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A Review of PCDD/F and dl-PCB Contamination in Foods and Dietary Exposure Assessment

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ABSTRACT

This review evaluates polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and dioxin-like polychlorinated biphenyls (dl-PCBs) analytical methods, occurrence and concentrations in major food groups from studies published worldwide over the last 20 years. The review reveals that in many developing countries the levels of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/Fs) plus dl-PCBs may be increasing due to rudimentary practices during thermal process including waste incinerations, metal industries, recycling and dumpsites. The review heightened the need to develop and capacitate laboratories from developing world for PCDD/Fs plus dl-PCBs monitoring as most of the analysis were performed in laboratories from developed worlds even on sentinels from developing countries, especially those of Africa. The review concluded that further data still need to be generated from other regions to complete the chemical inventories. It was concluded that, strict environmental controls of PCDD/Fs plus dl-PCBs emissions remain a priority, however reduction of these contaminants require global monitoring coordination.

1. INTRODUCTION

The polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and dioxin-like polychlorinated biphenyls (dl-PCBs) are well-known environmental and food contaminants that are highly toxic persistent organic pollutants capable of resisting degradation in the environment. PCDD/Fs are produced unintentionally during combustion processes or production of chlorine-containing materials, such as plastics. Whereas polychlorinated biphenyls (PCBs) are man-made products found in applications such as dielectric fluids in transformers and capacitators, additives in lubricating fluids, adhesives, building sealants, fire-proofing agents, plasticizers, paints, and ink products [1-3]. According to the study [4], humans are exposed to Persistent organic pollutants (POPs) through a variety of routes, including inhaling air, ingestion of food and non-food items, and dermal contact. PCDD/Fs plus dl-PCBs are mainly ingested through foods that are rich in fat, such as eggs, fish, meat, and meat fat, as well as dairy products that have a high lipophilicity [5]. Thus, compilation and evaluation of data on the levels and occurrence of PCDD/Fs plus dl-PCBs in major food of animal origin is required.

PCDD/Fs plus dl-PCBs are usually low in fruits, vegetables, nuts, and cereals, but their high consumption rate can lead to foodborne exposure of these pollutants [6, 7]. PCDD/Fs plus dl-PCBs in food remains a health risk as they are known to act as a risk factor for the tumor promotion and alter several physiological processes that adversely affect the liver, kidneys, neurological system, and endocrine system [8, 9]. The International Agency for Cancer Research (IARC) had concluded that 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) is the most toxic and carcinogenic congener to humans [10]. This toxic conger (2,3,7,8-TCDD), is also found as a major contaminant in herbicide 2,4,5 trichlorophenoxy acetic acid (2, 4, 5-T) [11]. PCDD/Fs plus dl-PCBs have also been discovered mostly in human breast milk and free-range eggs, because PCDD/Fs plus PCBs in human milk are a good reflection of the body burden, as human blood and adipose tissue concentrations are closely similar while chicken eggs are one of the most important components of the human diet [12]. Eggs have different exposure pathways such as soil, feed, animal bedding as well as specific point sources on a farm. They are seen as sensitive indicator of PCDD/Fs plus PCBs contamination in soil and are an important exposure pathway from soil contamination to human. Daily consumption of one egg can reach the EU regulatory limit, exceeding the tolerable daily intake (TDI) of 2pg TEQ/kg body weight for children set by the WHO [7, 13].

Although much effort has been made to monitor and reduce the levels of PCDD/Fs plus dl-PCBs in these different food groups, it remains an important question to which extent this is possible at the general level of exposure. For decades, dioxin contamination incidents of feeds and foodstuffs have severely impacted the environment and human health not only economically but also environmentally and socially [8].

Although several reports have reviewed pollution status, analytical methods, environmental fate, and body burdens associated with PCDD/Fs plus dl-PCBs [14-16], a comprehensive review is still required on the occurrences and levels of PCDD/Fs plus dl-PCBs across different food groups in different regions. It is on this premise that this study reviews and discusses the current state (levels and exposure assessment) of knowledge on PCDD/Fs plus dl-PCBs in different foodstuffs and compares the dietary exposure and risk assessment in different regions. The objective of this review is to evaluate the latest data on PCDD/Fs and dl-PCB contamination across the global food supply and discuss implications for dietary exposure and mitigation of long-term health risks.

2. METHODOLOGY

The search for scientific literature used in this review was obtained from online database from ScienceDirect, PubMed, Web of Science, Scopus, ResearchGate, and Google Scholar covering studies published from 2000 till 2023. The searches were restricted to only publication types in English language such as articles, journals, books, and conference papers. The following search terms were combined in Boolean operators like "AND" and "OR": PCDDs, or PCDFs, or analysis, or concentration, or dl-PCB, or food stuff or food products or exposure. The data was considered when it met the following criteria: (1) data was published in English; (2) data was published in a scientific journal; and (3) it referred to the occurrence of PCDD/Fs in different foodstuff or products (i.e., free range chicken, eggs, cattle's, goats/sheep's, pigs, and breast milk and the data was published from year 2000 onwards).

A total of 4,350 articles were found online with the search "polychlorinated dibenzo dioxins and dibenzo furans". These publications were screened by reviewing titles, abstracts and/or full texts to determine which studies met the inclusion criteria. Of the 4,350 articles found, 133 articles fitted the criteria above with published data from mostly developed countries (i.e., USA, Canada, and western Europe) and China contributing the highest from the developing world (Figure 1 and Figure 2). The screening, selection and resolving of any uncertainties was conducted. Other than the above-mentioned criteria, the inclusion criteria used also included: research articles were given high preference over case studies, sample type (e.g., food products for human consumption), the target population, demographic, and geographic characteristics (specific location where data was collected) and PCDD/Fs plus dl-PCBs analysis methodology (e.g., use of quantification). Exclusion criteria applied to articles that were not in English, not within the chosen date of publication and area of study, and to articles with data suspected to be inaccurate, biased, or inconsistent. Data extracted from each study included, e.g., study location, food types, analysis methods, PCDD/F and dl-PCB levels, and estimated daily intake (EDI) on PCDD/Fs levels in different food groups. There was no bias given to any publication, and all publications were assessed and screened using the same criteria listed above. Caution was observed when comparing the results as different approaches were used for the collection of samples from foodstuffs. Few challenges were encountered as some studies did not mention the number of samples collected, which made inter-comparison of studies challenging since the total population could not be confirmed.

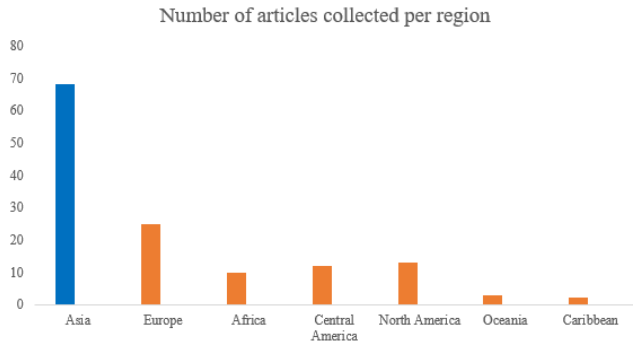

Figure 1. Number of publications used from different regions

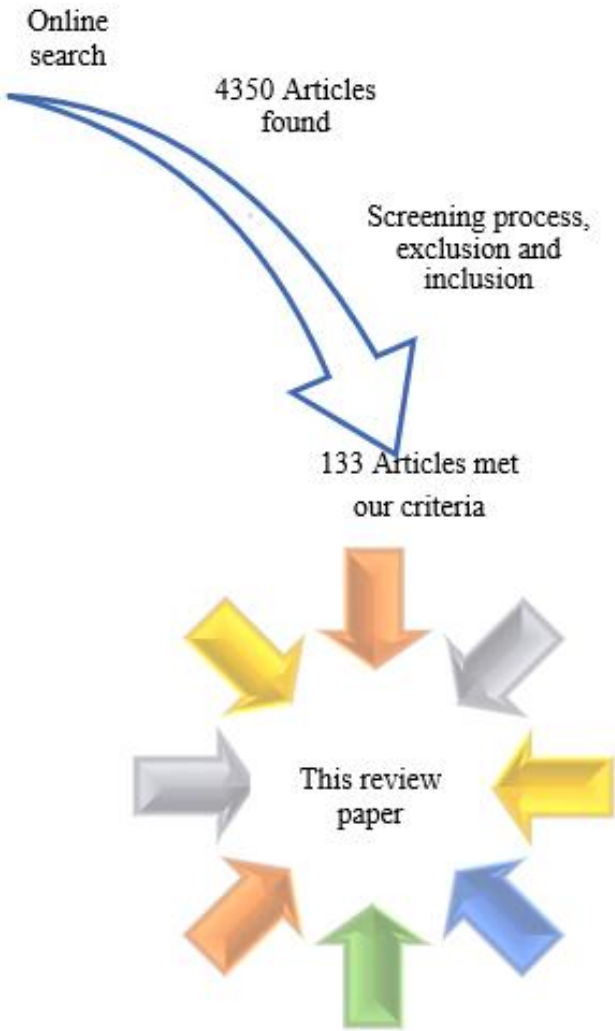

Figure 2. Study selection process and numbers of studies/ data included

3. PCDD/FS SAMPLING, EXTRACTION, CLEAN-UP, AND INSTRUMENTAL ANALYSIS

3.1 Eggs

Studies concerning analysis of foodstuff sentinels refers to eggs, fish, breastmilk, meat products as presented in Table 1. Eggs were collected from different hen farms such as free-range chickens, caged chickens, barn chickens and organic chickens [17-20]. Whole egg and egg yolk were mainly

analyzed for PCDD/Fs in eggs [10, 18, 21]. In these studies, eggs were collected and immediately transported to the laboratory. Egg samples were hard-boiled, frozen until analysis. The samples were normally homogenized, mixed with anhydrous sodium sulphate at ratio 1:2 and then re-homogenized [21-23]. The samples were spiked by internal standards and extracted by toluene in a Soxhlet apparatus and dried with anhydrous sodium sulphate. The samples were then cleaned on a silica gel column and further purified and fractionated on an activated carbon column. The fraction containing PCDD/Fs, were analyzed by HR GC-MS.

3.2 Breast milk

Breast milks were collected from mothers recruited while attending breastfeeding clinics [24-27]. Approximately, 30 - 60mL of breastmilk was collected from donors in a clean polypropylene container, transferred to the laboratory as soon as possible under cooling conditions. Once in the laboratory, the samples were stored at -18℃ until further analysis [28]. The participants in these studies were between 20 - 40 years of age, non-smokers and had lived in the respective areas for at least 4 years. Extraction solvents were exchanged to hexane and the fat content was gravimetrically determined after drying [29-31]. A mixture of $^{13}C_{12}$-PCDD/F standards was spiked to control potential losses during the extraction and clean-up processes. The clean-up procedure and fractionation were carried out by adsorption chromatography in a multi-step procedure using silica and alumina columns [31, 32]. Lipids were removed in a silica gel column with sulfuric acid and initially purified on an activated carbon column. The PCDD/Fs fraction was collected and concentrated to near dryness with a nitrogen flux. Finally, 25µL of $^{13}C_{12}$-PCDD/F injection standards were added. After drying and extraction with accelerated solvent extraction (ASE) the samples were purified and analyzed for PCDD/Fs [33]. The determination and quantification of PCDD/Fs congeners were performed by the Micromass Autospec Ultima system equipped with 7890A gas chromatograph using the DB-5MS capillary column (60m×0.25mm I.D, 0.25µm film thickness) [31, 34].

Table 1. Summary of analytical methods for the detection of PCDD/Fs in different matrices (compiled by the authors)

Matrix	Extraction	Solvent	Clean-up	Instrumental System	Recoveries	Reference
Eggs	Toluene in a Soxhlet apparatus	DCM:n-hexane (1:1, v/v)	Multilayer silica column and AIOx column	GC/MS Finnigan MAT 95	60%-120%	[10]
Eggs	Toluene in a Soxhlet apparatus	Organic solvents and chromatographic sorbents	Multistage column chromatography using a modified silica gel, Florisil and Carbopack C	HRGC/HRMS	60%-120%	[35]
Eggs	Toluene in a Soxhlet apparatus	1:1 Hexane: Ethanol	Activated carbon column (AX-21 Anderson Development Co.), multi-Iayer column	HRGC/HRMS	70%-125%	[20]
Eggs	Toluene in a Soxhlet apparatus	Dichloromethane (1:1)	5mL of 1:1 (v/v) Dichloromethane/ hexane solution and 500 µL of 1:250 clean-up standard	HRGC/HRMS	89%	[36]
Human Breast Milk	Accelerated Solvent Extraction	DCM:n-hexane (1:1, v/v)	Column chromatography with activated Florisil (60 - 100 mesh)	HRGC/HRMS	89%	[37]
Milk Powder	Accelerated Solvent Extraction	Mixture acetone: n-hexane (1/1, v/v) mixture	Multilayer silica, alumina and PX-21a carbon adsorbents respectively in a Power-Prep system	GCQ qQ (MS/MS) and GC-HRMS	65%	[36]
Feed (Corn Silage)	Accelerated Solvent Extraction	DCM:n-hexane (1:1, v/v)	Silica gel column	HRGC/HRMS	75%	[38]
CIam or Crab Tissue	Accelerated Solvent Extraction	DCM:n-hexane (1:1, v/v)	Silica gel 60 A and hexane (HEX)	HRGC/HRMS	89% and 78%	[39]
Yellow Eel	Pressurized Liquid Extraction	150 mL of hexane	Multilayer silica gel column contained 5g of sodium sulphate, 5g of silica gel, 20g of 44% sulphuric acid silica gel, and 20g of 22%	HRMS	72.5% and 97.7%	[40]

3.3 Fish

After fish collection, samples were normally wrapped with aluminum foil and transferred into the laboratory as soon as possible under cooling conditions. Once in the laboratory, species were measured for length, weight, and sex. Muscle tissues were dissected, weighed, wrapped in aluminum foils and stored at -20℃ until further analysis [38, 41-45]. Fish samples were grinded and freeze-dried for 36 hours at 60℃ under pressure of 10.66Pa until constant mass [46]. Subsequently, the samples were homogenized, stored at room temperature and protected from light and heat. PLE and Soxhlet were both used for the extraction of PCDD/Fs from fish samples Table 1. For the PLE extraction, a given mass of lyophilized fish (equivalent to 20.0g of wet weight) was placed in a 34mL cell and spiked with the ^{13}C-labeled standards (50mL of a solution prepared from a 100-fold dilution of the EDF-8999 stock solution with nonane). A silica-gel column was made by adding sequentially the following stationary phases into a glass cylindrical tube (25mm diameter, 25cm height): 30g of acidic silica-gel (roughly 10cm-long layer) and 3g of silica-gel activated overnight at 130℃ (roughly 1cm long layer). Acidic silica-gel was prepared by mixing concentrated H_2SO_4 (95% w/w minimum) and activated silica-gel in a proportion of 3:2 w/w. The column was conditioned with 50mL of n-hexane [41, 45-47].

3.4 Quality assurance and control

Several steps were taken to obtain data that would allow an assessment of the accuracy and reliability of the data e.g., use of surrogate and internal standards, instrument calibration, blank analysis, spike recovery tests, reproducibility tests. PCDD/Fs and PCBs data were corrected using twenty-one (21) $^{13}C_{12}$-labelled PCDD/Fs and PCBs isotope dilution standards. Analytical blanks, consisting of solvent and recovery standards were included and analyzed after every 12 samples. The method detection limit was calculated as 3 times the standard deviation of the concentrations found in the analytical blanks. If the concentrations in the blanks were below the instrumental detection limit, then the method detection limit was defined as equal to the instrumental detection limit. All results were blank corrected using the concentration of the field blanks. Field blanks were produced for each site and each quarter, and they were used to calculate method detection limits (MDLs). When compounds were not detected in the field blanks, laboratory blanks produced for each quarter were used to estimate MDLs. Certified materials were analyzed in some of the articles using comprehensive multi-dimensional gas chromatography (GC×GC), gas chromatography combined with low resolution ion-trap mass spectrometry (GCLRMS/MS), the CALUX bioassay and an Ah-PCR technique.

3.5 Summary

There is growing need to develop sensitive, selective, and reliable analytical methods for the determination of PCDD/Fs plus dl-PCBs in foodstuff at trace levels, especially in developing countries [48]. Gas chromatography in combination with high-resolution mass spectroscopy or tandem mass spectroscopy were used for PCDD/Fs plus dl-PCBs analysis in foodstuffs [27, 36, 40]. The advantage of the mass spectrometer is its ability to distinguish between the isotopic forms of the elements due to their differences in atomic mass. To improve the accuracy on the results, GC-API-MS is the new analytical tools that has been recently employed for all these food analytical challenges, especially food safety and metabolomics [49]. The low established minimum residue limits (MRLs) of these contaminants in foods require very sensitive analytical methods to determine the occurrence of these compounds. For this reason, GC-API-MS is becoming an alternative to the conventional GC-HRMS methods. One of the most common applications of GC-API-MS in food safety is the determination of POPs (i.e., list the POPs analyzed) residues in different foodstuffs, to monitor the responsible use of these products and ensure the safety of the final product for the consumers [50]. This method is not currently available in developing countries due to costs and lack of funding. Countries who are using GC-APCI-MS has reported that it is a reliable replacement for conventional GC-MS approaches since it significantly improves the selectivity as well as the sensitivity of the methodologies.

4. OCCURRENCES OF PCDD/FS PLUS DL-PCBS IN VARIOUS FOODSTUFF

PCDD/Fs plus dl-PCBs are persistent in the environment, can bio-magnify in the food chain and bio-accumulate in the tissues of living organisms [47, 51]. Consumers may be at risk through dietary exposure to PCDD/Fs through ingestion of contaminated food [52]. As a result of the risk identified in PCDD/Fs plus dl-PCBs exposure, scientists and regulatory agencies have assigned toxic equivalent factors (TEFs) to each PCDD/Fs plus dl-PCBs based on comparisons with 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). In 1990, the international toxic equivalency factors (I-TEFs) for PCDD/Fs were established and adopted by the World Health Organization (WHO) in 1998 and modified or revised in 2005 [51, 53, 54]. The most recent toxicological and occurrence data in food and feed prompted the European Food Safety Authority (EFSA) to reduce the tolerable weekly intake (TWI) for PCDD/Fs plus dl-PCBs sevenfold to 2pg WHO_{2005}-TEQ/kg bw/week [55], suggesting a tolerable daily intake (TDI) of 0.25pg WHO_{2005}-TEQ/kg bw/day. Although polybrominated diphenyl ethers (PBDEs) and biphenyls and mixed halogenated congeners all share many aspects of toxicity and the ability to bind to AH receptor they still lack TEF values and have insufficient data. The concentrations discussed in this section are reported using the WHO_{2005}-TEFs. A schematic diagram showing the human health exposure of PCDD/Fs through foodstuff is presented in Figure 3.

4.1 Chicken eggs

Chicken eggs are one of the most important components of the human diet due to their nutritional benefit toward human health [20]. This demand has led to eggs produced by organic and free-range housing systems due to sustainability reasons and consumers' awareness about protection of farm animal welfare [56-58] to increase. Due to soil foraging, studies report higher PCDD/Fs plus dl-PCBs concentrations in these eggs as compared to those from cage or barn eggs [7, 35, 59-62]. Summary of PCDD/Fs plus dl-PCBs concentrations in different eggs from different studies is presented in Figure 4. The concentration of PCDD/Fs around the globe showed that eggs from Agbogbloshie, Accra were the most contaminated

with concentration up to 661pg WHO_{2005} total toxic equivalent (TEQ) g^{-1} fat [62]. The detected concentration exceeded the EU regulatory limit of 2.5pg WHO_{2005}TEQ g^{-1} fat 260-fold. The dl-PCBs were detected at concentration of 195pg WHO_{2005}TEQ g^{-1} fat. The sum concentration of PCDD/Fs plus dl-PCBs was 856pg WHO_{2005}TEQ g^{-1} fat which exceeded the sum PCDD/Fs plus dl-PCBs 171.2-fold [62]. The site was influenced by rudimentary e-waste activities around the landfill site [62]. General population especially young children consuming contaminated eggs can easily exceed health-based standards and may be subject to high exposure levels. With the consumption of a single hen's egg (avg. 7 g fat) per day, a 4 - 5-year-old child (weighing 16 kg) would exceed the TDI of 2pg TEQ/kg bw, even if the egg complied with the EU regulatory limit for eggs of 5pg PCDD/F–PCB-TEQ/g fat [7].

Eggs consumed in Vietnam were also found to be contaminated with PCDD/Fs [20, 63, 64]. Kudryavtseva et al [20] reported PCDD/Fs concentrations of 361pg WHO_{2005}TEQ g^{-1} fat in eggs collected from Buu Long district, Vietnam. The reported concentration was >140 times above the EU regulatory limit. The suspected source of PCDD/Fs was the impact long-term use of Agent Orange [11, 20]. The major congener in their study was found to be 2,3,7,8-TCDD (TCDD) which was identified as the major contaminant in herbicide 2,4,5-trichlorophenoxy acetic acid. This exposure poses a very high risk to humans because long-term exposure, even at very low doses, can increase the risk of adverse health effects, such as hormonal imbalances, immunological disorders, reproductive disorders, and cancer [55]. In Taiwan, the research [65] determined the background levels of PCDD/Fs in duck eggs and determined the highest PCDD/F concentration of 1.956pg WHO-TEQ/g fat. Recently, Castellani et al. [66] measured the concentrations of PCDD/Fs (and PCBs) in free-range eggs from Central Italy and discovered the concentrations of ∑PCDD/Fs (plus DL-PCBs) ranged between 0.463 and 8.028pg TEQ/g fat.

Comparative levels were found by Traag et al. [63] who measured 249pg TEQ g^{-1} in Bien Hoa, Vietnam. Nghiem et al. [64] reported a toxic equivalent to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TEQ) in egg samples ranging up to 245pg TEQ/g lw in eggs from Dong Nai province, Vietnam. The concentrations were >72 times the regulatory limit as set by EU Commission regulation 1259/2011. Traag et al. [63] measured 214pg TEQ g^{-1} in Netherlands and while Petrlik et al. [67] measured 249pg TEQ g^{-1} in Bien Hoa. Both the researches had PCDD/Fs at above 99 times the regulatory limit [63, 67]. In both these studies, TCDD was the major congener, while Petrlik et al. [67] measured 182pg TEQ g^{-1} in China. Both Rusin et al. [68] and González et al. [69] found that out of all food items analysed, chicken eggs exhibited a higher prevalence of PCDD/Fs contamination. The lowest concentrations (≤2.5pg WHO_{2005}TEQ g^{-1} fat) of PCDD/Fs were reported in eggs from Germany; Kumasi, Ghana [62], Turkey [21], Southern Italy [70], Spain and Finland [71], Tuscany [72], Italy, Campania region [73] and Accra, Ghana [74], with concentrations of 2.5 and 0.39pg WHO_{2005}-TEQ g^{-1} fat [62], respectively. In a total diet study from Sub-Saharan Africa (comprising of Benin, Cameroon, Mali, and Nigeria) the sum concentration of PCDD/Fs plus dl-PCBs in eggs of 0.39pg WHO_{2005}-TEQ g^{-1} fat was reported [75]. This value was lower than the maximum permissible level in eggs set by EU. In the same study, the concentrations of ndl-PCBs of 64 ng g^{-1} ww [75] was reported which was above the maximum 40 ng g^{-1} ww set out by the EU. The PCDD/Fs plus dl-PCBs concentration in eggs detected from Luqiao was 2.8pg WHO_{2005}-TEQ g^{-1} ww while in Yuhang their concentration was 0.69pg WHO_{2005}-TEQ g^{-1} ww [76]. The major sources of these pollutants where e-waste recycling in Luqiao while in Yuhang the sources was suspected to be agricultural activities [76]. The high level of PCDD/Fs from free range eggs provokes a question of possible sources i.e., feed, soil, air and bedding which need to be strictly regulated to reduce the contamination in eggs. Tracking the source of PCDD/Fs in eggs can be easily done by comparing the fingerprints of congeners in eggs to those found in the suspected sources. The tracking and comparison could not be conducted in this review as the data from other environmental matrix was not available; however, PCDD/Fs plus dl-PCBs exposure in eggs is still high.

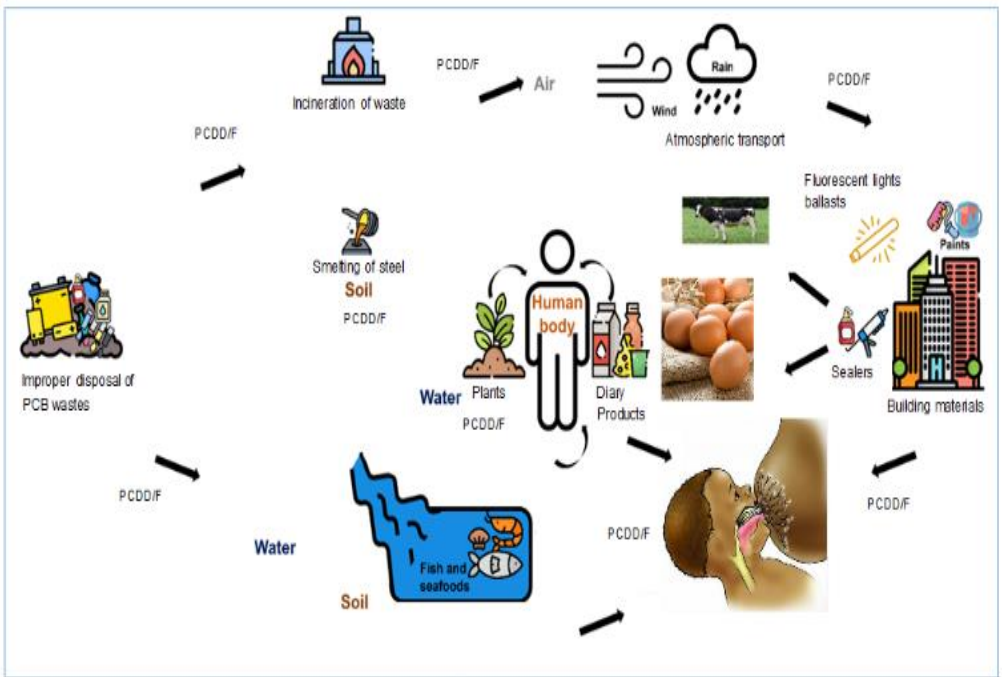

Figure 3. Schematic diagram showing exposure of PCDD/Fs plus dl-PCBs to humans through food

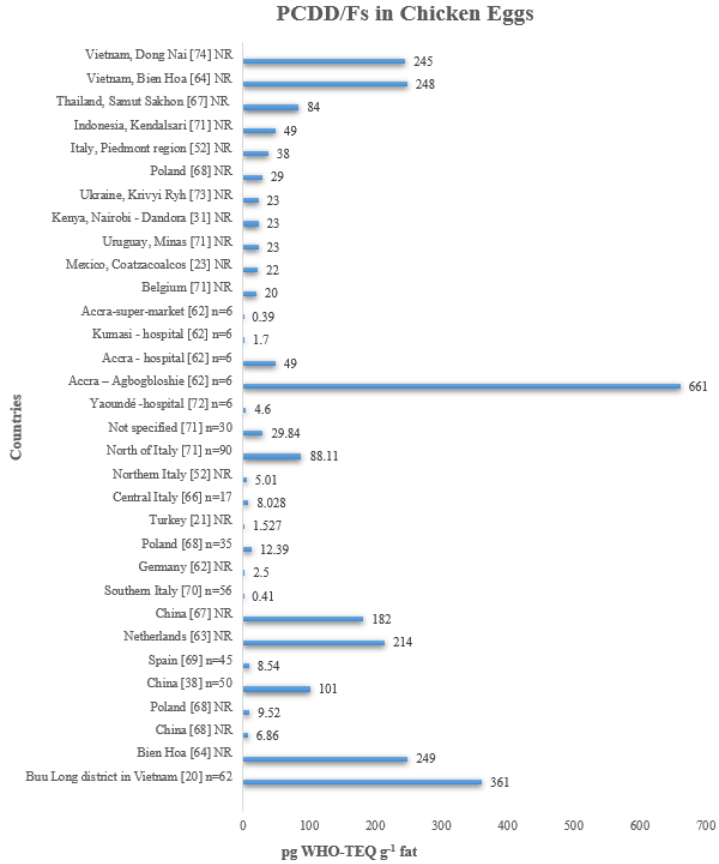

Figure 4. PCDD/Fs concentrations in chicken eggs in pg WHO_{2005}-TEQ g^{-1} fat
Note: n=number of samples; NR=not reported

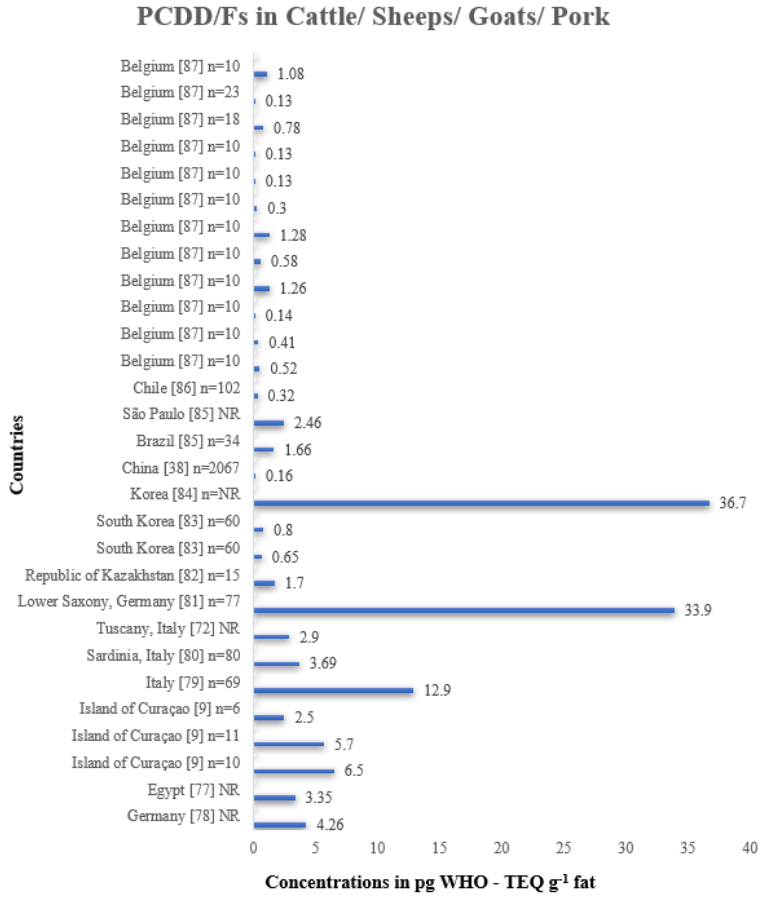

Figure 5. PCDD/Fs concentrations in cattle, sheep, pork and goats in pg WHO-TEQ g^{-1} fat
Note: n=number of samples; NR=not reported

4.2 Cattle/Goats/Sheep/Pork and products

Feeds and free-range grazing animals are the most important source of PCDD/Fs plus dl-PCBs [7, 75-77]. PCDD/Fs plus dl-PCBs accumulates in the fatty tissues of the animals and have been detected in meat and milk [76]. Figure 5 presents the concentrations of PCDD/Fs plus PCBs in cattle, sheep, pork and goats. Malisch [78] detected PCDD/Fs contamination in meat samples and found 2,3,7,8-TCDD and 1,2,3,7,8-PeCDD as major congeners in beef samples. They detected PCDD/Fs concentration ranged between 1.72 and 4.26pg I-TEQ g^{-1} fat (background contamination of 0.53pg I-TEQ g^{-1} fat) [78]. In the Island of Curaçao, adipose tissue, meat and livers of pigs, cows, sheep, and goat were monitored for PCDD/Fs [9]. Median (range) concentrations (pg I-TEQ g^{-1}) of PCDD/Fs plus dl-PCBs was 0.9 (0.3 - 35), 3.0 (0.5 - 14), 5.7 (0.3 - 28), and 6.5 (0.5 - 134) for pigs, cows, sheep, and goats were reported respectively [9]. The highest concentration from all the monitored samples had a maximum limit of 4pg I-TEQ g^{-1} fat exceeded between 3.5-fold for cows and 33.5-fold for goats [9]. In the same study, the concentrations of ndl-PCBs ranged from 1 - 281 ng g^{-1} fat (median: 14 ng g^{-1} fat) which exceeded the maximum limit of 40 ng g^{-1} fat 7-fold [9]. The higher range was found to have exceeded the maximum limit of 2.5pg I-TEQ g^{-1} fat nearly 2-fold.

Other studies reported the concentrations of PCDD/Fs plus PCBs, in animal milk around the globe. Esposito et al. [79] reported the levels of PCDD/Fs in sheep milk from Campania Italy and detected a concentration ranging between 3.89 - 12.90pg WHO_{2005}TEQ g^{-1} fat [79]. The detected concentrations exceeded the maximum level (2.5pg WHO_{2005}TEQ g^{-1} fat) set by EU. In another study, the PCDD/Fs concentration in sheep milk were below the maximum limit set by EU while the dl-PCBs concentration was 3.69pg WHO_{2005}TEQ g^{-1} fat [80]. The ndl-PCBs had the mean concentration of 4.92 ng g^{-1} fat which was below the maximum level of 40 ng g^{-1} fat [80]. In sheep milk sampled from the farms near incineration plants in Tuscany Italy, the PCDD/Fs concentration and dl-PCBs detected were between 0.71 - 2.9pg WHO_{1998}TEQ g^{-1} fat with a mean concentration of 1.45pg WHO_{1998}TEQ g^{-1} fat [72]. In Germany, Bruns-Weller et al. [81] investigated the PCDD/Fs plus dl-PCBs in sheep livers and found the median concentrations of 33.9, pg WHO_{2005}-TEQ g^{-1} fat. The concentrations exceeded the maximum limit of 10pg WHO_{2005}-TEQ g^{-1} by 3-fold [81]. Konuspayeva et al. [82] reported that the concentration of PCDD/Fs in camel milk from the Republic of Kazakhstan was 1.7 ± 0.7 ng g^{-1} fat, with a median of 1.5 ng g^{-1} fat and a range of 0.3-4.2 ng g^{-1} fat. Additionally, the ratio of NDL-PCB to DL-PCB (4.3) in camel milk was comparable to the levels reported in the European Union for dairy products derived from cows [82]. Kim et al. [83] reported a mean PCDD/Fs concentration of 0.65pg WHO_{2005}TEQ g^{-1} fat in milk from Republic of Korea. While Kim et al. [84] investigated PCDD/Fs in pork samples from Chile and found concentration levels of up to 36.7pg TEQ g^{-1} fat with 2,3,4,7,8-PeCDF, 1,2,3,4,7,8-HxCDF, 1,2,3,6,7,8-HxCDF, and 2,3,4,6,7,8-HxCDF reported as major congeners in all samples. 2,3,4,7,8-PeCDF showed the highest concentration and contributed about 30% among the congeners in most of the samples [84].

In Brazil, Rocha et al. [85] reported PCDD/Fs concentration of 1.36pg WHO_{2005}TEQ g^{-1} fat in cow milk with octa-chlorinated dioxin/ furan as a major congener. The mean concentration was below the maximum limit of 2.5pg WHO_{2005}TEQ g^{-1} fat. Pizarro-Aránguiz et al. [86] reported PCDD/Fs levels in dairy products from Chile from 2011 - 2013 period. The highest PCDD/Fs concentration of 0.32pg WHO_{2005}TEQ g^{-1} fat was detected in 2012 while the highest dl-PCBs of 0.17pg WHO_{2005}TEQ g^{-1} fat were detected in 2011, both concentrations were below the maximum limit. In milk samples from Belgium, Windal et al. [87] reported a sum concentration of PCDD/Fs plus dl-PCBs of 1.74pg WHO_{2005}-TEQ g^{-1} fat and this was below the maximum limit of 5.5pg WHO_{2005}-TEQ g^{-1} fat. In turn, Zhang et al. [88] measured the concentrations of PCDD/Fs in meat and detected a highest concentration of 0.17pg TEQ/g fw. Wu et al. [89] also measured the PCDD/Fs plus dl-PCBs levels and congener profiles in beef and pork samples from the Guangdong Province. They determined the median total PCDD/Fs+dl-PCBs concentration of 0.174, and 0.113pg TEQ/g fw, respectively. San Martin et al. [90] measured the levels of PCDD/Fs plus dl-PCBs in samples of meat of bovine, pork and ovine collected from 10 Chilean regions. They measured the highest mean concentrations of PCDD/Fs of 0.54pg WHO-TEQ/g fat in all the samples collected. Barone et al. [8] determined the levels of PCDD/Fs (and PCBs) in beef, pork from Italian supermarkets and measured the lowest levels of PCDD/Fs in pork sausage samples of 20.1pg/g lipid weight. Based on this review, many food contaminations have occurred in recent decades and more legislative measures is needed to reduce the occurrence of these contaminants in the environment and to comply with food safety limits. As a result, continuous monitoring of these contaminants in food remains necessary to reduce exposure risks to humans and assess the trends. However, a gradual decline in dietary exposure has been noted in cattle, sheep, pork, and goat's products since the launch of EFSA in 2018.

4.3 Fish and fish products

The consumption of fish is known to have several benefits such as aiding infant development, correcting unbalanced diet and countering obesity [91, 92]. Studies from around the world have reported significant levels of environmental pollutants in fish tissues [44, 47, 92-94]. The human exposure to POPs such as PCDD/Fs and PCBs in fish need to be monitored as these compounds are known to accumulate in fish and shellfish tissues. Blanco et al. [95] reported the levels of PCDD/Fs plus dl-PCBs in fish, seafood, and fish products in Spain. In fish oils, the concentration ranges of 3.3 - 30.7pg WHO_{2005}TEQ g^{-1} fat were reported for PCDD/Fs plus dl-PCBs, while the concentration ranges of <LOD - 1.7pg WHO_{2005} TEQ g^{-1} fat for PCDD/Fs plus dl-PCBs were reported in seafood products. Costopoulou et al. [44] assessed the levels of PCDD/Fs plus dl-PCBs in farmed fish produced from Greece. The mean concentrations of 0.88, 0.68 and 0.43pg WHO_{2005}TEQ g^{-1} ww were detected in sea bream, sea bass and rainbow trout, respectively [44]. For non-dioxin-like polychlorinated biphenyls (ndl-PCBs), they detected 8.02 ng g^{-1} ww in sea bream, 5.24 ng g^{-1} ww in sea bass and 2.90 ng g^{-1} ww in rainbow trout. The concentrations were below the maximum level as set by the EU [44]. Hasegawa et al. [96] analyzed PCDD/Fs plus dl-PCBs in 41 fish oil samples and detected the mean TEQ concentrations of 2.6 and 9.9pg WHO_{1998}-TEQ g^{-1} ww in PCDD/Fs and dl-PCBs, respectively. The concentrations exceeded the maximum levels for both PCDD/Fs and sum of PCDD/Fs plus dl-PCBs.

Mikolajczyk et al. [97] investigated PCDD/Fs and PCBs contamination in freshwater fish and found the PCDD/F concentration of 3.5pg WHO_{2005}-TEQ g^{-1} ww and 6.5pg WHO_{2005}-TEQ g^{-1} ww of dl-PCBs. The most dominant congeners in PCDD/F samples were 2,3,7,8-TCDF and 2,3,4,7,8-PeCDF except in Cracow where 1,2,3,4,7,8-HxCDF was dominant and in dl-PCB samples PCB 118 dominated in fish muscles [97]. In fish samples purchased in Southern Italy supermarkets [98] reported the PCDD/Fs plus dl-PCBs sum concentration of 0.28pg WHO_{2005}-TEQ g^{-1} ww which was below the maximum limit in fish. In the same study, the sum concentration of 0.01 and 0.03pg WHO_{2005}-TEQ g^{-1} ww were reported in cephalopods and crustaceans, respectively which were both below the maximum limit. Also, the sum of six PCBs (fish: 0.07 - 16.7 ng g^{-1} ww; cephalopods: 0.05 - 0.21 ng g^{-1} ww; crustaceans: 0.07 - 0.57 ng g^{-1} ww) were below the level prescribed by the legislation in all the species tested [98]. Zhang et al. [88] measured the concentrations of PCDD/Fs (also DL-PCBs) in aquatic foods, and detected the highest values of 0.44pg TEQ/g fw. In a similar study, Zhang et al. [88] determined the levels of PCDD/Fs in aquatic foods, and measured an average concentration of 0.19pg TEQ/g fw. Wu et al. [89] determined the levels and congener profiles of PCDD/Fs (also DL-PCBs) in freshwater fish from the Guangdong Province and found a sum concentration of 0.488pg TEQ/g fw. In South Korea, Shin et al. [99] analyzed the concentrations of PCDD/Fs in fish samples and detected an average concentration of 0.13pg TEQ/g fw. On the other hand, Barone et al. [98] determined the levels of PCDD/Fs and PCBs in fish collected from Southern Italy supermarkets and determined the greatest mean concentrations of PCDD/Fs of 38.4pg/g lipid fw in crustaceans, 15.1pg/g lipid fw in cephalopods and 21.5 pg/g lipid fw in fish, respectively.

In another study from Italy, the reasearch reported PCDD/Fs plus dl-PCBs sum concentration of 0.5pg WHO_{2005}-TEQ g^{-1} ww and 0.16pg WHO_{2005}-TEQ g^{-1} ww in fish and seafood, respectively [100]. Amongst the seafood group, the most contaminated species was shellfish, followed by crustaceans, and cephalopods being the least contaminated. However, all the concentrations were within the maximum limits set by the EU. In Nile perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*) from Lake Victoria, Ssebugere et al. [101, 102] measured the PCDD/Fs concentration of 0.01 - 0.16 WHO_{2005}TEQ g^{-1} ww, while the dl-PCBs concentration ranged from 0.001 - 0.74pg WHO_{2005}TEQ g^{-1} ww. In Mediterranean, the dl-PCBs concentration in Bluefin tuna was 0.7pg WHO_{2005}-TEQ g^{-1} ww and 1.9pg WHO_{2005}-TEQ g^{-1} ww for PCDD/Fs, their sum concentration of 2.6pg WHO_{2005}-TEQ g^{-1} ww was below the maximum limits allowed for human consumption proposed by EU [100]. In another study from three region of the Algerian coast, the PCDD/Fs plus dl-PCBs sum concentrations of 0.19, 0.27 and 0.08pg WHO_{2005} TEQ g^{-1} ww was detected in Algiers, Bejaia and Oran, respectively [103]. In seafood purchased from Catalan (Spain) market, the mean concentration of PCDD/Fs plus dl-PCBs was 0.97pg WHO_{2005}-TEQ g^{-1} ww and these levels were below the maximum limit set by EU [104]. In fish samples from Benin, Cameroon, Mali and Nigeria, the sum concentration of PCDD/Fs plus dl-PCBs was 4.03pg WHO_{2005}-TEQ g^{-1} fat, and these concentrations were below the EU MRL value of 6.5pg WHO_{2005}-TEQ g^{-1} fat [105]. In the same study reported the ndl-PCB concentration of 852 ng g^{-1} ww which was 20-fold higher the EU MRL value [105].

In summary, more than 90% of human exposure to PCDD/Fs plus dl-PCB is found to be through food supply, mainly eggs, meat, dairy products, fish and shellfish. However, due to aggressive legislative controls implemented PCDD/Fs plus dl-PCBs concentrations in fish is slowly declining. This review shows that the PCDD/Fs plus dl-PCBs concentrations in fish and fish products from different geographical origin show clear variations that are not only related to consumption but also to different legislative controls. According to the European Food Safety Authority (EFSA), 2pg WHO-2005-TEQ per kg body weight (BW) per week is a tolerable weekly intake (TWI) [55]. A significant lack of data on dioxin and dl-PCB concentrations is observed from Africa and Oceania due to lack of studies conducted, and so data from those countries is needed for future evaluations. In the meantime, prevention or reduction of human exposure to such contaminants can be best done by reducing the release of contaminants from source-directed measures by means of strict control of industrial processes to reduce formation of PCDD/Fs and PCBs.

4.4 Human breast milk

The presence of PCDD/Fs and PCBs in the body and their residual concentrations in breast milk raises concerns of infant exposure. Exposure to POPs over a period of time is a major health concern due to a broad range of adverse health effects, including reproduction and developmental effects, neurotoxicity, metabolic syndrome, and obesity [7, 14, 26, 106, 107]. Global Environment Monitoring System of the World Health Organization (GEMS/ WHO) has been collecting data on some POPs in food, including breast milk, for more than 25 years covering 1988 - 1988, 1992 - 1992, and 2000 - 2003 [26]. Breastfed infants are at risk of being exposed to considerable amounts of PCBs and PCDD/Fs during this sensitive period because these compounds are transferred into breast milk. PCDD/Fs plus dl-PCB levels were reported from three cities in Chile [26] and the results showed a PCDD/Fs plus dl-PCBs sum concentration of 4.32 for Coltauco, 6.31 for Arica, and 5.50pg WHO_{2005}-TEQ g^{-1} fat for Molina, respectively (Figure 6). The sum concentration of PCDD/Fs plus dl-PCBs from Arica exceeded the maximum limit in human breast milk.

Vigh et al. [108] investigated the exposure of individuals to PCDD/Fs and PCBs from 22 mothers who delivered their infants during 2007 in Baranya County, Hungary. The samples were collected at three times point days i.e., at day 5, 12 and 84 postpartum and found the total toxic equivalent (TEQ) concentrations of 3.17±1.72, 2.70±1.57 and 2.41±47pg WHO_{2005}-TEQ g^{-1} fat for PCDD/Fs and 33.5±29.2, 27.4±20.6 and 26.9±24.8 ng g^{-1} fat for ndl-PCB, respectively. The concentrations were below the maximum level for both PCDD/Fs plus dl-PCBs [108]. In China, the reasearch reported mean concentration of 6.96 and 2.13pg WHO_{2005}-TEQ g^{-1} lipid for PCDD/Fs and dl-PCBs, respectively [109]. Hue et al. [110] investigated the level of PCDD/Fs in breastmilk from women who lived more than 5 years near the Da Nang Agent Orange hotspot. They detected concentrations of 8.1, 26, 19, and 18pg WHO_{2005}-TEQ g^{-1} fat for Khue Trang, An Khe, Chinh Giang, and Hoa Thuan Tay, respectively. All the concentrations were above the maximum level of PCDD/Fs in milk. Hue et al. [110] investigated the levels and distribution of PCDD/Fs in woman from Bien Hoa airbase, a hotspot in Agent Orange. They found a mean concentration of 13.6, 12.3, and 6.4pg WHO_{2005}-TEQ g^{-1} lipid for Buu Long, Tan Phong, and Trung Dung, respectively. The concentrations were all

above the maximum level allowable in human milk of Spanish lactating mothers [110].

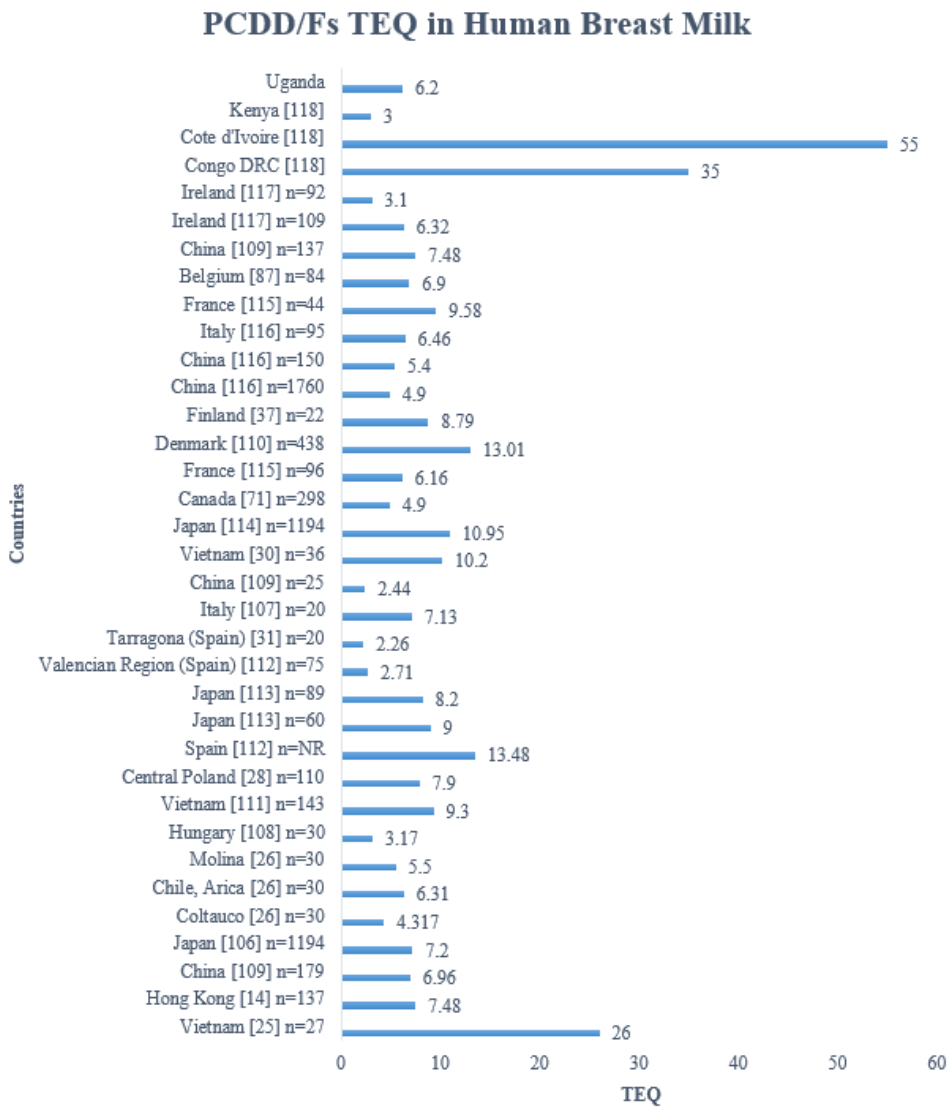

Figure 6. PCDD/Fs concentrations in human breast milk
Note: n=number of samples, NR=not reported

In 2018, González and Domingo [111] measured the sum concentration of PCDD/Fs plus dl-PCB of 9.09pg WHO_{2005}-TEQ g^{-1} fat, this was found to be comparable with the concentration obtained in their 2011 study (8.4 - 9.0pg WHO_{2005}-TEQ g^{-1} fat) indicating that PCDD/Fs plus dl-PCBs were stable during the period of 2011 - 2018 [109]. Then in three other hotspots of Bien Hoa, Phu Cat, and Da Nang (Thanh Khe and Son Tra), the research [111] reported concentrations of 9.3, 14.1, 14.3 and 13.9pg WHO_{2005}-TEQ g^{-1} fat respectively and the major congener from all the sites was TCDD, a major contaminant found in Agent Orange herbicide [111]. Hernández et al. [112] found that, age from lactating Spanish women had a significant impact on milk ∑PCDD/Fs + dl-PCBs levels, with higher concentrations observed in the milk from older mothers. Todaka et al. [113] reported a sum concentration of 9.8pg WHO_{2005}-TEQ g^{-1} fat for PCDD/Fs plus dl-PCBs in breastmilk from mothers from Sapporo City, Japan. A study of different age groups was conducted in Japan, and Zhang et al. [114] investigated the concentrations of PCDD/Fs plus dl-PCBs in mothers in the range of 20-25 years, 26-30 years, and those >31 years. They detected concentrations 15.1, 16.8 and 17.8pg WHO_{2005}-TEQ g^{-1} fat for 20-25, 26-30, >31 years, respectively. The concentrations exceeded the maximum limit in all age groups. In France, Focant et al [115] reported PCDD/Fs plus dl-PCB in breastmilk and detected mean concentration of 17.8pg WHO_{2005}-TEQ g^{-1} fat, which exceeded the maximum limit by 3-fold. In Taiwan, Chen et al. [116] investigated PCDD/Fs in 25 breast milk samples and found means of 2.44 pg WHO_{2005}-TEQ/g lipid. While Tlustos et al. [117] detected relatively lower levels in breast milk of Irish mothers compared with breast milk levels reported for other European countries. Contrary to this, Ssebugere et al. [118] reported that the concentrations of PCDD/Fs and dl-PCBs from Africa were in the same range as those from Asia but lower than those from Europe.

Antignac et al. [119] reported the concentrations of PCDD/Fs, dl-PCBs, and ndl-PCBs in breast milk of French, Danish and Flemish women. They measured a PCDD/Fs plus dl-PCBs sum concentrations of 10.4, 19.8 and 13.6pg WHO_{2005}-TEQ g^{-1} lipid for French, Danish and Flemish breastmilk, respectively [119]. All the concentrations were above the maximum level with French, Danish and Flemish exceeding the level 1.5, 6, 2-fold, respectively. The concentrations of ndl-PCBs detected in the breastmilk from the same study [119] were 85.2, 161, and 104 ng g^{-1} lipid for

breastmilk from French, Danish and Flemish women respectively. The concentrations were more than 2-fold the maximum level set by EU.

In Hong Kong, Wong et al. [14] reported a sum concentration of 11.3pg WHO_{2005}-TEQ g^{-1} fat PCDD/Fs plus dl-PCB and discovered that older mothers and those who stayed longer in area had higher concentrations of PCDD/Fs plus dl-PCB in their milk and this pattern was clearer in PCB though there were variations in PCDD/Fs [14]. Another study in Japan investigated the relationship between PCDD/fs plus dl-PCB concentrations in maternal blood and those in breast milk [106]. The level in maternal blood were higher than those in breast milk and the concentrations reported were 16.6 and 11.2pg WHO_{2005}-TEQ g^{-1} fat for maternal blood and breast milk, respectively. The ndl-PCB pattern followed that of the dioxin-like compounds with concentrations of 120 and 90 ng g^{-1} fat for maternal blood and breast milk, respectively [106].

With high concentrations of PCDD/Fs plus dl-PCB reported in breastmilk, newborns and developing fetus with rapidly developing organ systems are more vulnerable andmost sensitive to PCDD/Fs plus dl-PCB exposure [120]. This review confirms that many countries in the Southern Hemisphere had high levels of PCDD/Fs and PCBs. In Africa, the widest variation in exposure contamination was observed. Kenya and Uganda had the lowest levels of PCDD/Fs, while Côte d'Ivoire and the Democratic Republic of the Congo had the highest levels in these surveys. It is noticeable that the latter countries did not have exceptional high levels of PCBs indicating that the high PCDDs and PCDFs contamination is not associated with PCB-related occurrence. Most Asian countries studied in this review had relatively high levels of PCDD/Fs and PCBs. Limited information was obtained from the Caribbean and Central/ South American countries, but relatively higher levels of PCDDs, PCDFs and PCBs were found from those countries studied, indicating high contamination of human milk with these compounds.

5. ESTIMATING DIETARY EXPOSURE TO PCDD/FS PLUS DL-PCBS AROUND THE WORLD

PCDD/Fs have been found in many foodstuffs including milk, eggs, meat, fishes, and animal feedstuffs. These matrices can be used for estimating the dietary intake of PCDD/Fs, and PCBs in the general population based on the background levels [60]. The estimation of PCDD/Fs plus dl-PCBs dietary intake is significant in determining cancer and non-cancer health risks in different food groups relative to different sex/age groups. Understanding the amount of these contaminants in food is a critical component for evaluating the human exposure and to prevent possible diseases. As part of this initiative, maximum levels for dioxins plus dl-PCB in animal-derived foods and vegetable oils, have been established in the EU to encourage a proactive approach to reduce the PCDD/Fs plus dl-PCBs present in food [121]. World Health Organization recommends that countries conduct regular assessment of human exposure to PCDD/Fs plus dl-PCBs contaminants [26]. Dietary intake estimates are therefore suitable tools for estimating exposure to PCDD/Fs and PCBs and assessing potential health risks in populations.

Table 2 demonstrates different EDI obtained from different food groups in various countries based on studies of risk of exposure to populations. In our current search we have found that the study [111] is one of the few studies conducted/published in recent years, aimed at estimating the dietary intake of PCDD/Fs. EDI can be assessed by using a probabilistic approach, where all data available are used, or by using a deterministic or point estimate approach, where a mean or median value of the parameters are used. Foerster et al. [26] calculated EDI in pg/kg bw/day via the deterministic approach for different infant ages based on Eq. (1), with the following assumptions:

$$EDI=C\times V\times F\times 0.95 \quad (1)$$

Table 2. The recent (2010 - 2021) estimated daily intake (EDI) on PCDD/Fs levels in different food groups [111]

Country	Food	∑PCDD/Fs	EDI	Target Population	References
Luqiao and Yuhang (China)	Rice, vegetable, hen eggs, chicken, duck and carps	ND - 66.86pg WHO-TEQ g^{-1} fw	Luqiao: 805.17pg WHO-TEQ day^{-1} Yuhang: 74.31pg WHO-TEQ/day	General population	[122]
Zhejiang (China)	Rice, fresh milk, milk powder, infant formula, marine fatty fish, marine shellfish, marine fish oil, herbivorous freshwater fish, omnivorous freshwater fish, chicken egg, pork, pork liver and beef	0.02 - 3.64pg WHO-TEQ/g ww	22pg TEQ/kg bw/month	General population	[123]
Guangdong (China)	Beef, freshwater fish and pork	0.113 - 0.488pg TEQ/g fw*	19.17 - 23.26pg TEQ/kg bw/month*	6 - 18 years and 18 - 70 years (male and female)	[89]
12 Provinces (China)	Aquatic food, meat and meat products, egg and egg products, milk and dairy products, cereals, bean products, potatoes and vegetables	0.001 - 0.44pg TEQ/g fw	15.4 - 38.7pg TEQ/kg bw/month*	3 - 6 years, 7 - 12 years, 13 - 17 years, 18 - 44 years, 45 - 59 years, >60 years (male and female)	[124]
Hong Kong (China)	Cereals and their products, meat, poultry, game and their products, eggs and their products, fish and seafood and their products, dairy products, fats and oils, beverages, mixed dishes and other food.	0.011 - 0.440pg TEQ/g*	21.9 pg TEQ/kg bw/month*	20 - 29 years, 30 - 39 years, 40 - 49 years, 50 - 59 years, 60 - 69 years, 70 - 84 years and 20 - 84 years (male and female)	[125]
Greece	Beef, chicken, olive oil, lamb, eggs, formula milk, human milk	0.33 - 7.83pg TEQ/g fat	Human milk: 19.76 - 24.95pg TEQ/kg bw/day*	6 - 12 months	[126]

Germany	Fish, fruits and nuts, vegetables, beverages, cereals, eggs, oily seeds and fruits, dairy products, non-allocated foods	-	Formula milk: 1.60 - 2.24 pg TEQ/kg bw/day* Average consumers: 1.53 - 2.11pg WHO-TEQ/kg bw/day* High-end consumers: 2.85 - 3.56pg WHO-TEQ/kg bw/day*	General population	[127]
Kuwait	Animal feed samples, lamb, beef, chicken, milk and dairy products, eggs and fish	-	1.20 - 3.48pg DR CALUX-BEQ/kg bw/day*	6 - 9 years, 10 - 19 years, 20 - 49 years, >50 years (male and female)	[128]
Valencia (Spain)	Vegetables, cereals, fats and oils, eggs, milk and dairy products, fish products, meat and meat products, and fish oil	0.04 - 1.22pg WHO-TEQ/g	1.17pg WHO-TEQ/kg bw/day	General population	[129]
Japan	Rice and rice products, cereals, seeds, potatoes, sugar and confectionery, fats and oils, pulses, fruits, green vegetables, other vegetables, mushrooms, seaweeds, fish and shellfish, meat, eggs, milk and dairy products, prepared foods, drinking water	-	2000: 2.08pg TEQ/kg bw/day* 2001: 1.45pg TEQ/kg bw/day* 2002: 1.74pg TEQ/kg bw/day*	General population	[130]

Source: Neus Gonzalez, Jose L Domingo

According to the WHO, child growth standards for boys and girls median infant weight (kg) and daily infant intake of breast milk is assumed as following:

- At 2 months old or less the infant weighs 4.6kg, and consumes 780mL of breastmilk.
- At 3 - 4months old, the infant weighs 6.4kg and consumes 900mL of breastmilk.
- At 5 - 6 months old, the infant weighs 7.3kg and consumes 930mL of breastmilk.
- At 7 - 12 months old, the infant weighs 8.7kg and consumes 600mL of breastmilk.
- It is assumed an absorption efficiency of PCBs and PCDD/Fs in the gastrointestinal tract is 95% [26].

Where, C is the concentration of PCDD, PCDF, and DL-PCBs in the pooled sample, expressed in pg TEQ/g of fat; V is the volume of daily breast milk intake adjusted to body weight (bw) per group of age expressed in g/kg bw; and F is the breast milk fat content, expressed in g/100g of milk. An estimation considering the average fat content was also made (fat content of 2.7g/100mL).

When the EDI was estimated with a mean fat content of 2.75 g/100mL, the EDI ranged from 6.7pg TEQ/kg bw/day for 7 - 12 months old, 8.7pg TEQ kg^{-1} bw/day for 2 months old, 10.1pg TEQ kg^{-1} bw/day for 3 - 4 months old and 10.4pg TEQ kg^{-1} bw/day for 5 - 6 months old. It is difficult to compare results of EDI estimations reported from different countries due to varying methodologies used for calculation.

Song et al. [122] measured PCDD/Fs in rice, vegetable, hen eggs, chicken, duck and carps and detected a concentration of up to 66.86pg WHO-TEQ/g fw, although the contaminants were not detected in some food group. Using the measured concentration, Song et al. [122] used a probabilistic approach to estimate the EDI of a general public in Luqiao and Yuhang (China) and found the highest EDI of 805.17pg WHO-TEQ/day in Luqiao and 74.31pg WHO-TEQ/day in Yuhang. The monthly intake of PCDD/Fs plus dl-PCBs were above the provisional tolerable monthly intake (PTMI) set by the Joint FAO/WHO Expert Committee on Food Additives (JECFA). In a similar study, Shen et al. [123] measured PCDD/Fs levels in 620 foods (rice, fresh milk, milk powder, infant formula, marine fatty fish, marine shellfish, marine fish oil, herbivorous freshwater fish, omnivorous freshwater fish, chicken egg, pork, pork liver and beef) near the municipal waste incinerator (MWI) and e-waste disassembling areas. These samples were collected between 2006 - 2015 and detected a concentration ranging from 0.02 - 3.64pg WHO-TEQ g^{-1} ww. Using the concentration measured, they estimated a EDI of 22pg TEQ kg^{-1} bw/month to a general population which was below the standard of 70pg TEQ $(kg\ bw)^{-1}\ month^{-1}$ set by the Joint FAO/WHO Expert Committee on Food Additives (JECFA).

Wu et al. [89] measured a concentration of PCDD/Fs in 226 individual samples of beef, freshwater fish and pork from Guangdong (China) markets and discovered levels between 0.113 - 0.488pg TEQ g^{-1} fw. They estimated EDI levels of 19.17 - 23.26pg TEQ kg^{-1} bw/month for 6 - 18 years and 18 - 70 years (male and female) population. The dietary exposures were all lower than the provisional tolerable monthly intake (PTMI, 70pg TEQ kg^{-1} bw/month) established by Joint FAO/WHO Expert Committee on Food Additive. Zhang et al. [124] measured PCDD/Fs concentrations in 96 food composite samples from eight varieties of food groups from China. They collected samples from aquatic food, meat and meat products, egg and egg products, milk and dairy products, cereals, bean products, potatoes and vegetables and measured a concentration between 0.001 - 0.44pg TEQ g^{-1} fw. Dietary intake of PCDD/Fs plus dl-PCBs of 12 age/gender subgroups of the Chinese population was subsequently estimated between 15.4pg TEQ kg^{-1} bw $month^{-1}$ to 38.7pg TEQ kg^{-1} bw $month^{-1}$ for average population and from 68.5pg TEQ kg^{-1} bw $month^{-1}$ to 226.1pg TEQ kg^{-1} bw $month^{-1}$ for high consumers (the 97.5th percentile). Dietary exposure of children (mean: 32.5pg TEQ kg^{-1} bw $month^{-1}$) was significantly higher than that of the adults (mean: 21.5pg TEQ kg^{-1} bw $month^{-1}$) ($p<0.01$) presumably due to more food consumed by children relative to their body weight compared to adults. The targeted population was 3 - 6 years, 7 - 12 years, 13 - 17 years, 18 - 44 years, 45 - 59 years, >60 years (male and female). Dietary exposures of average population of various subgroups were all

below the PTMI recommended by JECFA.

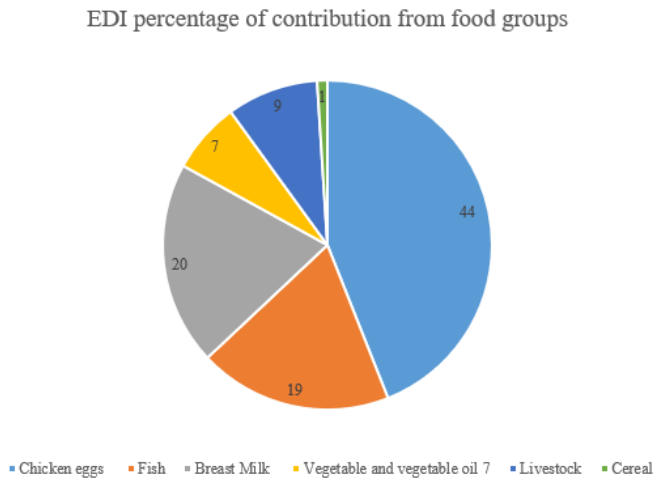

Figure 7. EDI (%) contribution from food categories to the estimated monthly intake of PCDD/Fs and DL-PCBs

Wong et al. [125] analyzed PCDDs, PCDFs and dioxin-like PCBs from a total of 142 composite food samples taken from cereals and their products, meat, poultry, game and their products, eggs and their products, fish and seafood and their products, dairy products, fats and oils, beverages, mixed dishes, and other foods. They measured PCDDs, PCDFs and dioxin-like PCBs concentrations between 0.011 - 0.440pg TEQ g^{-1}. Dietary exposures of Hong Kong adults were estimated between 21.9 and 59.7pg toxic equivalent (TEQ) kg^{-1} body weight (bw) $month^{-1}$ respectively, which was below the recommended limits for Hong Kong population. Costopoulo et al. [126] measured the dietary exposure of infants to PCDD/Fs and dl-PCBs. Their study included two age groups: 0 – 6 months, when infants fed exclusively by human milk and/or formula milk, and 6 – 12 months, when solid food was introduced to nutrition. In the first study group 0 - 6 months they measured a sum of PCDD/Fs and dioxin-like PCBs of 60.3 - 80.4 TEQpg kg^{-1} bw which was significantly higher than that of infants that consumed a combination of human milk and formula (31.2 - 41.6 TEQpg kg^{-1} bw). In the second study group 6 - 12 months for babies receiving human milk, they estimated total daily intake of 19.76 - 24.95 TEQpg kg^{-1} bw) and babies receiving formula milk had estimated total daily intake of 1.60 - 2.24 TEQpg kg^{-1} bw).From the reviewed studies, it can be concluded that chicken eggs contributed at least 44% of estimated monthly intake of PCDD/Fs plus dl-PCBs in different population groups, followed by 20% for breastmilk, and 19% for fish, seafood, shellfish, their products and beef, goats, sheep, and other food products. Although breastmilk contributed 20% EDI, it must be noted that the exposure is only limited to breastfed infants (Figure 7). Most studies made use of the probabilistic approach, involving statistical distributions of contamination and consumption data to calculate a statistical distribution of the daily intake. Only a handful of studies used the deterministic approach where randomness was incorporated.

6. DICUSSIONS AND RESEARCH GAPS

This review reveals that the levels of PCDD/Fs plus dl-PCBs in many developing countries may be increasing due to rudimentary practices during thermal process including waste incinerations, metal industries, recycling, and dumpsites [10, 62]. The exposure of humans to PCDD/Fs plus dl-PCBs is still through consumption of food of animal origin (eggs, milk, and meat) [7]. Few studies in this review showed high concentrations of PCDD/Fs plus dl-PCBs from direct sources (i.e., PCDD/Fs concentration of 661pg WHO_{2005}-TEQ g^{-1} fat in free-range chickens from Agbogbloshie dumpsite in Accra as well as few studies reporting concentrations of PCDD/Fs in area where agent orange was used in the past [62-64, 110, 111, 131]. The review also showed that PCDD/Fs plus dl-PCBs are most investigated in eggs and human breast milk around the globe. Of the few studies performed in Africa, the highest concentration of 661pg WHO_{2005}-TEQ g^{-1} fat for PCDD/Fs has been detected in eggs of free-range chicken from Agbogbloshie, Accra. The major source of the PCDD/Fs was the uncontrolled e-waste activities around the Agbogbloshie dumpsite [62]. The concentration obtained in that study was the highest reported in this review.

Other regions with higher PCDD/Fs in eggs included Buu Long district, Vietnam; Bien Hoa, Vietnam; The Netherland and China with concentration of 361, 249, 248, 214 and 182pg WHO_{2005}-TEQ g^{-1} fat, respectively [20, 63, 64, 111, 110, 131]. The major congener detected in egg samples was TCDD in Vietnam, a major contaminant found in Agent Orange [63, 131]. Consumption of contaminated eggs can lead to significant increases in PCDD/Fs blood serum concentrations for general population including children and adults. It has been shown that soil contaminated with between 2 - 4 ng PCDD/F-TEQ kg^{-1} dry mass (dm) is sufficient to meet or exceed the maximum limit concentration in eggs [7]. There is a significant correlation between TEQ levels in paired eggs and soil as free-range hens are ingesting a high amount of contaminated soil in their feed. Most studies reviewed had a maximum concentration above the EU maximum limits for PCDD/Fs (2.5pg PCDD/F-TEQ g^{-1} fat) or the sum of PCDD/Fs and dioxin-like PCBs (5pg PCDD/Fs+PCBs-TEQ g^{-1} fat). The maximum limits in soil for other gazing animals (i.e., cattle, sheep, goats, etc.) were not yet specified. In human breast milk around the globe, the level of PCDD/Fs were mostly above the maximum limit of 2.5 and 5.5pg WHO_{2005}-TEQ g^{-1} fat for PCDD/Fs and sum PCDD/Fs plus dl-PCBs, respectively [132]. The contamination levels of PCDD/Fs and PCBs in human breast milk are potentially affected by many factors, such as the place where the mother resides, age of the mother, parity, lactation period, and dietary habits [110, 111]. A comprehensive comparison of the results with studies in this review showed that the potential health risks posed by PCDD/Fs and PCBs pollutants were high for mothers and infants.

Although this review shows that emissions of toxic compounds from industrial countries have declined, this may not be the case for the developing world due to rudimentary recycling process as well as reservoir sources (i.e., high concentration from dumpsites in Ghana and high concentration from agent orange hotspots in Vietnam) [62-64]. This observation may call for new inventories of dioxin-like compounds around the globe. National and international organizations should revise the maximum permissible limit of dioxin-like compounds to reduce the contamination of the abiotic environment as this have a direct effect on the levels of these compounds in food, and therefore dietary exposure. The (1) lack of data from other regions such as African, Latin American, and South Asian countries, (2) limited research on dl-PCBs relative to PCDD/Fs; emerging pollutants of concern

(like polybrominated compounds), and (3) the need for more longitudinal data to evaluate dietary exposure over time, need to be investigated further. Although the emission of PCDD/Fs from incineration of municipal solid waste may be decreasing, waste such as medical waste, containing polyvinyl chloride (PVC) is the major source of PCDD/Fs [133]. Thus, health care institutions should implement regulations to minimize the use of PVC plastic as much as possible. As the regulatory limits are decreased, the need to use more sensitive and affordable methods such as soft ionization atmospheric photoionization mass spectrometry (API-MS) is recommended. With waste getting more diversified, the development, validation, and quantification methods for mixed-halide dioxin-like compounds at trace levels is of utmost importance. Further support is needed by laboratories from developing countries like Africa and Latin America in order to develop capacity building to accurately monitor dioxin-like compounds on a routine basis.

7. CONCLUSIONS

The PCDD/Fs plus dl-PCBs concentrations have been reported in food from animal origin around the globe. This review summarized research on PCDD/Fs plus dl-PCBs concentrations in foods of animal origin, including eggs, milk, fish and meat from locations around the globe. Gas chromatography in combination with high-resolution mass spectroscopy or tandem mass spectroscopy were used for PCDD/Fs plus dl-PCBs analysis in foodstuffs. However, there is still a great need to incorporate artificial intelligence with robotic and automated technologies to deal with the new challenges and improve the accuracy of results. Studies showed that chicken eggs and breast milk were the most sentinel studied for PCDD/Fs plus dl-PCBs contamination [7, 35, 55, 60-62]. E-waste activities were the major contributor of PCDD/Fs plus dl-PCBs in eggs while reservoir sources (agent orange hotspot) were the major contributor in breast milk. Due to soil foraging, studies have reported higher PCDD/Fs plus dl-PCBs concentrations in free range eggs as compared to cage or barn eggs [64], therefore maximum permissible concentration of PCDD/Fs and dl-PCB in soil need to be revised as evidence has been presented that 2 - 4 ng WHO_{2005} TEQ g^{-1} are sufficient to meet or exceeds the EU standards for chickens that consume approximately 30 g day^{-1} of soil.

As solid waste becomes more complex, the quantification of mixed halides-dioxin-like compounds become of utmost importance as mixed halogenated congeners and polybrominated dioxins, furans and biphenyls all share many aspects of toxicity and the ability to bind to AH receptor. The synergic interaction between chlorine/ bromine/ fluoride and the precursors must be well understood during combustion and thermal processes as this is how these compounds are transported from the environment into the pathways that lead to human foods. From the literature presented, it is evident that the major route of human exposure to PCDD/Fs plus dl-PCBs is through the food of animal origin. It is therefore recommended that more studies be conducted to further understand the fate and transport of dioxin-like compounds in the environment and biota as well as adverse health impacts of mixed-halide dioxin-like compounds congeners in wildlife and humans. Though there was sufficient data available in most EU countries, data from Canada and South American countries was deemed to be insufficient. Data from African countries were also scarce, and therefore regional, and intercontinental transportation of PCDD/Fs plus dl-PCBs could not be confirmed. Further data on these compounds still need to be generated from these countries to complete the chemical inventories for the continent and to facilitate the implementation of the Stockholm Convention on POPs. Lastly, strict environmental controls of PCDD/Fs plus dl-PCBs emissions remain a priority to minimize the contamination of the surrounding environments.

DECLARATIONS

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AVAILABILITY OF DATA

All data was included in the paper.

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CREDIT AUTHOR STATEMENT

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REFERENCES

[1] Breivik, K., Sweetman, A., Pacyna, J.M., Jones, K.C. (2007). Towards a global historical emission inventory for selected PCB congeners - A mass balance approach: 3. An update. Science of The Total Environment, 377(2-3): 296-307. https://doi.org/10.1016/j.scitotenv.2007.02.026

[2] Kampire, E., Rubidge, G., Adams, J.B. (2017). Characterization of polychlorinated biphenyls in surface sediments of the North End Lake, Port Elizabeth, South Africa. Water SA, 43 (4): 646-654. https://doi.org/10.4314/wsa.v43i4.12

[3] Akinrinade, O.E., Stubbings, W., Abdallah, M.A.E., Ayejuyo, O., Alani, R., Harrad, S. (2020). Status of brominated flame retardants, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons in air and indoor dust in Africa: A review. Emerging Contaminants, 6: 405-420. https://doi.org/10.1016/j.emcon.2020.11.005

[4] Mehouel, F., Bouayad, L., Berber, A., Boutaleb, S., Miri, M., Scippo, M.L. (2021). Health risk assessment of exposure to polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (DL-PCBs) in swordfish from the Mediterranean Sea. Environmental Science and Pollution Research, 28: 26106–26111. https://doi.org/10.1007/s11356-021-12479-8

[5] Perelló, G., Díaz-Ferrero, J., Llobet, J.M., Castell, V., Vicente, E., Nadal, M., Domingo, J.L. (2015). Human

exposure to PCDD/Fs and PCBs through consumption of fish and seafood in Catalonia (Spain): Temporal trend. Food and Chemical Toxicology, 81: 28-33. https://doi.org/10.1016/j.fct.2015.04.010

[6] Bramwell, L., Mortimer, D., Rose, M., Fernandes, A., Harrad, S., Pless-Mulloli, T. (2016). UK dietary exposure to PCDD/Fs, PCBs, PBDD/Fs, PBBs and PBDEs: Comparison of results from 24-h duplicate diets and total diet studies. Food Additives & Contaminants: Part A, 34(1): 65-77. https://doi.org/10.1080/19440049.2016.1258493

[7] Weber, R., Herold, C., Hollert, H., Kamphues, J., Blepp, M., Ballschmiter, K. (2018). Reviewing the relevance of dioxin and PCB sources for food from animal origin and the need for their inventory, control and management. Environmental Sciences Europe, 30: 1-42. https://doi.org/10.1186/s12302-018-0166-9

[8] Barone, G., Storelli, A., Quaglia, N.C., Dambrosio, A., Garofalo, R., Chiumarulo, R., Storelli, M.M. (2019). Dioxin and PCB residues in meats from Italy: Consumer dietary exposure. Food and Chemical Toxicology, 133: 110717. https://doi.org/10.1016/j.fct.2019.110717

[9] Hoogenboom, R.L., Ten Dam, G., van Leeuwen, S.P., van Egmond, H., Nicolina, J., Dwarkasing, A.J. (2021). High levels of dioxins and PCBs in meat, fat and livers of free ranging pigs, goats, sheep and cows from the island of Curaçao. Chemosphere, 263: 128057. https://doi.org/10.1016/j.chemosphere.2020.128057

[10] Rauscher-Gabernig, E., Mischek, D., Moche, W., Prean, M. (2013). Dietary intake of dioxins, furans and dioxin-like PCBs in Austria. Food Additives & Contaminants: Part A, 30(10): 1770-1779. https://doi.org/10.1080/19440049.2013.814169

[11] Bouwman, H. (2004). South Africa and the Stockholm Convention on persistent organic pollutants: Science policy. South African Journal of Science, 100(7): 323-328. https://hdl.handle.net/10520/EJC96286.

[12] Ferreira, A.P., Moreira, M.D.F.R. (2015). Dioxins and furans in breast milk: A case study of mothers from southern Rio de Janeiro, Brazil. Cadernos de Saúde Pública, 31(5): 1107-1111. https://doi.org/10.1590/0102-311X00052914

[13] Petrlik, J., Bell, L., DiGangi, J., Allo'o, S.M.A.O., Kuepouo, G., Ochola, G.O., Grechko, V., Jelinek, N., Strakova, J., Skalsky, M., Drwiega, Y.I., Hogarh, J.N., Akortia, E., Adu-Kumi, S., Teebthaisong, A., Carcamo, M., Beeler, B., Behnisch, P., Baitinger, C., Herold, C., Weber, R. (2022). Monitoring dioxins and PCBs in eggs as sensitive indicators for environmental pollution and global contaminated sites and recommendations for reducing and controlling releases and exposure. Emerging Contaminants, 8: 254-279. https://doi.org/10.1016/j.emcon.2022.05.001

[14] Wong, T.W., Wong, A.H.S., Nelson, E.A.S., Qiu, H., Ku, S.Y.K. (2013). Levels of PCDDs, PCDFs, and dioxin-like PCBs in human milk among Hong Kong mothers. Science of The Total Environment, 463-464: 1230-1238. https://doi.org/10.1016/j.scitotenv.2012.07.097

[15] Fürst, P., Bernsmann, T., Baumeister, D. (2016). Optimization of GC-MS/MS for the determination of dioxins and PCBs in feed and food and comparison of results with GC-HRMS. Dioxin and Related Compounds: Special Volume in Honor of Otto Hutzinger. In Alaee, M. (eds)The Handbook of Environmental Chemistry. Springer, Berlin, 95-120.

[16] Franchina, F.A., Lazzari, E., Scholl, G., Focant, J.F. (2019). Assessment of a new GC-MS/MS system for the confirmatory measurement of PCDD/Fs and (N) DL-PCBs in food under EU regulation. Foods, 8(8): 302. https://doi.org/10.3390/foods8080302

[17] Quinn, L.P. (2010). Doctoral dissertation. Assessment of organic pollutants in selected wild and domesticated bird eggs from Gauteng, South Africa, North-West University. Mafikeng, South Africa.

[18] Polder, A., Müller, M.B., Brynildsrud, O.B., de Boer, J., Hamers, T., Kamstra, J.H., Lie, E., Mdegela, R.H., Moberg, H., Nonga, H.E., Sandvik, M., Skaare, J.U., Lyche, J.L. (2016). Dioxins, PCBs, chlorinated pesticides and brominated flame retardants in free-range chicken eggs from peri-urban areas in Arusha, Tanzania: Levels and implications for human health. Science of The Total Environment, 551-552: 656-667. https://doi.org/10.1016/j.scitotenv.2016.02.021

[19] Petrlík, J., Strakova, J., Skalsky, M., Soroka, M. (2018). Use of Free-Range Poultry Eggs as an Indicator of the Pollution in Eastern Ukraine. Arnika-Citizens Support Centre, Ekodiya: Kyiv-Prague, Ukraine, 1-29.

[20] Kudryavtseva, A.D., Shelepchikov, A.A., Brodsky, E.S. (2020). Free-range chicken eggs as a bioindicator of dioxin contamination in Vietnam, including long-term Agent Orange impact. Emerging Contaminants, 6: 114-123. https://doi.org/10.1016/j.emcon.2020.02.003

[21] Olanca, B., Cakirogullari, G.C., Ucar, Y., Kirisik, D., Kilic, D. (2014). Polychlorinated dioxins, furans (PCDD/Fs), dioxin-like polychlorinated biphenyls (dl-PCBs) and indicator PCBs (ind-PCBs) in egg and egg products in Turkey. Chemosphere, 94: 13-19. https://doi.org/10.1016/j.chemosphere.2013.08.056

[22] Petrlik, J., Hlebarov, I., Digangi, J. (2005). Contamination of Chicken Eggs from Kovachevo, Bulgaria by Dioxins, PCBs and Hexachlorobenzene. Arnika - Toxics and Waste Programme, IPEN, Prague.

[23] Petrlik, J., Ochola, G.O., Mng'anya, S. (2020). Plastic Waste Poisons the Food Chain in Kenya and Tanzania. Arnika - Toxics and Waste Programme, IPEN, Prague.

[24] Hedley, A.J., Wong, T.W., Hui, L.L., Malisch, R., Nelson, E.A. (2006). Breast milk dioxins in Hong Kong and pearl River Delta. Environmental Health Perspectives, 114(2): 202-208. https://doi.org/10.1289/ehp.8116

[25] Hue, N.T.M., Nam, V.D., Thuong, N.V., Huyen, N.T., Phuong, N.T.H., Hung, N.X., Tuan, N.H., Son, L.K., Minh, N.H. (2014). Determination of PCDD/Fs in breast milk of women living in the vicinities of Da Nang Agent Orange hot spot (Vietnam) and estimation of the infant's daily intake. Science of The Total Environment, 491-492: 212-218. https://doi.org/10.1016/j.scitotenv.2014.02.054

[26] Foerster, C., Zúñiga-Venegas, L., Enríquez, P., Rojas, J., Zamora, C., Muñoz, X., Pancetti, F., Muñoz-Quezada, M.T., Lucero, B., Saracini, C., Salas, C., Cortés, S. (2021). Levels of polychlorinated dibenzo-p-dioxins/furans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (DL-PCBs) in human breast milk in chile: A pilot study. International Journal of Environmental Research and Public Health, 18(9): 4825. https://doi.org/10.3390/ijerph18094825

[27] Houlihan, M., Wemken, N., Keogh, M., O'Riordain, C., Noone, C., Tierney, J., Cellarius, C., Cleere, K.,

Morrison, J.J., Daly, S., Harrad, S., Tlustos, C., Coggins, M.A. (2021). Concentrations of polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polychlorinated biphenyls (PCBs) in human milk from Ireland: temporal trends and implications for nursing infant exposure. Journal of Environmental Exposure Assessment, 1(2). https://dx.doi.org/10.20517/jeea.2021.02

[28] Grešner, P., Zieliński, M., Ligocka, D., Polańska, K., Wąsowicz, W., Gromadzińska, J. (2021). Environmental exposure to persistent organic pollutants measured in breast milk of lactating women from an urban area in central Poland. Environmental Science and Pollution Research, 28: 4549-4557. https://doi.org/10.1007/s11356-020-10767-3

[29] Mari, M., Rovira, J., Sánchez-Soberón, F., Nadal, M., Schuhmacher, M., Domingo, J.L. (2017). Environmental trends of metals and PCDD/Fs around a cement plant after alternative fuel implementation: human health risk assessment. Environmental Science: Processes & Impacts, 19(7): 917-927. https://doi.org/10.1039/C7EM00121E

[30] Boda, H., Nghi, T.N., Nishijo, M., Thao, P.N., Tai, P.T., Van Luong, H., Anh, T.H., Morikawa, Y., Nishino, Y., Nishijo, H. (2018). Prenatal dioxin exposure estimated from dioxins in breast milk and sex hormone levels in umbilical cord blood in Vietnamese newborn infants. Science of The Total Environment, 615: 1312-1318. https://doi.org/10.1016/j.scitotenv.2017.09.214

[31] Schuhmacher, M., Mari, M., Nadal, M., Domingo, J.L. (2019). Concentrations of dioxins and furans in breast milk of women living near a hazardous waste incinerator in Catalonia, Spain. Environment international, 125: 334-341. https://doi.org/10.1016/j.envint.2019.01.074

[32] Ae, R., Nakamura, Y., Tada, H., Kono, Y., Matsui, E., Itabashi, K., Ogawa, M., Sasahara, T., Matsubara, Y., Kojo, T., Kotani, K., Makino, N., Aoyama, Y., Sano, T., Kosami, K., Yamashita, M., Oka, A. (2018). An 18-year follow-up survey of dioxin levels in human milk in Japan. Journal of Epidemiology, 28(6): 300-306. https://doi.org/10.2188/jea.JE20170032

[33] Holma-Suutari, A., Ruokojärvi, P., Komarov, A.A. et al. (2016). Biomonitoring of selected persistent organic pollutants (PCDD/Fs, PCBs and PBDEs) in Finnish and Russian terrestrial and aquatic animal species. Environmental Sciences Europe, 28(5). https://doi.org/10.1186/s12302-016-0071-z

[34] Çok, I., Donmez, M.K., Uner, M., Demirkaya, E., Henkelmann, B., Shen, H.Q., Kotalik, J., Schramm, K.W. (2009). Polychlorinated dibenzo-p-dioxins, dibenzofurans and polychlorinated biphenyls levels in human breast milk from different regions of Turkey. Chemosphere, 76(11): 1563-1571. https://doi.org/10.1016/j.chemosphere.2009.05.032

[35] Piskorska-Pliszczyńska, J., Struciński, P., Mikołajczyk, S., Maszewski, S., Rachubik, J., Warenik-Bany, M. (2015). Dioxins, furans, and polychlorinated biphenyls in hen eggs-a new source of hazard for consumers? Journal of Veterinary Research, 59(4): 519-526. https://doi.org/10.1515/bvip-2015-0078

[36] Lee, C.C., Chang, W.H., Lin, H.T., Chang, J.W. (2020). Spatiotemporal patterns of polychlorinated dibenzo-p-dioxins and dibenzofurans and dioxin-like polychlorinated biphenyls in foodstuffs in air quality regions in Taiwan. Journal of Food and Drug Analysis, 28(3): 375-398. https://doi.org/10.38212%2F2224-6614.1216

[37] Rawn, D.F.K., Sadler, A.R., Casey, V.A., Breton, F., Sun, W.F., Arbuckle, T.E., Fraser, W.D. (2017). Dioxins/furans and PCBs in Canadian human milk: 2008-2011. Science of The Total Environment, 595: 269-278. https://doi.org/10.1016/j.scitotenv.2017.03.157

[38] Sun, H.Z., Wang, P., Li, H.H., Li, Y.M., Zheng, S.C., Matsiko, J., Hao, Y.F., Zhang, W.W., Wang, D., Zhang, Q.H. (2017). Determination of PCDD/Fs and dioxin-like PCBs in food and feed using gas chromatography-triple quadrupole mass spectrometry. Science China Chemistry, 60: 670-677. https://doi.org/10.1007/s11426-016-9017-9

[39] Subedi, B., Aguilar, L., Williams, E.S., Brooks, B.W., Usenko, S. (2014). Selective pressurized liquid extraction technique capable of analyzing dioxins, furans, and PCBs in clams and crab tissue. Bulletin of Environmental Contamination and Toxicology, 92: 460-465. https://doi.org/10.1007/s00128-013-1162-9

[40] Geeraerts, C., Focant, J.F., Eppe, G., De Pauw, E., Belpaire, C. (2011). Reproduction of European eel jeopardised by high levels of dioxins and dioxin-like PCBs?. Science of The Total Environment, 409(19): 4039-4047. https://doi.org/10.1016/j.scitotenv.2011.05.046

[41] Baeyens, W., Leermakers, M., Elskens, M., Van Larebeke, N., De Bont, R., Vanderperren, H., Fontaine, A., Degroodt, J.M., Goeyens, L., Hanot, V., Windal, I. (2007). PCBs and PCDD/FS in fish and fish products and their impact on the human body burden in Belgium. Archives of Environmental Contamination and Toxicology, 52: 563-571. https://doi.org/10.1007/s00244-005-0266-6

[42] Roots, O., Kiviranta, H., Pitsi, T., Rantakokko, P., Ruokojarvi, P., Simm, M., Vokk, R., Jarv, L. (2011). Monitoring of polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and polychlorinated biphenyls in Estonian food. Proceedings of the Estonian Academy of Sciences, 60(3): 193-200. https://doi.org/10.3176/proc.2011.3.08

[43] Piskorska-Pliszczynska, J., Maszewski, S., Warenik-Bany, M., Mikolajczyk, S., Goraj, L. (2012). Survey of persistent organochlorine contaminants (PCDD, PCDF, and PCB) in fish collected from the Polish Baltic fishing areas. The Scientific World Journal, 2012: 973292. https://doi.org/10.1100/2012/973292

[44] Costopoulou, D., Vassiliadou, I., Leondiadis, L. (2016). PCDDs, PCDFs and PCBs in farmed fish produced in Greece: Levels and human population exposure assessment. Chemosphere, 146: 511-518. https://doi.org/10.1016/j.chemosphere.2015.12.019

[45] Järv, L., Raid, T., Simm, M., Radin, M., Kiviranta, H., Ruokojärvi, P. (2019). Dioxins and Dioxin-like PCB-s in Perch and Sander of North-Eastern Baltic Sea and Peipsi Lake. In Sustainable Development and Innovations in Marine Technologies, CRC Press, Boca Raton, 605-611.

[46] Augusti, D.V., Magalhaes, E.J., Nunes, C.M., dos Santos, E.V., Prates, R.G.D., Pissinatti, R. (2014). Method validation and occurrence of dioxins and furans (PCDD/Fs) in fish from Brazil. Analytical Methods, 6(6): 1963-1969. https://doi.org/10.1039/C3AY41838C

[47] Pandelova, M., Henkelmann, B., Roots, O., Simm, M., Järv, L., Benfenati, E., Schramm, K.W. (2008). Levels of

PCDD/F and dioxin-like PCB in Baltic fish of different age and gender. Chemosphere, 71(2): 369-378. https://doi.org/10.1016/j.chemosphere.2007.08.050

[48] Guidotti, M., Protano, C., Dominici, C., Chiavarini, S., Cimino, N., Vitali, M. (2013). Determination of selected polychlorinated dibenzo-p-dioxins/furans in marine sediments by the application of gas-chromatography-triple quadrupole mass spectrometry. Bulletin of Environmental Contamination and Toxicology, 90: 525-530. https://doi.org/10.1007/s00128-012-0956-5

[49] Ford, B.A., McElvania, E. (2020). Machine learning takes laboratory automation to the next level. Journal of Clinical Microbiology, 58(4): 10-1128. https://doi.org/10.1128/jcm.00012-20

[50] Gawkowski, P. (2020). LIMS Trends 2020: Digital Transformation Drives Changes in Laboratories. https://solution4labs.com/en/blog/lims/lims-trends-2020, retrieved 4 September 2020.

[51] Rose, M. (2016). Dioxins and dioxin-like compounds in food and feed. Dioxin and Related Compounds: Special Volume in Honor of Otto Hutzinger, In The Handbook of Environmental Chemistry. Springer, Berlin, 253-276.

[52] Squadrone, S., Brizio, P., Nespoli, R., Stella, C., Abete, M.C. (2015). Human dietary exposure and levels of polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), dioxin-like polychlorinated biphenyls (DL-PCBs) and non-dioxin-like polychlorinated biphenyls (NDL-PCBs) in free-range eggs close to a secondary aluminum smelter, Northern Italy. Environmental Pollution, 206: 429-436. https://doi.org/10.1016/j.envpol.2015.07.048

[53] Chang, H.J., Lin, T.F., Whang, L.M., Wu, Y.J. (2016). Congener profiles of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/Fs) in sediment, water, and fish at a soil contamination site in Taiwan. Journal of Environmental Science and Health, Part A, 51(3): 251-261. https://doi.org/10.1080/10934529.2015.1094346

[54] Van den Berg, M., Birnbaum, L.S., Denison, M., De Vito, M., Farland, W., Feeley, M., Fiedler, H., Hakansson, H., Fiedler, H., Hanberg, A., Haws, L., Rose, M., Safe, S., Schrenk, D., Tohyama, C., Tritscher, A., Tuomisto, J., Tysklind, M., Walker, N., Peterson, R.E. (2006). The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. Toxicological sciences, 93(2): 223-241. https://doi.org/10.1093/toxsci/kfl055

[55] Knutsen, H.K., Alexander, J., Barregård, L. et al. (2018). Risk for animal and human health related to the presence of dioxins and dioxin-like PCBs in feed and food. European Food Safety Authontyy,16(11): e05333. https://doi.org/10.2903/j.efsa.2018.5333

[56] Pajurek, M., Pietron, W., Maszewski, S., Mikolajczyk, S., Piskorska-Pliszczynska, J. (2019). Poultry eggs as a source of PCDD/Fs, PCBs, PBDEs and PBDD/Fs. Chemosphere, 223: 651-658. https://doi.org/10.1016/j.chemosphere.2019.02.023

[57] Reiner, E.J. (2016). Analysis of dioxin and dioxin-like compounds. Dioxin and Related Compounds: Special Volume in Honor of Otto Hutzinger. In The Handbook of Environmental Chemistry, Springer, Berlin, 51-94.

[58] Rondoni, A., Asioli, D., Millan, E. (2020). Consumer behaviour, perceptions, and preferences towards eggs: A review of the literature and discussion of industry implications. Trends in Food Science & Technology, 106: 391-401. https://doi.org/10.1016/j.tifs.2020.10.038

[59] Hsu, J.F., Chen, C., Liao, P.C. (2010). Elevated PCDD/F levels and distinctive PCDD/F congener profiles in free range eggs. Journal of Agricultural and Food Chemistry, 58(13): 7708-7714. https://doi.org/10.1021/jf100456b

[60] Lin, Y.C., Wu, T.Y., Chen, Y.M., Hsieh, Y.P., Hu, M.T. (2011). PCDD/F levels in the stacks and food of fast food restaurants. Aerosol and Air Quality Research, 11(4): 437-447. https://doi.org/10.4209/aaqr.2011.05.0056

[61] Olanca, B. (2017). Polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and dioxin-like polychlorinated biphenyls in chicken eggs. In Egg Innovations and Strategies for Improvements. Academic Press, San Diego, 485-498.

[62] Petrlik, J., Adu-Kumi, S., Hogarh, J., Akortia, E., Kuepouo, G., Behnisch, P., Bell, L., DiGangi, J. (2019). Persistent Organic Pollutants (Pops) in Eggs: Report From Africa. Accra-Yaounde-Gothenburg-Prague, IPEN, Arnika-Toxics and Waste Programme, CREPD-Centre de Recherche et d 'Education pour le Développement, 48.

[63] Traag, W.A., Kan, C.A., Van der Weg, G., Onstenk, C., Hoogenboom, L.A.P. (2006). Residues of dioxins (PCDD/Fs) and PCBs in eggs, fat and livers of laying hens following consumption of contaminated feed. Chemosphere, 65(9): 1518-1525. https://doi.org/10.1016/j.chemosphere.2006.04.001

[64] Nghiem, T.X., Hoang, A.Q., Nguyen, T.D., Nguyen, T.T., Tran, P.D., Nguyen, T.T., Tu, M.B. (2022). PCDD/Fs and dioxin-like PCBs in chicken eggs and soils in Dong Nai Province, Southern Vietnam: Impacts of raising methods and nearby pollution sources. Bulletin of Environmental Contamination and Toxicology, 108: 136-144. https://doi.org/10.1007/s00128-021-03419-w

[65] Chang, J.W., Liao, P.C., Lee, C.C. (2012). Dietary intake of PCDD/Fs and dioxin-like PCBs from fresh foods around Taiwan. Journal of Food and Drug Analysis, 20(4): 12. https://doi.org/10.6227/jfda.2012200409

[66] Castellani, F., Manzoli, L., Martellucci, C. A., Flacco, M. E., Astolfi, M. L., Fabiani, L., Mastrantonio, R., Avino, P., Protano, C., Vitali, M. (2021). Levels of polychlorinated dibenzo-p-dioxins/furans and polychlorinated biphenyls in free-range hen eggs in central italy and estimated human dietary exposure. Journal of Food Protection, 84(8): 1455-1462. https://doi.org/10.4315/JFP-21-126

[67] Petrlik, J., Teebthaisong, A., Bell, L., Behnisch, P.A., Da, M., Saetang, P., Ritthichat, A., Kalmykov, D. (2018). PCDD/Fs and PCBs in eggs–data from China, Kazakhstan and Thailand. In Abstracts Book of the Dioxin, Kraków, Poland, 794-798.

[68] Rusin, M., Dziubanek, G., Marchwińska-Wyrwał, E., Ćwieląg-Drabek, M., Razzaghi, M., Piekut, A. (2019). PCDDs, PCDFs and PCBs in locally produced foods as health risk factors in Silesia Province, Poland. Ecotoxicology and Environmental Safety, 172: 128-135. https://doi.org/10.1016/j.ecoenv.2019.01.052

[69] González, N., Marquès, M., Nadal, M., Domingo, J.L. (2018). Levels of PCDD/Fs in foodstuffs in Tarragona County (Catalonia, Spain): Spectacular decrease in the dietary intake of PCDD/Fs in the last 20 years. Food and Chemical Toxicology, 121: 109-114. https://doi.org/10.1016/j.fct.2018.08.035

[70] Lambiase, S., Serpe, F.P., Cavallo, S., Rosato, G., Baldi, L., Neri, B., Esposito, M. (2017). Occurrence of polychlorinated dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs) and polychlorinated biphenyls (PCBs) in eggs from free-range hens in Campania (southern Italy) and risk evaluation. Food Additives & Contaminants: Part A, 34(1): 56-64. https://doi.org/10.1080/19440049.2016.1260167

[71] European Food Safety Authority. (2012). Update of the monitoring of levels of dioxins and PCBs in food and feed. European Food Safety Authority Journal, 10(7): 283. https://doi.org/10.2903/j.efsa.2012.2832

[72] Ingelido, A. M., Abballe, A., Di Domenico, A., Fochi, I., Iacovella, N., Saragosa, A., Spagnesi, M., Valentini, S., De Felip, E. (2009). Levels and profiles of polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and polychlorinated biphenyls in feedstuffs and milk from farms in the vicinity of incineration plants in Tuscany, Italy. Archives of environmental contamination and toxicology, 57: 397-404. https://doi.org/10.1007/s00244-008-9262-y

[73] Lambiase, S., Fiorito, F., Serpe, F.P., Trifuoggi, M., Gallo, P., Esposito, M. (2022). Bioaccumulation of PCDD/Fs and PCBs in free-range hens: Congener fingerprints and biotransfer factors. Chemosphere, 309: 136602. https://doi.org/10.1016/j.chemosphere.2022.136602

[74] Bruce-Vanderpuije, P., Megson, D., Jobst, K., Jones, G.R., Reiner, E., Sandau, C.D., Clarke, E., Adu-Kumi, S., Gardella Jr, J.A. (2019). Background levels of dioxin-like polychlorinated biphenyls (dlPCBs), polychlorinated, polybrominated and mixed halogenated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs, PBDD/Fs & PXDD/Fs) in sera of pregnant women in Accra, Ghana. Science of The Total Environment, 673: 631-642. https://doi.org/10.1016/j.scitotenv.2019.04.060

[75] Scortichini, G., Amorena, M., Brambilla, G., Ceci, R., Chessa, G., Diletti, G., Esposito, M., Nardelli, V. (2016). Sheep farming and the impact of environment on food safety. Small Ruminant Research, 135: 66-74. https://doi.org/10.1016/j.smallrumres.2015.12.013

[76] Piskorska-Pliszczyńska, J., Mikołajczyk, S., Maszewski, S., Warenik-Bany, M. (2012). Study of dioxin levels in raw milk of cows and goats in Poland. Proceedings of ECOpole, 6(1): 77-83. https://doi.org/2012 10.2429/proc.2012.6(1)010

[77] Loutfy, N., Fuerhacker, M., Tundo, P., Raccanelli, S., Ahmed, M.T. (2007). Monitoring of polychlorinated dibenzo-p-dioxins and dibenzofurans, dioxin-like PCBs and polycyclic aromatic hydrocarbons in food and feed samples from Ismailia city, Egypt. Chemosphere, 66(10): 1962-1970. https://doi.org/10.1016/j.chemosphere.2006.07.081

[78] Malisch, R. (2000). Increase of the PCDD/F-contamination of milk, butter and meat samples by use of contaminated citrus pulp. Chemosphere, 40(9-11): 1041-1053. https://doi.org/10.1016/S0045-6535(99)00352-5

[79] Esposito, M., Serpe, F.P., Cavallo, S., Pellicanò, R., Gallo, P., Colarusso, G., D'ambrosio, R., Baldi, L., Lovane, G., Serpe, L. (2010). A survey of dioxins (PCDDs and PCDFs) and dioxin-like PCBs in sheep and goat milk from Campania, Italy. Food Additives and Contaminants: Part B, 3(1): 58-63. https://doi.org/10.1080/19440040903527350

[80] Storelli, M.M., Scarano, C., Spanu, C., De Santis, E.P.L., Busco, V.P., Storelli, A., Marcotrigiano, G.O. (2012). Levels and congener profiles of polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polychlorinated biphenyls (PCBs) in sheep milk from an industrialised area of Sardinia, Italy. Food and Chemical Toxicology, 50(5): 1413-1417. https://doi.org/10.1016/j.fct.2012.01.008

[81] Bruns-Weller, E., Knoll, A., Heberer, T. (2010). High levels of polychlorinated dibenzo-dioxins/furans and dioxin like-PCBs found in monitoring investigations of sheep liver samples from Lower Saxony, Germany. Chemosphere, 78(6): 653-658. https://doi.org/10.1016/j.chemosphere.2009.12.014

[82] Konuspayeva, G., Faye, B., De Pauw, E., Focant, J.F. (2011). Levels and trends of PCDD/Fs and PCBs in camel milk (Camelus bactrianus and Camelus dromedarius) from Kazakhstan. Chemosphere, 85(3): 351-360. https://doi.org/10.1016/j.chemosphere.2011.06.097

[83] Kim, M., Kim, D.G., Yun, S.J., Son, S.W. (2008). Relationship of PCDD/Fs congener profiles between beef and raw milk in South Korea. Chemosphere, 70(9): 1563-1567. https://doi.org/10.1016/j.chemosphere.2007.08.060

[84] Kim, M., Kim, D.G., Choi, S.W., Guerrero, P., Norambuena, J., Chung, G.S. (2011). Formation of polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDD/Fs) from a refinery process for zinc oxide used in feed additives: a source of dioxin contamination in Chilean pork. Chemosphere, 82(9): 1225-1229. https://doi.org/10.1016/j.chemosphere.2010.12.040

[85] Rocha, D.A., Torres, J.P., Reichel, K., Novotny, E.H., Estrella, L.F., Medeiros, R.O., Netto, A.D.P. (2016). Determination of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) in Brazilian cow milk. Science of The Total Environment, 572: 177-184. https://doi.org/10.1016/j.scitotenv.2016.07.179

[86] Pizarro-Aránguiz, N., Galbán-Malagón, C.J., Ruiz-Rudolph, P., Araya-Jordan, C., Maddaleno, A., San Martin, B. (2015). Occurrence, variability and human exposure to polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and dioxin-like polychlorinated biphenyls (DL-PCBs) in dairy products from Chile during the 2011-2013 survey. Chemosphere, 126: 78-87. https://doi.org/10.1016/j.chemosphere.2014.10.087

[87] Windal, I., Vandevijvere, S., Maleki, M., Goscinny, S., Vinkx, C., Focant, J.F., Eppe, G., Hanot, V., Van Loco, J. (2010). Dietary intake of PCDD/Fs and dioxin-like PCBs of the Belgian population. Chemosphere, 79(3): 334-340. https://doi.org/10.1016/j.chemosphere.2010.01.031

[88] Zhang, L., Yin, S.X., Wang, X.Y., Li, J.G., Zhao, Y.F., Li, X.W., Shen, H.T., Wu, Y.N. (2015). Assessment of dietary intake of polychlorinated dibenzo-p-dioxins and dibenzofurans and dioxin-like polychlorinated biphenyls from the Chinese Total Diet Study in 2011. Chemosphere, 137: 178-184. https://doi.org/10.1016/j.chemosphere.2015.07.031

[89] Wu, W.L., Deng, X.L., Zhou, S.J., Liang, H., Yang, X.F., Wen, J.M., Zhang, C.Z., Zhang, Y.H., Zou, F. (2018). Levels, congener profiles, and dietary intake assessment of polychlorinated dibenzo-p-dioxins/dibenzofurans and

dioxin-like polychlorinated biphenyls in beef, freshwater fish, and pork marketed in Guangdong Province, China. Science of The Total Environment, 615: 412-421. https://doi.org/10.1016/j.scitotenv.2017.09.273

[90] San Martín, B.V., Pizarro-Aránguiz, N., García-Mendoza, D., Araya-Jordán, C., Maddaleno, A., Abad, E., Galbán-Malagón, C.J. (2016). A four-year survey in the farming region of Chile, occurrence and human exposure to polychlorinated dibenzo-p-dioxins and dibenzofurans, and dioxin-like polychlorinated biphenyls in different raw meats. Science of The Total Environment, 573: 1278-1286. https://doi.org/10.1016/j.scitotenv.2016.06.132

[91] Food and Agriculture Organization of the United Nations (2016). The State of World Fish and Aquaculture: Contributing to Food Security and Nutrition for All. Rome, 200.

[92] Chokwe, T.B., Krüger, E., Magubane, M.N., Abafe, O. A., Mporetji, S.M., Okonkwo, J.O., Sibali, L.L., Hariram, R. (2022). Legacy and novel brominated flame-retardants in different fish types from inland freshwaters of South Africa: levels, distribution and implications for human health. International Journal of Environmental Health Research, 32(2), 321-331. https://doi.org/10.1080/09603123.2020.1757042

[93] Leong, Y.H., Chiang, P.N., Jaafar, H.J., Gan, C.Y., Majid, M.I.A. (2014). Contamination of food samples from Malaysia with polychlorinated dibenzo-p-dioxins and dibenzofurans and estimation of human intake. Food Additives & Contaminants: Part A, 31(4): 711-718. https://doi.org/10.1080/19440049.2014.880519

[94] Azlan, A., Mohamad Nasir, N.N., Shamsudin, N., Rahman, H.A., Khoo, H.E., Razman, M.R. (2015). PCDD and PCDF exposures among fishing community through intake of fish and shellfish from the Straits of Malacca. BMC public health, 15(1): 1-13. https://doi.org/10.1186/s12889-015-2044-3

[95] Blanco, L., Martínez, A., Ferreira, M., Vieites, J., Cabado, A. (2013). Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (dl-PCBs) in fish, seafood products and fish oil in Spain. Food Additives & Contaminants: Part B, 6(3): 218-230. https://doi.org/10.1080/19393210.2013.804590

[96] Hasegawa, J., Guruge, K. S., Seike, N., Shirai, Y., Yamata, T., Nakamura, M., Handa, H., Yamanaka, N., Miyazaki, S. (2007). Determination of PCDD/Fs and dioxin-like PCBs in fish oils for feed ingredients by congener-specific chemical analysis and CALUX bioassay. Chemosphere, 69(8): 1188-1194. https://doi.org/10.1016/j.chemosphere.2007.06.021

[97] Mikolajczyk, S., Warenik-Bany, M., Maszewski, S., Pajurek, M. (2020). Dioxins and PCBs-Environment impact on freshwater fish contamination and risk to consumers. Environmental Pollution, 263: 114611. https://doi.org/10.1016/j.envpol.2020.114611

[98] Barone, G., Giacominelli-Stuffler, R., Garofalo, R., Castiglia, D., Storelli, M.M. (2014). PCBs and PCDD/PCDFs in fishery products: Occurrence, congener profile and compliance with European Union legislation. Food and Chemical Toxicology, 74: 200-205. https://doi.org/10.1016/j.fct.2014.09.020

[99] Shin, E.S., Kim, J., Choi, S.D., Kang, Y.W., Chang, Y.S. (2016). Estimated dietary intake and risk assessment of polychlorinated dibenzo-p-dioxins and dibenzofurans and dioxin-like polychlorinated biphenyls from fish consumption in the Korean general population. Chemosphere, 146: 419-425. https://doi.org/10.1016/j.chemosphere.2015.10.089

[100] Barone, G., Storelli, A., Garofalo, R., Mallamaci, R., Quaglia, N.C., Storelli, M.M. (2018). PCBs and PCDD/Fs in bluefin tuna: occurrence and dietary intake. International Journal of Environmental Research and Public Health, 15(5): 911. https://doi.org/10.3390/ijerph15050911

[101] Ssebugere, P., Kiremire, B.T., Henkelmann, B., Bernhöft, S., Wasswa, J., Kasozi, G.N., Schramm, K.W. (2013). PCDD/Fs and dioxin-like PCBs in surface sediments from Lake Victoria, East Africa. Science of The Total Environment, 454-455: 528-533. https://doi.org/10.1016/j.scitotenv.2013.03.046

[102] Ssebugere, P., Kiremire, B.T., Henkelmann, B., Bernhöft, S., Kasozi, G.N., Wasswa, J., Schramm, K.W. (2013). PCDD/Fs and dioxin-like PCBs in fish species from Lake Victoria, East Africa. Chemosphere, 92(3): 317-321. https://doi.org/10.1016/j.chemosphere.2013.03.033

[103] Moussaoui, Y., Tuduri, L., Kerchich, Y., Meklati, B. Y., Eppe, G. (2012). Atmospheric concentrations of PCDD/Fs, dl-PCBs and some pesticides in northern Algeria using passive air sampling. Chemosphere, 88(3): 270-277. https://doi.org/10.1016/j.chemosphere.2012.02.025

[104] Bocio, A., Domingo, J.L., Falcó, G., Llobet, J.M. (2007). Concentrations of PCDD/PCDFs and PCBs in fish and seafood from the Catalan (Spain) market: Estimated human intake. Environment International, 33(2): 170-175. https://doi.org/10.1016/j.envint.2006.09.005

[105] Barone, G., Storelli, A., Busco, A., Mallamaci, R., Storelli, M.M. (2021). Polychlorinated dioxins, furans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (dl-PCBs) in food from Italy: Estimates of dietaryintake and assessment. Journal of Food Science, 86(10): 4741-4753. https://doi.org/10.1111/1750-3841.15901

[106] Todaka, T., Hirakawa, H., Kajiwara, J., Hori, T., Tobiishi, K., Yasutake, D., Onozuka, D., Sasaki, S., Miyashita, C., Yoshioka, E., Yuasa, M., Kishi, R., Iida, T., Furue, M. (2010). Relationship between the concentrations of polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and polychlorinated biphenyls in maternal blood and those in breast milk. Chemosphere, 78(2): 185-192. https://doi.org/10.1016/j.chemosphere.2009.09.047

[107] Roberto, M., Fabiola, F., Valter, C., Silva, F., Rita, F. A., Nicola, I., Maria, I.A., Elena, D.F. (2018). Chemical indicators of exposure to polychlorodibenzo-p-dioxins, polychlorodibenzofurans and polychlorobiphenyls in breast milk samples from mothers residing in Trento, Italy, and neighboring country municipalities. Journal of Environmental Science and Health, Part B, 53(8): 510-518. https://doi.org/10.1080/03601234.2018.1462920

[108] Vigh, É., Colombo, A., Benfenati, E., Håkansson, H., Berglund, M., Bódis, J., Garai, J. (2013). Individual breast milk consumption and exposure to PCBs and PCDD/Fs in Hungarian infants: A time-course analysis of the first three months of lactation. Science of The Total

Environment, 449: 336-344. https://doi.org/10.1016/j.scitotenv.2013.01.024
[109] Huang, R., Wang, P., Zhang, J., Chen, S., Zhu, P., Huo, W., Peng, J. (2019). The human body burden of polychlorinated dibenzo-p-dioxins/furans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (DL-PCBs) in residents' human milk from Guangdong Province, China. Toxicology Research, 8(4): 552-559. https://doi.org/10.1039/c8tx00337h
[110] Hue, N.T.M., Van Thuong, N., Mai, P.T.N., Minh, N. H. (2018). Site-specific bioaccumulation of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/PCDFs) in mothers and their infants living in vicinity of Bien Hoa airbase, Southern Vietnam. Environmental Geochemistry and Health, 40(6): 2539-2549. https://doi.org/10.1007/s10653-018-0118-8
[111] González, N., Domingo, J.L. (2021). Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) in food and human dietary intake: An update of the scientific literature. Food and Chemical Toxicology, 157: 112585. https://doi.org/10.1016/j.fct.2021.112585
[112] Hernández, C.S., Pardo, O., Corpas-Burgos, F., Fernández, S.F., López, A., Coscollà, C., Vento, M., Yusà, V. (2020). Biomonitoring of polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and dioxin-like polychlorinated biphenyls (dl-PCBs) in human milk: Exposure and risk assessment for lactating mothers and breastfed children from Spain. Science of The Total Environment, 744: 140710. https://doi.org/10.1016/j.scitotenv.2020.140710
[113] Todaka, T., Hirakawa, H., Kajiwara, J., Hori, T., Tobiishi, K., Onozuka, D., Kato, S., Sasaki, S., Nakajima, S., Saijo, Y., Sata, F., Kishi, R., Iida, T., Furue, M. (2008). Concentrations of polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and dioxin-like polychlorinated biphenyls in blood and breast milk collected from 60 mothers in Sapporo City, Japan. Chemosphere, 72(8): 1152-1158. https://doi.org/10.1016/j.chemosphere.2008.03.050
[114] Zhang, L., Pei, Z., Lyu, B., Li, J., Zhao, Y., Wu, Y. (2023). Polychlorinated dibenzo-p-dioxins and dibenzofurans and dioxin-like polychlorinated biphenyls in human milk from national human breast milk monitoring in 2016–2019 in China. Science of The Total Environment, 872: 162243. https://doi.org/10.1016/j.scitotenv.2023.162243
[115] Focant, J.F., Fréry, N., Bidondo, M.L., Eppe, G., Scholl, G., Saoudi, A., Oleko, A., Vandentorren, S. (2013). Levels of polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and polychlorinated biphenyls in human milk from different regions of France. Science of the Total Environment, 452-453: 155-162. https://doi.org/10.1016/j.scitotenv.2013.02.057
[116] Chen, M.W., Castillo, B.A.A., Lin, D.Y., Chao, H.R., Tayo, L.L., Gou, Y.Y., Chen, F.A., Huang, K.L. (2018). Levels of PCDD/Fs, PBDEs, and PBDD/Fs in breast milk from southern Taiwan. Bulletin of environmental contamination and toxicology, 100: 369-375. https://doi.org/10.1007/s00128-018-2278-8
[117] Tlustos, C., Anderson, W., Flynn, A., Pratt, I. (2014). Exposure of the adult population resident in Ireland to dioxins and PCBs from the diet. Food Additives & Contaminants: Part A, 31(6): 1100-1113. https://doi.org/10.1080/19440049.2014.905713
[118] Ssebugere, P., Sillanpää, M., Matovu, H., Mubiru, E. (2019). Human and environmental exposure to PCDD/Fs and dioxin-like PCBs in Africa: A review. Chemosphere, 223: 483-493.
[119] Antignac J.P., Main K.M., Virtanen H.E. et al. (2016). Country-specific chemical signatures of persistent organic pollutants (POPs) in breast milk of French, Danish and Finnish women. Environmental Pollution, 218: 728-738. https://doi.org/10.1016/j.chemosphere.2019.02.065
[120] Koskenniemi, J.J., Virtanen, H.E., Kiviranta, H., Damgaard, I.N., Matomäki, J., Thorup, J.M., Toppari, J. (2015). Association between levels of persistent organic pollutants in adipose tissue and cryptorchidism in early childhood: A case-control study. Environmental Health, 14(1): 1-10. https://doi.org/10.1186/s12940-015-0065-0
[121] Xu, W., Cai, Z. (2015). Risk assessment of dietary exposure to PCDD/Fs, DL-PCBs and NDL-PCBs of Hong Kong resident. Science China Chemistry, 58: 1082-1088. https://doi.org/10.1007/s11426-014-5309-2
[122] Song, Y., Wu, N.X., Han, J.L., Shen, H.T, Tan, Y.F, Ding, G.Q, Xiang, J.X., Tao, H., Jin, S.L. (2011). Levels of PCDD/Fs and DL-PCBs in selected foods and estimated dietary intake for the local residents of Luqiao and Yuhang in Zhejiang, China. Chemosphere, 85(3): 329-334. https://doi.org/10.1016/j.chemosphere.2011.06.094
[123] Shen, H.T., Guan, R.F., Ding, G.Q., Chen, Q., Lou, X.M., Chen, Z.J., Xing, M.L., Han, Y.L., Wu, Y.N. (2017). Polychlorinated dibenzo-p-dioxins/furans (PCDD/Fs) and polychlorinated biphenyls (PCBs) in Zhejiang foods (2006–2015): Market basket and polluted areas. Science of The Total Environment, 574: 120-127. https://doi.org/10.1016/j.scitotenv.2016.09.038
[124] Zhang, L., Li, J.G., Liu, X., Zhao, Y.F., Li, X.L., Wen, S., Wu, Y.N. (2013). Dietary intake of PCDD/Fs and dioxin-like PCBs from the Chinese total diet study in 2007. Chemosphere, 90(5): 1625-1630. https://doi.org/10.1016/j.chemosphere.2012.08.040
[125] Wong, W.W., Yip, Y.C., Choi, K.K., Ho, Y.Y., Xiao, Y. (2013). Dietary exposure to dioxins and dioxin-like PCBs of Hong Kong adults: Results of the first Hong Kong total diet study. Food Additives & Contaminants: Part A, 30(12): 2152-2158. https://doi.org/10.1080/19440049.2013.849388
[126] Costopoulou, D., Vassiliadou, I., Leondiadis, L. (2013). Infant dietary exposure to dioxins and dioxin-like compounds in Greece. Food and Chemical Toxicology, 59: 316-324. https://doi.org/10.1016/j.fct.2013.06.012
[127] Schwarz, M.A., Lindtner, O., Blume, K., Heinemeyer, G., Schneider, K. (2014). Dioxin and dl-PCB exposure from food: the German LExUKon project. Food Additives & Contaminants: Part A, 31(4): 688-702. https://doi.org/10.1080/19440049.2013.878041
[128] Husain, A., Gevao, B., Dashti, B., Brouwer, A., Behnisch, P.A., Al-Wadi, M., Al-Foudari, M. (2014). Screening for PCDD/Fs and dl-PCBs in local and imported food and feed products available across the State of Kuwait and assessment of dietary intake. Ecotoxicology and Environmental Safety, 100: 27-31. https://doi.org/10.1016/j.ecoenv.2013.12.002
[129] Marin, S., Villalba, P., Diaz-Ferrero, J., Font, G., Yusà, V. (2011). Congener profile, occurrence and

estimated dietary intake of dioxins and dioxin-like PCBs in foods marketed in the Region of Valencia (Spain). Chemosphere, 82(9): 1253-1261. https://doi.org/10.1016/j.chemosphere.2010.12.033

[130] Nakatani, T., Yamamoto, A., Ogaki, S. (2011). A survey of dietary intake of polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and dioxin-like coplanar polychlorinated biphenyls from food during 2000-2002 in Osaka City, Japan. Archives of Environmental Contamination and Toxicology, 60(3): 543-555. https://doi.org/10.1007/s00244-010-9553-y

[131] Hoang, T.T., Traag, W.A., Murk, A.J., Hoogenboom, R.L.A.P. (2014). Levels of polychlorinated dibenzo-p-dioxins, dibenzofurans (PCDD/Fs) and dioxin-like PCBs in free range eggs from Vietnam, including potential health risks. Chemosphere, 114: 268-274. https://doi.org/10.1016/j.chemosphere.2014.05.010

[132] Deng, B., Zhang, J.Q., Zhang, L.S., Jiang, Y.S., Zhou, J., Fang, D.K., Zhang, H.M., Huang, H.Y. (2012). Levels and profiles of PCDD/Fs, PCBs in mothers' milk in Shenzhen of China: Estimation of breast-fed infants' intakes. Environment International, 42: 47-52. https://doi.org/10.1016/j.envint.2011.03.022

[133] Pan, X.C., Yan, J.H., Xie, Z.M. (2013). Detoxifying PCDD/Fs and heavy metals in fly ash from medical waste incinerators with a DC double arc plasma torch. Journal of Environmental Sciences, 25(7): 1362-1367. https://doi.org/10.1016/S1001-0742(12)60196-X

NOMENCLATURE

PCDD/Fs	Polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans
dl-PCBs	Dioxin-like polychlorinated biphenyls
ndl-PCBs	Non-dioxin-like polychlorinated biphenyls
PCBs	Polychlorinated biphenyls
POPs	Persistent organic pollutants
HRGC	High resolution gas chromatography
HRMS	High-resolution mass spectroscopy
ASE	Accelerated solvent extraction
TCDD	Tetrachlorodibenzo-p-dioxin
TCDF	Tetrachlorodibenzofuran
TDI	Tolerable daily intake
TEQ	Total toxic equivalent
TEFs	Toxic equivalent factors
EDI	Estimated daily intake
I-TEFs	The international toxic equivalency factors
PLE	Pressurized Liquid Extraction
GC-MS	Gas chromatography-mass spectrometry
EFSA	European Food Safety Authority
TWI	Tolerable weekly intake
TDI	Tolerable daily intake
HxCDF	Hexachlorodibenzofuran
PeCDD	Pentachlorodibenzo-P-dioxin
PeCDF	Pentachlorodibenzofuran