

Quantitative Analysis of Dioxins and Dioxin-like Polychlorinated Biphenyls in İnci Kefali (*Alburnus tarichi*, Güldenstädt, 1814): Implications for Public Health Risk Assessment

İnci Kefali (Alburnus tarichi, Güldenstädt, 1814)'nde Dioksin ve Dioksin Benzeri Poliklorlu Bifenillerin Kantitatif Analizi: Halk Sağlığı Risk Değerlendirmesi Açısından Sonuçları

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ABSTRACT

Objective: Polychlorinated dibenzo-p-dioxin and furans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (dl-PCBs) classified as persistent organic pollutants can enter the human food chain, especially through animal-based products like fish, and pose significant toxicological risks. The inci kefali (*Alburnus tarichi*, Güldenstädt, 1814) an endemic species in Lake Van, is a widely consumed fish by the local population. Therefore, assessing the levels of these pollutants in inci kefali is of considerable importance for public health monitoring and risk assessment.

Material and Method: In this study, a total of 30 inci kefali specimens were collected from ten different local fishers in Van Province. Sample preparation was performed in an accredited laboratory authorized by the Turkish Ministry of Agriculture, following EPA standard methods. PCDD/Fs, dl-PCBs, and indicator PCBs were analyzed by APGC-MS/MS using isotope dilution with ¹³C-labeled internal standards.

Results: The mean concentrations of PCDD/Fs, PCDD/Fs + dl-PCBs and indicator PCBs in the analyzed samples were found to be 0.056 ± 0.008 pgWHO-TEQ/g wet weight, 0.220 ± 0.019 pgWHO-TEQ/g wet weight and 0.135 ± 0.010 ng/g wet weight, respectively. The Tolerable Daily Intake (TDI) and Tolerable Weekly Intake (TWI) were calculated as 0.063 pgWHO-TEQ/kg body weight/day and 0.440 pgWHO-TEQ/kg body weight/week, respectively.

Conclusion: The results show that PCDD/Fs, PCDD/Fs + dl-PCBs, and indicator PCBs in inci kefali samples obtained from Lake Van are well below the legal limits set by the European Commission and the Turkish Food Codex. Furthermore, TDI and TWI values were also found to be below the limits set by the European Food Safety Authority. These findings show that inci kefali consumption does not currently pose a significant health risk to human health.

Keywords: Dioxins, Dioxin-like polychlorinated biphenyls, İnci kefali, APGC-MS/MS

ÖZET

Giriş: Kalıcı organik kirleticiler olarak sınıflandırılan poliklorlu dibenzo-p-dioksin ve furanlar (PCDD/F'ler) ve dioksin benzeri poliklorlu bifeniller (dl-PCB'ler), özellikle balık gibi hayvansal ürünler yoluyla insan besin zincirine girebilir ve önemli toksikolojik riskler oluşturabilir. Van Gölü'ne endemik bir tür olan inci kefali (*Alburnus tarichi*, Güldenstädt, 1814), yerel halk tarafından yaygın olarak tüketilen bir balıktır. Bu nedenle, inci kefali'deki bu kirleticilerin seviyelerinin değerlendirilmesi, halk sağlığı izleme ve risk değerlendirmesi açısından büyük önem taşımaktadır.

Materyal ve Metot: Bu çalışmada, Van ilindeki on farklı yerel balıkçıdan toplam 30 inci kefali örneği toplanmıştır. Örnek hazırlama, Tarım Bakanlığı tarafından yetkilendirilmiş akredite bir laboratuvarında, EPA standart yöntemleri izlenerek gerçekleştirilmiştir. PCDD/F'ler, dl-PCB'ler ve indikatör PCB'ler, ¹³C etiketli iç standartlarla izotop seyreltmesi kullanılarak APGC-MS/MS ile analiz edilmiştir.

Bulgular: Analiz edilen örneklerdeki PCDD/F, PCDD/F + dl-PCB ve indikatör PCB'lerin ortalama konsantrasyonları sırasıyla 0.056 ± 0.008 pgWHO-TEQ/g ıslak ağırlık, 0.220 ± 0.019 pgWHO-TEQ/g ıslak ağırlık ve 0.135 ± 0.010 ng/g ıslak ağırlık olarak bulundu. Toleranslı Günlük Alım (TDI) ve Toleranslı Haftalık Alım (TWI) sırasıyla 0.063 pgWHO-TEQ/kg vücut ağırlığı/gün ve 0.440 pgWHO-TEQ/kg vücut ağırlığı/hafta olarak hesaplandı.

Sonuç: Sonuçlar, Van Gölü'nden elde edilen inci kefali örneklerindeki PCDD/F'ler, PCDD/F + dl-PCB'ler ve indikatör PCB'lerin Avrupa Komisyonu ve Türk Gıda Kodeksi tarafından belirlenen yasal limitlerin oldukça altında olduğunu göstermektedir. Ayrıca, TDI ve TWI değerleri de Avrupa Gıda Güvenliği Otoritesi tarafından belirlenen sınırların altında bulunmuştur. Bu bulgular, inci kefali tüketiminin insan sağlığı açısından şu an için önemli bir sağlık riski taşımadığını göstermektedir.

Anahtar kelimeler: Dioksinler, Dioksin benzeri poliklorlu bifeniller, İnci kefali, APGC-MS/MS

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INTRODUCTION

Polychlorinated dibenzo-p-dioxins/furans (PCDDs/PCDFs) and dioxin-like PCBs (dl-PCBs) are toxic persistent organic pollutants (POPs) characterized by stable polyhalogenated aromatic

structures (Barone et al., 2021). PCDDs feature two chlorinated benzene rings linked by two oxygen bridges, PCDFs by one oxygen bridge, and PCBs consist of chlorinated biphenyls (Figure 1).

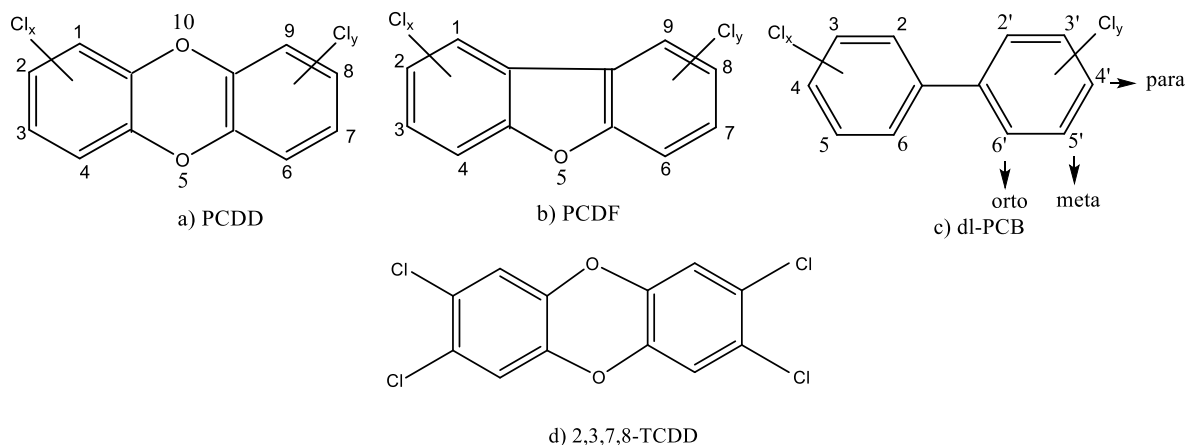


Figure 1. Chemical structures of PCDD (a), PCDF (b), dl-PCB (c), and 2,3,7,8-TCDD (d) (Leeuwen et al., 2005).

Chlorine atoms attach to specific positions on the molecular skeleton, producing 75 PCDD and 135 PCDF congeners, totaling 210 dioxin-like compounds. Twelve PCBs share structural and toxicological properties with PCDD/Fs. Toxicity of congeners varies with chlorine number and position. 2,3,7,8-TCDD (Figure 1) is the most toxic PCDD (Hişmioğulları et al., 2012). PCDD/Fs, primarily by-products, enter the environment via natural sources (volcanic eruptions, forest fires) and anthropogenic activities (waste incineration, chlorine bleaching in paper production, chlorinated pesticide synthesis, cement kilns, coal power plants). PCBs were widely used as insulating fluids and in various industrial products. Currently, they are released unintentionally during synthesis or combustion of chlorinated compounds like pesticides, paints, PVC, etc. (Druga et al., 2021). These pollutants can bioaccumulate in fatty tissues due to their lipophilic (fat-soluble) nature and are not easily eliminated from the body. Their chemical and biological stability, persistence in the environment, and potential to threaten human health through the food chain make them significant global pollutants (Arıkan et al., 2009; Pacini et al., 2013). Fish and seafood consumed through diet are among the primary sources of exposure to these contaminants. Therefore, monitoring these contaminants is crucial for ensuring food safety and public health. Their toxic effects occur through interaction with the aryl hydrocarbon receptor (AHR). This activation leads to adverse effects including chloracne, neurotoxicity, immunotoxicity, developmental and reproductive disorders, wasting syndrome, and cancers (Barroso et al., 2021). PCDD/Fs and dl-PCBs congeners in fish and related matrices are analyzed using sensitive techniques such as gas chromatography (GC)/mass spectrometry (MS) and tandem mass spectrometry (MS/MS). Bioassays like the aryl hydrocarbon

receptor-dependent chemical activated luciferase (AhR-dependent CALUX) gene expression assay and immunological methods such as enzyme immunoassays (EIA) employing anti-dioxin antibodies are also utilized. Sample preparation often involves the Quick, Easy, Cheap, Effective, Rugged and Safe (QuEChERS) method for efficient extraction and cleanup prior to analysis (Çetintürk et al., 2025; Nagyová and Tölgyessy, 2019).

Determining contaminant levels in aquatic organisms such as fish is crucial for assessing potential public health risks in line with regulatory standards. Due to its status as Türkiye's largest closed basin, Lake Van may be vulnerable to the accumulation POPs such as PCDD/Fs and dl-PCBs. Past anthropogenic practices, particularly uncontrolled waste incineration, poor management of chlorinated organic compounds, and the use of PCB-containing products may have contributed to the formation and transport of these pollutants to the lake environment. However, no published studies currently address POP pollution in Lake Van.

In this study, the concentrations of PCDD/Fs and dl-PCBs were quantified in the inci kefalı (*Alburnus tarichi*, Gldenstdt, 1814), an endemic species of Lake Van, employing high-sensitivity APGC-MS/MS. Additionally, compliance with relevant national and international regulatory limits was assessed, and the potential public health risks arising from dietary exposure through the consumption of this fish were examined.

MATERIALS and METHODS

Fish Samples

In this study, a total of 30 fish samples (69-131 g), were collected from ten fishermen in Van province (October 2024). After the muscle tissues of the fish

were carefully separated under sterile conditions, the samples were stored at -20 °C until analysis.

Solvents, Standards and Quantification

All solvents (toluene, isooctane, dichloromethane, n-hexane, cyclohexane, 2-propanol and sodium sulfate) were purchased from Merck (Darmstadt, Germany). The standards EDF-7999, EDF-8999, EC-4986, EC-4987, EC-5179, EC-4187, EC-4188, EC-4058, ED-911, ED-996 and ED-907, all obtained from Cambridge Isotope Laboratories (CIL, USA), were used in the analysis. Dioxins (PCDD/PCDFs) were quantitatively determined using a 7-point calibration curve with a range of 0.02 to 20 pg/ μ L, and non-ortho, mono-ortho, and indicator PCBs were determined using an 8-point calibration curve with a range of 0.10 to 50 pg/ μ L. For PCDD/PCDF and dl-PCB analysis, ^{13}C -labeled analogues of the target congeners were added to standards and samples prior to analysis. The mass spectrometer measured both isotopically labeled (^{13}C) and unlabeled (^{12}C) mass-to-charge (m/z) values of the analytes, and concentrations were determined based on the ratios of these two signals.

Extraction, Clean-up, and APGC-MS/MS Analysis Conditions

Analysis of PCDD/Fs and dl-PCBs in fish samples was conducted at an accredited laboratory approved by the Republic of Türkiye Ministry of Agriculture and Forestry. Composite sampling was used: muscle tissues from 30 fish were homogenized, and 53.445 g (wet weight) of this homogenate (total lipid content: 3.05%) was analyzed as a representative sample. Analyses of PCDD/F, dl-PCB, and indicator PCB congeners were conducted using APGC-MS/MS with isotope dilution, employing ^{13}C -labeled internal standards. The analysis of PCDD/Fs was carried out using EPA Method 1613 Revision B, which employs isotope dilution combined with high-resolution gas chromatography and high-resolution mass spectrometry (EPA, 1994) to detect tetra- to octachlorinated dioxins and furans. EPA Method 1668B (USEPA, 2008) was applied for the determination of

PCB congeners, including non-ortho, mono-ortho, and indicator PCBs. A DB-5MS GC column (250 $\mu\text{m} \times 0.25 \mu\text{m} \times 60 \text{ m}$) was employed. High-purity helium gas (99.999%) was used. For the first fraction, injections were performed in Pulsed Splitless mode at 280 °C using a Back-Inlet system. The oven temperature program included ramps from 100 °C to 315 °C with specific hold times to ensure optimal separation. Ionization settings included a corona pin current of 2.5 μA , cone voltage of 40 V, and gas flow of 230 L/hour. For the second fraction, a Cool On-Column inlet was used at 280 °C (Ramped Temperature mode), with the oven initially at 110 °C, ramping to 300 °C in programmed steps. The cone gas flow was maintained at 200 L/hour to ensure consistent ionization conditions.

RESULTS

In this study, the concentrations of PCDD/Fs, dl-PCBs, and indicator PCBs (pg/g wet weight) in a total of 30 composite inci kefali (*Alburnus tarichi*) samples obtained from ten different local fishers in Van province were determined using APGC-MS/MS. Indicator PCBs are used for screening and monitoring purposes in the analysis of fish and seafood products (Van den Berg, et al., 2006). The Toxic Equivalency Factor (TEF) is a coefficient used to compare the toxicities of dioxins, furans, and dioxin-like PCBs. TEF values for environmental matrices and food have been published by the World Health Organization and in the Turkish Food Codex (TFC) Regulation on Contaminants (TGK, 2023). The concentrations in pg/g wet weight were calculated based on the measured concentration values from the instrument: if the concentration was below the limit of quantification (LOQ), the LOQ value was used; if it was above, the actual measured concentration was used. Toxic Equivalent Quantities (TEQ, in pgTEQ/g wet weight) were determined by multiplying each congener's concentration by its TEF. The measured concentrations, limit of detection (LOD), LOQ, TEF, and resulting TEQ values for fish muscle samples are detailed in Table 1 and Table 2.

Table 1. PCDD/F levels in inci kefali (*Alburnus tarichi*) (N=3).

Congeners	Concentration (pg/g wet weight)	LOD (pg/g wet weight)	LOQ (pg/g wet weight)	WHO- TEF	WHO-TEQ (pg/g wet weight)
Polychlorinated dibenzo-p-dioxins (PCDDs)					
2,3,7,8-TCDD	0.0062 ± 0.0008*	0.00010	0.00029	1.0	0.0062
1,2,3,7,8-PeCDD	0.0160 ± 0.0030	0.00004	0.00008	1.0	0.0160
1,2,3,4,7,8-HxCDD	0.0122 ± 0.0016	0.00004	0.00007	0.1	0.0012
1,2,3,6,7,8-HxCDD	0.0046 ± 0.0006	0.00002	0.00006	0.1	0.0005
1,2,3,7,8,9-HxCDD	0.0052 ± 0.0009	0.00002	0.00006	0.1	0.0005
1,2,3,4,6,7,8-HpCDD	0.0344 ± 0.0068	0.00005	0.00010	0.01	0.0003
OCDD	0.0062 ± 0.0004	0.00010	0.00038	0.0003	0.0000
Polychlorinated dibenzofurans (PCDFs)					
2,3,7,8-TCDF	0.0881 ± 0.0124	0.00002	0.00005	0.1	0.0088
1,2,3,7,8-PeCDF	0.0190 ± 0.0033	0.00003	0.00009	0.03	0.0006
2,3,4,7,8-PeCDF	0.0570 ± 0.0060	0.00002	0.00006	0.3	0.0171
1,2,3,4,7,8-HxCDF	0.0109 ± 0.0016	0.00005	0.00011	0.1	0.0011
1,2,3,6,7,8-HxCDF	0.0133 ± 0.0021	0.00005	0.00014	0.1	0.0013
2,3,4,6,7,8-HxCDF	0.0135 ± 0.0013	0.00005	0.00010	0.1	0.0014
1,2,3,7,8,9-HxCDF	0.0040 ± 0.0005	0.00004	0.00011	0.1	0.0004
1,2,3,4,6,7,8-HpCDF	0.0098 ± 0.0009	0.00007	0.00019	0.01	0.0001
1,2,3,4,7,8,9-HpCDF	0.0118 ± 0.0027	0.00011	0.00028	0.01	0.0001
OCDF	0.0022 ± 0.0002	0.00004	0.00008	0.0003	0.0000
Σ PCDD/F					
WHO-TEQ pg/g wet weight		0.056 ± 0.008			

*: Mean ± standart deviation; TCDF: Tetrachlorodibenzofuran; PeCDF: Pentachlorodibenzofuran; HxCDF: Hexachlorodibenzofuran; HpCDF: Heptachlorodibenzofuran; OCDF: Octachlorodibenzofuran; PeCDD: Pentachlorodibenzo-p-dioxin; HxCDD: Hexachlorodibenzo-p-dioxin; HpCDD: Heptachlorodibenzo-p-dioxin; OCDD: Octachlorodibenzo-p-dioxin. LOD (Limit of Detection): $3 \times S/N$ (signal-to-noise ratio); LOQ (Limit of Quantification): $10 \times S/N$ (signal-to-noise ratio); TEF: Toxic Equivalency Factor; TEQ: Toxic Equivalent. $TEQ = \sum (Concentration_i \times TEF_i)$.

The concentrations of PCDDs in fish muscle samples ranged from 0.0046 to 0.0344 pg/g wet weight, and PCDFs from 0.0022 to 0.0881 pg/g wet weight. Mono- and non-ortho dl-PCBs ranged from 0.395-12.6 pg/g wet weight and 0.437-1.46 pg/g wet weight, respectively; indicator PCBs ranged from 12.5-38.4 pg/g wet weight. TEQ values were 0.056 ± 0.008 pgWHO-PCDD/Fs-TEQ/g wet weight, 0.220 ± 0.019 pgWHO-PCDD/Fs + dl-PCBs-TEQ/g wet weight and 0.135 ± 0.010 ng/g wet weight (indicator PCBs), respectively. For fish muscle tissue, the European Union (EU, 2023) Commission and the TFC set maximum residue limits (MRLs) at 3.5 pg WHO-PCDD/Fs-TEQ/g wet weight, 6.5 pg WHO-PCDD/F + dl-PCB-TEQ/g wet weight,

and 75 ng/g wet weight for indicator PCBs (ICES-6) (EU, 2023). When compared with these regulatory thresholds, the measured PCDD/F levels represent approximately 1.6% of the MRL ($0.056/3.5 \times 100$). For total PCDD/F + dl-PCBs, the result corresponds to about 3.4% of the established limit ($0.220/6.5 \times 100$). Similarly, the concentration of indicator PCBs amounts to just 0.2% of the legal limit ($0.135/75 \times 100$). These findings clearly indicate that all measured contaminant levels in the analyzed fish samples are substantially below the maximum legal limits set by both EU and TFC regulations, supporting the conclusion that the fish muscle tissue poses no significant risk in terms of PCDD/F and dl-PCB contamination (Figure 2).

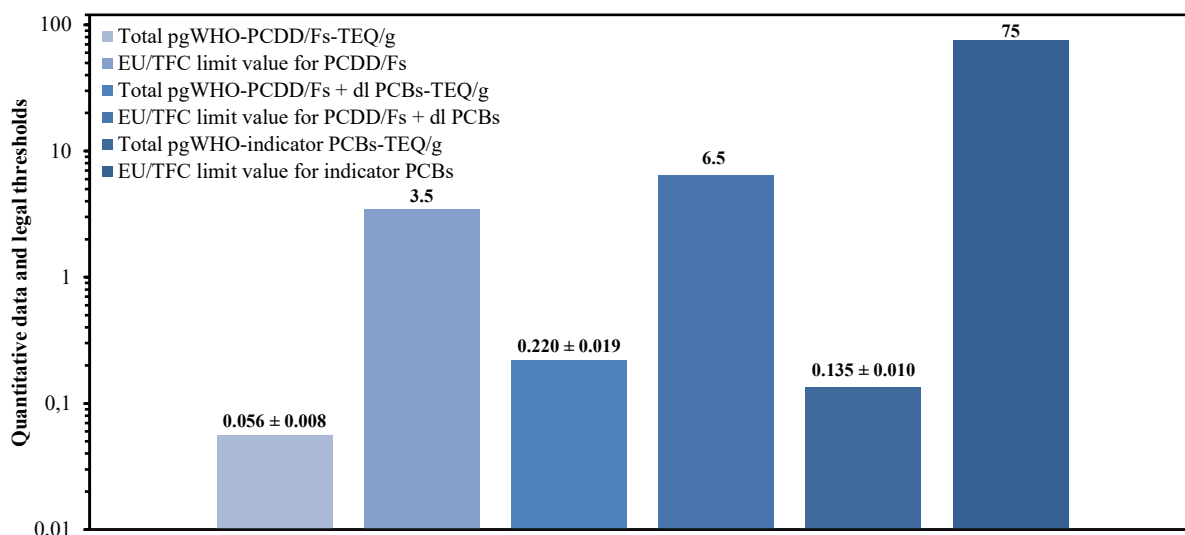


Figure 2. The mean TEQ amounts of PCDD/PCDFs, the sum of PCDD/PCDFs and dl-PCBs, and indicator PCBs in inci kefalı and the maximum permissible levels established by the EU Commission and the TFC for fish.

Table 2. Mono-ortho and non-ortho dioxin-like polychlorinated biphenyls (dl-PCBs) and indicator PCBs levels in inci kefalı (*Alburnus tarichi*) (N=3).

Congeners	Concentration (pg/g wet weight)	LOD (pg/g wet weight)	LOQ (pg/g wet weight)	WHO-TEF	TEQ (pg/g wet weight)
Mono-ortho dl-PCBs					
PCB 123	0.395 ± 0.063	0.376	1.000	0.00003	0.00003
PCB 118	12.6 ± 2.0	0.103	0.274	0.00003	0.00038
PCB 114	0.649 ± 0.090	0.391	1.040	0.00003	0.00003
PCB 105	5.51 ± 0.94	0.338	0.902	0.00003	0.00017
PCB 167	2.49 ± 0.47	0.435	1.160	0.000013	0.00007
PCB 156	3.55 ± 0.57	0.424	1.130	0.00003	0.00011
PCB 157	1.28 ± 0.21	0.337	0.898	0.000013	0.00004
PCB 189	1.83 ± 0.37	0.072	0.193	0.00003	0.00005
Non-ortho dl-PCBs					
PCB 81	0.437 ± 0.138	0.00090	0.00232	0.00030	0.00013
PCB 77	1.07 ± 0.32	0.00050	0.00135	0.00010	0.00011
PCB 126	1.46 ± 0.28	0.00004	0.00009	0.10000	0.14600
PCB 169	0.583 ± 0.070	0.00014	0.00036	0.03000	0.01749
Σ PCDD/F + dl-PCB	0.220 ± 0.019				
WHO-TEQ pg/g wet weight					
Congeners	Concentration (pg/g wet weight)	LOD (pg/g wet weight)	LOQ (pg/g wet weight)	WHO-TEF	TEQ (ng/g wet weight)
Indicator PCBs					
PCB 28	13.5 ± 3.7	0.241	0.642	-	0.01350
PCB 52	12.5 ± 2.4	0.626	1.670	-	0.01250
PCB 101	21.9 ± 6.0	0.286	0.762	-	0.02190
PCB 138	26.3 ± 4.8	0.206	0.550	-	0.02630
PCB 153	38.4 ± 7.2	0.212	0.566	-	0.03840
PCB 180	22.4 ± 4.4	0.148	0.394	-	0.02240
Σ Indicator PCB	0.135 ± 0.010				
WHO-TEQ pg/g wet weight					

PCB: Polychlorinated Biphenyl.

Tolerable Daily Intake (TDI) was determined by taking the detected concentration of 0.220 ± 0.019 pg WHO-TEQ per gram of wet fish tissue, multiplying it by the average daily intake of fish at 20 grams, and then dividing the result by the standard adult body weight of 70 kilograms (TÜİK, 2021; Türkmen, 2011) ($\text{TDI} = 0.220 \times 20/70 = 0.063$ pgWHO-TEQ/kg bw/day). This corresponds to ~21.7% of the EFSA (2018) TDI limit of 0.29 pgWHO-TEQ/kg bw/day, indicating safe exposure levels. Tolerable Weekly Intake (TWI) is the amount that can be safely consumed weekly. Using weekly fish

consumption of 140 g ($20 \text{ g/day} \times 7$), TWI was calculated as $0.220 \times 140/70 = 0.440$ pgWHO-TEQ/kg bw/week. This is about 22% of the EFSA TWI limit of 2 pgWHO-TEQ/kg bw/week. Figure 3 displays the TDI and TWI values as well as the EFSA-established maximum permissible levels for PCDD/Fs and dl-PCBs.

In conclusion, the levels of PCDD/Fs, PCDD/Fs + dl-PCBs, and indicator PCBs in inci kefali, endemic to the highly alkaline and saline Lake Van, were well below regulatory limits (MRL, TDI, TWI), indicating negligible risk to public health through consumption.

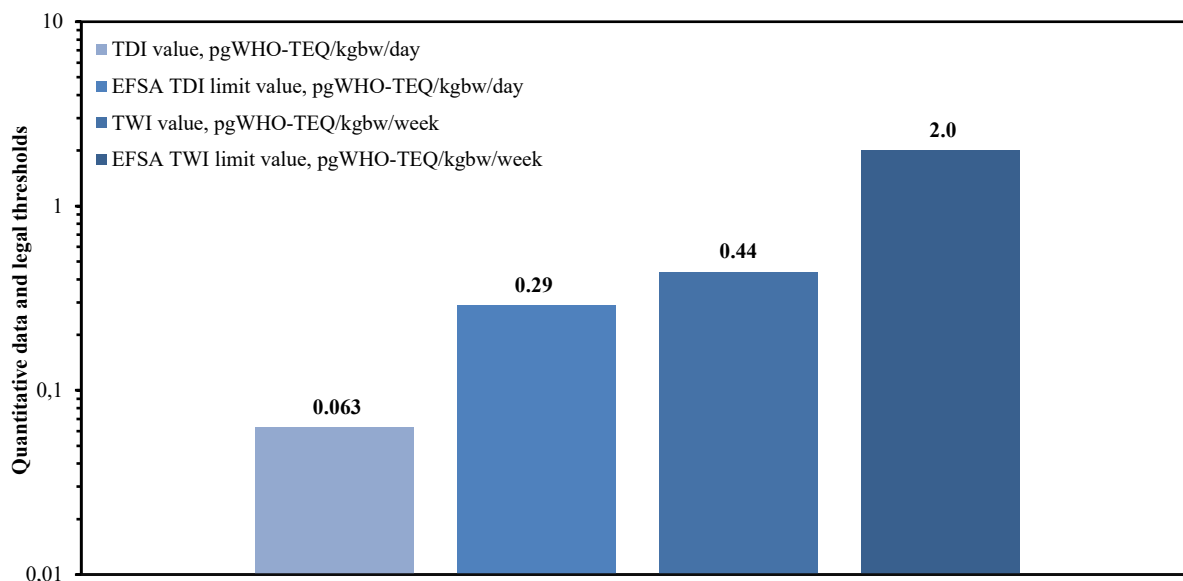


Figure 3. The amounts of TDI and TWI values in inci kefali and the maximum permissible levels determined by EFSA.

DISCUSSION

PCDD/Fs and dl-PCBs are stable, fat-loving pollutants that bioaccumulate in aquatic organisms like fish, making their monitoring crucial for public health and regulatory compliance. Measured concentrations of PCDD/Fs (0.056 ± 0.008 pg WHO-TEQ/g), total PCDD/Fs + dl-PCBs (0.220 ± 0.019 pg WHO-TEQ/g), and indicator PCBs (0.135 ± 0.010 ng/g wet weight) were substantially below EU and TFC maximum residue limits (3.5 pg WHO-TEQ/g, 6.5 pg WHO-TEQ/g, and 75 ng/g wet weight, respectively). EFSA's TDI and TWI for PCDD/Fs and dl-PCBs are 0.29 and 2 pg WHO-TEQ/kg body weight/day and week, respectively. Based on fish concentrations (0.220 pg WHO-TEQ/g), estimated intake was 0.063 pg/kg/day (21.7% TDI) and 0.440 pg/kg/week (22% TWI), indicating low exposure. These findings indicate that current dioxins and dioxin-like pollutant levels in Lake Van fish are well below current legal limits and do not pose a serious risk to consumers. However, due to the persistent and bioaccumulative properties of these compounds, ongoing periodic monitoring is important for environmental and public health.

Various studies have investigated PCDD/F, dl-PCB, and indicator PCB levels in fish and fish products. Çakıroğulları et al. (2010) reported PCDD/F-TEQ, dl-

PCB-TEQ and indicator PCB levels in Black Sea fish ranging from 0.28-0.91 pgWHO-TEQ/g, 0.56-1.89 pgWHO-TEQ/g wet weight and 3.05 to 10.94 ng/g wet weight. Kılıç et al. (2011) measured PCDD/Fs and dl-PCBs in animal foods and oils in Türkiye, finding concentrations between 0.20-4.19 pg WHO-TEQ/g fat and indicator PCBs from 57.2 to 1710 pg/g fat. Tolerable daily intakes were 0.509 and 0.588 pg WHO-TEQ/kg body weight/day in Afyon and Kocaeli, respectively, with dairy and fish as main contamination sources. Çakıroğulları et al. (2010) analyzed farmed sea bass fillets, finding PCDD/PCDFs at 0.18 pgWHO-TEQ/g wet weight, dl-PCBs at 0.85 pgWHO-TEQ/g wet weight, and indicator PCBs at 3.68 ng/g wet weight.

A study in Korea (Moon and Choi, 2009), which also considered different age groups, analyzed 26 different seafood products. Daily PCDD/F and dl-PCB exposure through seafood consumption was determined to be an average of 1.23 pg TEQ/kg bw/day. The highest WHO-TEQ PCB levels were observed in mackerel, tuna, and hairtail fish, which are, from highest to lowest, fat content. According to age, TEQ exposure was highest in children aged 3-6, followed by those aged 50-64, 30-39, and children under 2. Furthermore, it has been noted that, particularly in children under 2, there may be

potential risks from exposure through breast milk, in addition to seafood consumption. Frozen anchovy samples were analyzed for microbiological parameters, radionuclides, and POPs. PCDD/Fs, dl-PCBs, and indicator PCBs measured 0.02 ± 0.00 pgWHO-TEQ/g wet weight, 0.050 ± 0.01 pgWHO-TEQ/g wet weight and 2.91 ± 0.43 ng/g wet weight, respectively (Öğretmen 2022). Bartalini et al. (2020) analyzed PCBs in Mediterranean anchovy, sardine, and bogue. WHO-TEQ PCB levels ranged from 0.410-1.24 pg/g wet weight (sardine), 0.078-0.396 pg/g wet weight (anchovy) and 0.073-0.268 pg/g wet weight (bogue). TWI values were 1.2, 0.29, and 0.35 pg WHO-TEQ/kg/week for sardine, anchovy, and bogue, respectively. De Mul et al. (2008) reported that the highest dioxin levels were found in shrimp, eel and herring (>1.8 pg TEQ/g product), while the lowest amount was found in haddock, which is a lean fish (0.02 pg TEQ/g product). Comparison with previously reported data indicates that the levels of PCDD/Fs, total PCDD/F + dl-PCBs, and indicator PCBs detected in inci kefali are relatively low. The low levels in fish samples are thought to be due to environmental and biological factors such as Lake Van's limited pollution sources due to fewer industrial activities, the further decrease in solubility of lipophilic pollutants in water due to the alkaline and soda nature of the water, and the inci kefali's low fat content. These conditions also explain the lower pollutant levels observed compared to fish in the Mediterranean and Black Seas, which may have higher pollutant content.

Conclusion

In conclusion, this study is the first to comprehensively assess PCDD/F and dl-PCB levels in inci kefali from Lake Van, revealing contaminant concentrations well below regulatory thresholds, indicating a minimal risk to human health from dietary exposure at present. However, it should be noted that this study was based on fish samples collected during only a single sampling period. For the development of environmental policies, protection of public health, and establishment of effective monitoring strategies, additional studies conducted periodically are necessary to more accurately assess the potential health risks associated with long-term exposure to these pollutants.

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