični, otporni na razgradnju i uglavnom ulaze u okoliš putem industrijskih procesa. Uključuju poliklorirane dibenzo-p-dioksine (PCDD), dibenzofurane (PCDF) i dioksinima slične poliklorirane bifenile (DL-PCB). Dioksini se nakupljaju u masnim tkivima životinja i ljudi zbog svoje lipofilne prirode, što predstavlja značajan rizik za zdravlje, uključujući rak, reproduktivne i razvojne probleme. Kontaminirana hrana, osobito ona iz životinjskih izvora poput ribe, mliječnih i mesnih proizvoda, glavni je put ljudske izloženosti.

Istraživanja pokazuju da razine dioksina kod stoke ovise o čimbenicima poput kontaminacije hrane i duljine izloženosti. Goveda, ovce i koze, koje su izložene kontaminiranom tlu tijekom ispaše, posebno su osjetljive. Studije su pokazale da se dioksini koncentriraju u jetri i masnom tkivu, pri čemu je veća akumulacija u jetri. Zbog svoje lipofilne prirode, dioksini se vežu za masno tkivo i bioakumuliraju u tijelima životinja i ljudi, što dovodi do produljene izloženosti. Ljudska izloženost uglavnom dolazi putem konzumacije životinjskih proizvoda, a prehrambeni unos čini 90-95 % izloženosti dioksinima. Obrada hrane, osobito kuhanje na visokim temperaturama i odvajanje masti, može smanjiti sadržaj dioksina, iako neki kongeneri mogu ostati prisutni.

Regulativne mjere značajno su smanjile industrijske emisije dioksina, no postojanost u okolišu uz bioakumulaciju i dalje predstavljaju izazove. Europska unija postavila je stroge granice za razine dioksina u hrani kako bi zaštitila javno zdravlje, a istraživanja su usmjerena na smanjenje izloženosti poboljšanjem poljoprivrednih praksi i metoda obrade hrane.

Ključne riječi: dioksini, bioakumulacija, utjecaj na zdravlje, sigurnost mesa, životinjske masti

Dioxine in tierischen Erzeugnissen: Quellen, Bioakkumulation und Gesundheitsauswirkungen

Zusammenfassung

Dioxine, eine Gruppe persistenter organischer Schadstoffe, sind hochgiftig, widerstandsfähig gegen Abbau und gelangen hauptsächlich durch industrielle Prozesse in die Umwelt. Zu ihnen gehören polychlorierte Dibenzo-p-dioxine (PCDD), Dibenzofurane (PCDF) und dioxinähnliche polychlorierte Biphenyle (DL-PCB). Dioxine reichern sich aufgrund ihrer lipophilen Beschaffenheit im Fettgewebe von Tieren und Menschen an und stellen ein erhebliches Gesundheitsrisiko dar, einschließlich Krebs, Fortpflanzungs- und Entwicklungsstörungen. Kontaminierte Lebensmittel, insbesondere aus der Viehzucht wie Milch- und Fleischerzeugnisse sowie Fisch, sind der wichtigste Expositionsweg für den Menschen. Studien zeigen, dass der Dioxingehalt in Nutztieren von Faktoren wie der Futtermittelkontamination und der Expositionsdauer abhängt. Rinder, Schafe und Ziegen, die beim Weiden kontaminiertem Boden ausgesetzt sind, sind besonders gefährdet. Studien haben ergeben, dass sich Dioxine in Leber und Fett anreichern, wobei sie in der Leber stärker gebunden werden. Da Dioxine lipophil sind, binden sie sich an das Fettgewebe und reichern sich im Körper von Tieren und Menschen an, was zu einer längeren Exposition führt. Die Exposition des Menschen erfolgt in erster Linie durch den Verzehr von tierischen Erzeugnissen, wobei 90-95 % der Dioxinexposition auf die Ernährung zurückzuführen sind. Die Verarbeitung von Lebensmitteln, insbesondere das Garen bei hohen Temperaturen und das Entfernen von Fett, kann den Dioxingehalt verringern, obwohl einige Kongenere weiterhin vorhanden sein können.

Die Dioxinemissionen aus der Industrie konnten durch regulatorische Maßnahmen erheblich reduziert werden, aber die Persistenz und Bioakkumulation in der Umwelt stellen weiterhin ein Problem dar. Die Europäische Union hat zum Schutz der öffentlichen Gesundheit strenge Grenzwerte für den Dioxingehalt in Lebensmitteln festgelegt, und die laufende Forschung konzentriert sich auf die Verringerung der Exposition durch verbesserte landwirtschaftliche Praktiken und Lebensmittelverarbeitungsmethoden.

Schlüsselwörter: Dioxine, Bioakkumulation, gesundheitliche Auswirkungen, Fleischsicherheit, Tierfett

Dioxinas en productos ganaderos: fuentes, bioacumulación e impactos en la salud

Resumen

Las dioxinas, un grupo de contaminantes orgánicos persistentes, son altamente tóxicas, resistentes a la degradación y entran principalmente en el medio ambiente a través de procesos industriales. Incluyen dibenzo-p-dioxinas policloradas (DDPCs), dibenzofuranos (DFP) y bifenilos policlorados con características similares a las dioxinas (DL-PCBs). Las dioxinas se acumulan en los tejidos grasos de animales y humanos debido a su naturaleza lipofílica, lo que representa graves riesgos para la salud, como cáncer, problemas reproductivos y de desarrollo. Los alimentos contaminados, en particular los productos ganaderos como los lácteos y la carne, así como el pescado, son la principal vía de exposición humana.

Los estudios demuestran que los niveles de dioxinas en el ganado dependen de factores como la contaminación del alimento y la duración de la exposición. El ganado bovino, ovino y caprino que pastorea en suelos contaminados es especialmente vulnerable. Las investigaciones han encontrado que las dioxinas se concentran en el hígado y en el tejido graso, siendo mayor la acumulación en el hígado. Debido a su naturaleza lipofílica, las dioxinas se adhieren a los tejidos grasos y se bioacumulan en los cuerpos de animales y humanos, lo que provoca una exposición prolongada. La exposición humana se da principalmente a través del consumo de productos de origen animal, con la ingesta alimentaria responsable del 90-95% de la exposición a las dioxinas. El procesamiento de alimentos, especialmente la cocción a altas temperaturas y la eliminación de grasas, puede reducir el contenido de dioxinas, aunque algunos congéneres pueden persistir.

Las medidas regulatorias han reducido significativamente las emisiones industriales de dioxinas, pero su persistencia en el medio ambiente y bioacumulación siguen siendo un desafío. La Unión Europea ha establecido límites estrictos sobre los niveles de dioxinas en los alimentos para proteger la salud pública, y se sigue investigando en métodos de reducción de la exposición mediante mejoras en las prácticas agrícolas y de procesamiento de alimentos.

Palabras claves: dioxinas, bioacumulación, impacto en la salud, seguridad alimentaria, grasa animal

Diossine nella carne: fonti, bioaccumulo e impatto sulla salute

Riassunto

Le diossine, un gruppo di inquinanti organici persistenti, sono estremamente tossiche, resistenti alla decomposizione ed entrano nell'ambiente principalmente attraverso processi industriali. Includono policloro-dibenzo-p-diossine (PCDD), dibenzo-furani (PCDF) e policlorobifenili simili alle diossine (DL-PCB). Le diossine si accumulano nei tessuti adiposi degli animali e degli esseri umani a causa della loro natura lipofila, comportando rischi significativi per la salute, tra cui cancro e problemi riproduttivi e di sviluppo. Il cibo contaminato, soprattutto quello di origine animale come pesce, latticini e prodotti a base di carne, rappresenta la principale via di esposizione umana.

Le ricerche mostrano che i livelli di diossina nel bestiame dipendono da fattori quali la contaminazione dei mangimi e la durata dell'esposizione. I bovini, gli ovini e i caprini, esposti al suolo contaminato durante il pascolo, sono particolarmente sensibili. Gli studi hanno dimostrato che le diossine si concentrano nel fegato e nel tessuto adiposo, con un maggiore accumulo nel fegato. A causa della loro natura lipofila, le diossine si legano al tessuto adiposo e si bioaccumulano nel corpo degli animali e dell'uomo, determinando un'esposizione prolungata. L'esposizione umana avviene principalmente attraverso il consumo di prodotti animali e l'assunzione alimentare rappresenta il 90-95% dell'esposizione alla diossina. La lavorazione degli alimenti, in particolare la cottura ad alte temperature e la separazione dei grassi, può ridurre il contenuto di diossina, sebbene alcuni congeneri possano permanere.

Le misure normative hanno ridotto significativamente le emissioni industriali di diossina, ma la persistenza nell'ambiente insieme al bioaccumulo rappresentano ancora delle sfide. L'Unione Europea ha fissato limiti rigorosi per i livelli di diossina negli alimenti per proteggere la salute pubblica, mentre la ricerca si concentra sulla riduzione dell'esposizione con il miglioramento delle pratiche agricole e dei metodi di lavorazione degli alimenti.

Parole chiave: diossine, bioaccumulo, impatto sulla salute, sicurezza della carne, grassi animali