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Investigations of Some Endocrine Disruptors in Cat Genital Organs

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Abstract
Environmental pollution, particularly from endocrine-disrupting chemicals (EDCs), poses a significant threat to living beings. Despite extensive research in humans, studies on companion animals like cats remain limited. This work aimed to investigate the exposure of owned male and female cats to EDCs and the residue levels in their reproductive organs. Reproductive tissues (50 ovaries, 50 uteruses, and 50 testicles) from cats presented for sterilization were analyzed for residues of organochlorinated pesticides (OCPs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and polycyclic aromatic hydrocarbons (PAHs) using gas chromatography-mass spectrometry. The method was validated following international standards. DDTs were the most commonly appointed contaminants, particularly in cats exposed to cigarette smoke and meat-based diets. PAHs were the second most prevalent, with higher concentrations in female reproductive organs compared to male testicles. PCBs were primarily found in testicles, potentially linked to higher meat consumption among male cats. PBDEs were the least frequently detected and only in testicles, at low concentrations. Notably, DDT concentrations were higher in ovaries than in uteruses from the same animals. These findings suggest that indoor cats are vulnerable to EDC exposure, with diet and environmental tobacco smoke as potential sources. Owners should minimize such exposures to safeguard both pet and human health. Given the shared environments and exposure risks between humans and cats, the study highlights the relevance of a One Health perspective.

Keywords Endocrine disruptors · Ovary · One health · Testis · Uterus

Introduction

Industrial production has increased in parallel with the growth in the world's population. This situation has gradually increased the variety and quantity of chemicals required in different fields (Reincke et al. 2024). The negative effects of these compounds, which are industrially produced and widely used in many fields, on the biological system are among the most discussed issues today (He et al. 2024). Awareness of endocrine-disrupting chemicals (EDCs) has increased, especially in recent years, due to their negative effects on the immune, gastrointestinal and nervous systems, particularly the reproductive system (US Environmental Protection Agency 2024). EDCs are exogenous substances that disrupt the endocrine system and cause adverse health effects in living organisms and their offspring. (WHO/IPCS 2002).

The most well-known EDCs are OCPs (such as DDT), industrial chemicals (such as PCBs) and unintentional by-products (such as dioxins and furans) (Sevin et al. 2018; WHO 2022). PCBs have been extensively used in industry from the 1930s to the 1970s because of properties such as flammability and low electrical conductivity (Adewunmi Adekunle et al. 2025). Polybrominated Diphenyl Ethers (PBDEs) are substances added to various consumer products due to their flame retardant properties (Reincke et al. 2024). In addition to causing bioaccumulation, toxicity and environmental pollution, PBDEs tend to bind to particulate matter due to their hydrophobic structure (Ma et al. 2019; Pei et al. 2018). Polycyclic aromatic hydrocarbons (PAHs) are organic substances with toxic, mutagenic and carcinogenic properties. They are produced when organic

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substances are incompletely combusted. (Simşek and Bilgili 2022). In the past, OCPs were widely used as insecticides in agriculture and as sprays for mosquito control to combat vector-borne diseases such as malaria and typhus. Despite their effectiveness, these compounds have been banned in most developed countries due to their high persistence in the environment, resistance to degradation, and adverse effects on ecosystems and living organisms. Their lipophilic nature and long half-lives allow them to persist in soil, water, and biological tissues long after their application (Acaröz et al. 2020).

Humans and animals are exposed to EDCs in quite different ways, such as orally through food and/or water, dermal contamination, inhalation, intravenously, through biological transfer from placenta and breast milk (Aksoy et al. 2013; Parent et al. 2025). As they share the same indoor environment as humans and exhibit similar disease profiles, domestic cats are considered an effective indicator of human environmental exposure (Reincke et al. 2024). Adverse health outcomes similar to those observed in humans following exposure to organochlorine pesticides (OCPs) and PCBs have also been documented in companion animals such as cats and dogs. Furthermore, exposure to EDCs through diet has been linked to the development of various conditions in these animals, including malignant lymphoma, cancer, hyperthyroidism and kidney failure (Ali et al. 2013; Storelli et al. 2009).

Dioxins and dioxin-related compounds found in the genital organs of domestic cats and dogs in Japan have been suggested to originate from pet food (Kunisue et al. 2005). However, the fact that PCDDF isomers were not found in the genital organs of dogs and cats, although they were detected in pet foods, suggests that they are rapidly metabolized. It was reported that the concentrations of coplanar PCB isomers found in the genital organs of dogs were higher in male dogs than in females. No significant difference was discovered in OCP concentrations between male and female cats and it was reported that the dominant chlorinated compounds detected in cats were DDT and PCB, followed by chlordane, hexachlorohexane and hexachlorobenzene concentrations (Kunisue et al. 2005).

Previous biomonitoring studies in companion animals have primarily focused on blood, serum, adipose tissue, or hair to assess exposure to EDCs (Ali et al. 2013; Mizukawa et al. 2013; Yavuz et al. 2024). While these studies have been invaluable in establishing cats as sentinels for human exposure, there is a critical gap in the literature regarding the direct accumulation of these contaminants in the reproductive organs. The investigation of reproductive tissues is paramount, as these organs are not only potential storage sites for lipophilic contaminants but also direct targets for endocrine disruption, which can have profound implications for fertility and reproductive health. A few studies have detected EDCs in the genital organs of dogs and cats in Japan (Kunisue et al. 2005), but these had limited sample sizes and/or a narrower scope of analytes. Our study directly addresses this gap by conducting a comprehensive analysis of a wide spectrum of EDCs- including OCPs, PCBs, PBDEs, and PAHs- in a substantial number of reproductive tissue samples (50 ovaries, 50 uteruses, 50 testicles) from a defined geographical region. By quantifying the residue levels in ovaries, uteruses, and testicles simultaneously and correlating them with environmental factors such as diet and tobacco smoke exposure, this research provides unprecedented insights into the specific vulnerability of the feline reproductive system to environmental pollutants. This approach not only fills a significant knowledge gap but also enhances our understanding of the potential reproductive toxicological risks in both pets and, by extension, the humans sharing their environment.

Thus, the aim of this study was to investigate the exposure of male/female cats to certain EDCs, which are environmental pollutants, for various reasons and the residue levels in their reproductive organs after this exposure. Moreover, knowledge of the contamination status in animal populations would be an important step not only for estimating the magnitude of environmental pollution, but also for predicting human health risks from exposure to environmental pollutants. Thus, it was aimed to detect the investigated pollutants in reproductive organs and to make an evaluation according to the anamnesis taken in order to establish the relationship between the amount of pollutant and exposure. Studies show that environmental pollutants, which are quite common in the environment, can also be transmitted to cats. In this case, it was hypothesized that "Cats living in a domestic environment are exposed to environmental pollutants and these chemicals may accumulate in the genital organs".

Materials and Methods

Sampling

Reproductive tissue samples were collected from a total of 100 client-owned healthy cats presented for routine ovariohysterectomy (50 females) and orchiectomy (50 males) at veterinary clinics. All surgical procedures were performed by licensed veterinarians following standard clinical protocols. The animals were placed under general anesthesia, and the surgical sites were prepared aseptically. For female cats, following a standard midline celiotomy for ovariohysterectomy, the entire uterus and both ovaries were exteriorized. The ovarian pedicles and uterine body were ligated and

transected, and the reproductive tract (uterus and ovaries) was removed *en bloc*. For male cats, a standard pre-scrotal approach was used for orchiectomy. Both testicles were exteriorized through a single incision, the spermatic cords were ligated, and the testicles were removed. Immediately after removal, the target tissues (ovaries, uterus, and testes) were dissected from the surrounding connective tissue and vasculature. Samples were collected from the organs post-anesthesia as part of the routine surgical procedure; no additional invasive steps were taken solely for research purposes. The tissue samples were then placed in a cold environment and transported to the laboratory via a cold chain on the same day and stored in a deep freezer at -20 °C until analysis and analyzed within 5 days at the latest in accordance with the Directorate-General for Health and Food Safety (SANTE/11312/2021) guidelines. For the samples, a pool sample was created with the right and left organs of the genital organ of each cat. Since both ovaries and uterus were taken from female cats, the number of samples was 150. Samples were collected from male and female cats that did not have any obvious discomfort on preliminary examination (no fever, respiratory or digestive system disorders, no irregular heartbeat, and females were not in estrus) after obtaining the permission of the owners and signing a consent form. Permission for the study was obtained from the Ankara University Animal Experiments Local Ethics Committee on 19 January 2022 (decision number 2022-2-15). The ages of the neutered male and female cats were between 8 months and 2 years.

Chemicals

All reagents and solvents used in the study were HPLC pure. n-hexane, isooctane, toluene, acetonitrile, sodium sulfate (Na_2SO_4) and magnesium sulfate ($MgSO_4$) were purchased from Sigma Aldrich (Steinheim, Germany), and primary secondary amine (PSA) and C18 were purchased from Agilent Technologies (Santa Clara, USA). The glass Pasteur pipettes used for solid phase extraction (SPE) were prepared by adding 0.5 g C18 and 0.5 g PSA on it. Indicator PCB analytical standards (PCB28, PCB30, PCB52, PCB101, PCB118, PCB138, PCB153, PCB180 and PCB209), OCP standards [alpha-hexachlorocyclohexane (α-HCH), beta-hexachlorocyclohexane (β-HCH), gamma-hexachlorocyclohexane (lindane, γ-HCH), hexachlorobenzene (HCB), *4,4'*-dichlorodiphenyl dichloroethane (*4,4'*-DDD), *4,4'*-dichlorodiphenyl dichloroethylene (*4,4'*-DDE), *2,4'*-dichlorodiphenyl trichloroethane (*2,4'*-DDT), *4,4'*-dichlorodiphenyl trichloroethane (*4,4'*-DDT), heptachlor (HEP), aldrin (ALD), dieldrin, alpha-endosulfan, beta-endosulfan and methoxychlor] were procured from Dr. Ehrenstorfer Laboratories (Augsburg, Germany), PBDE standards (PBDE17, PBDE47, PBDE66, PBDE100, PBDE153, PBDE183) from Wellington Laboratories (Guelph, Canada), isotope labelled PCB153 (13C12) from Cambridge Isotope Laboratories (Andover, MA, USA). PCB209 and isotope labelled PCB153 (13C12) were used as internal standard and PCB30 was used as injection internal standard. Analytical standards for polyaromatic hydrocarbons [naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3,c, d) pyrene, dibenz(a, h)anthracene, benzo(g, h,i)perylene and deuterium internal standard solutions (naphthalene-d8, acenaphthene-d10, phenanthrene-d10, chrysene-d12 and perylene-d12)] were obtained from Wellington Laboratories-Terra Chem Inc. (Shawnee Mission, Kansas, USA). Polychlorinated biphenyls were selected as indicators and PCB118 was used to represent ND-PCBs. PBDEs were selected from those specified in the European Union Water Framework Directive 2000/60/EC and PAHs were selected from those recognized as a priority by the US Environmental Protection Agency (USEPA). OCPs were selected from those most frequently detected in food and the environment in previous studies conducted in Turkey.

Stock standard solutions were prepared in acetonitrile at a concentration of 1 µg/mL each. Internal standards were prepared in toluene at a concentration of 4 µg/mL each and stored in dark glass bottles at 4 °C. Standard working solutions were prepared daily from stock standards.

Extraction

For the extraction of the samples, the method previously used in our laboratory for the analysis of endocrine disrupting compounds in placentas was modified (Yurdakök-Dikmen et al. 2022). The overall procedure is also summarized in Fig. 1. Accordingly, the samples removed from the deep freezer were thawed at room temperature. The testis, ovary and uterus tissues, separated into right and left, were homogenized and mixed thoroughly with tissue scissors and a scalpel tip. 1 g each of testicular and uterine tissues and 0.5 g of ovarian tissue were taken and placed in glass tubes. The internal standard was added and kept for 20 min for homogenization. Then 5 ml acetonitrile was added to the tubes and mixed by vortexing for 10 min and homogenization was achieved. Immediately afterwards, the tubes were subjected to sonic bath for 5 min. Then 0.5 g NaCl was added to the tubes, shaken manually for 30 s and centrifuged at 3000 rpm for 15 min at 20 °C. The upper phase (supernatant) was transferred to another tube. For the second extraction, 2 mL acetonitrile was added to the residue remaining in the tube, vortexed for 10 min, kept in an ultrasonic bath for 5 min and centrifuged again. The supernatant obtained from repeated

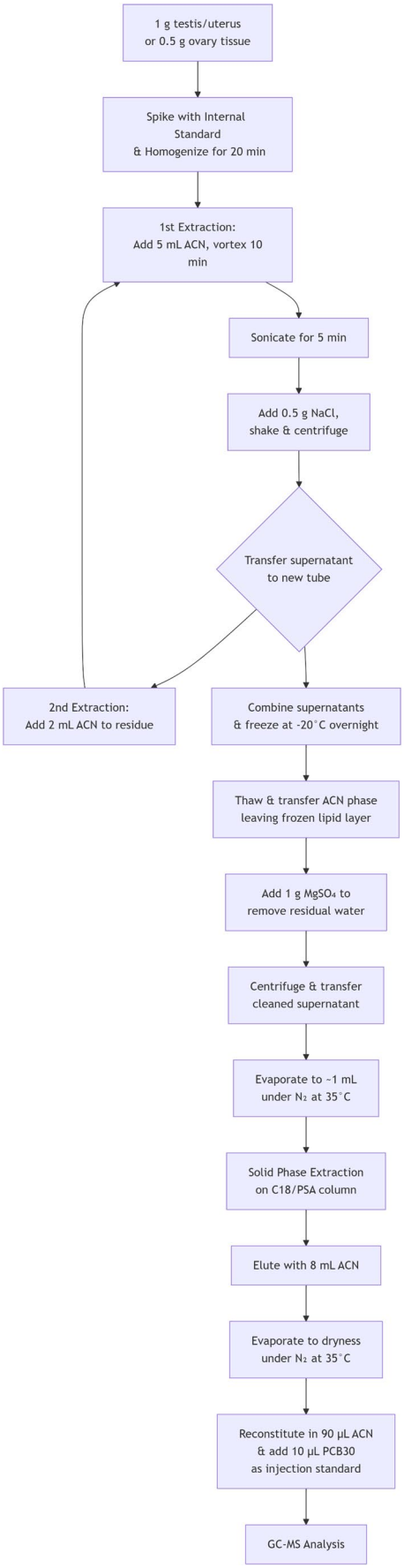


Fig. 1 Flow chart of the sample preparation and extraction procedure for the analysis of endocrine-disrupting compounds in cat reproductive tissues

centrifugation was transferred on top of the other. The supernatants collected in separate tubes were kept at −20 °C for overnight. The next day, acetonitrile was taken with a pipette and transferred to another tube without removing the top frozen oily part and the sediment at the bottom. 1 g $MgSO_4$ was added to it, shaken by hand and centrifuged for 15 min to remove water molecules. The supernatant was transferred to a separate tube and evaporated under a stream of nitrogen at 35 °C until 1 mL remained. After conditioning the previously prepared SPE column with 5 × 1 ml acetonitrile, the samples were filtered and collected by passing 8 mL acetonitrile. The collected filtrate was dried completely at 35 °C under a stream of nitrogen and the residue was collected with 90 µL acetonitrile and 10 µL PCB30 was added and applied to the GC-MS.

Gas Chromatography-Mass Spectrometry Analysis

A DB-5MS capillary column (30 m × 0.25 mm i.d., 0.25 µm film coated) (Agilent Technologies, PaloAlto, CA, USA) and a Thermo Finnigan Trace GC Polaris Q gas chromatography mass spectrometer (GC-MS) (San Jose, California, USA) were used for separation of analytes. The instrument was operated in splitless mode. The detector temperature was set to 250 °C, the transfer line to 270 °C and the injection port temperature to 280 °C. Analytical purity helium gas (99.995%) used as mobile phase was set to a flow rate of 1.0 ml/min. Program settings were selected according to the method used by Yurdakök-Dikmen et al. (2022).

For organic chlorinated pesticides, PBDEs and PCBs, the oven temperature of the GC-MS was initially kept at 70 °C for 2 min. It was then increased by 25 °C per minute to 150 °C. From here, it was increased by 5 °C per minute to 200 °C. After being kept here for 5 min, it was again increased by 5 °C per minute to 270 °C. Immediately afterwards, it was increased to 290 °C by increasing 25 °C per minute without waiting and kept here for 7 min. Total program time was calculated as 44 min and recorded.

A separate program was used for PAHs and the GC oven was kept at 70 °C for 2 min at the beginning of the program. Then it was increased by 25 °C per minute to 150 °C, increased by 5 °C per minute to 200 °C and kept there for 5 min. From here, it was increased by 5 °C per minute to 270 °C and kept for 2 min. Finally, it was brought to 290 °C by increasing 5 °C per minute and kept here for 5 min. Thus, the total oven program time for PAHs was determined as 45.2 min.

The solvent delay time was set to 11 min to skip the solvent peak. For mass scanning, 70 eV energy was applied

to scan ions between 100 and 800 m/z values. The analytes were analyzed and validated by Selective Ion Imaging (SIM) mode using one quantifier and two descriptor ions previously used by Simşek et al. (2020) and given in Supplementary Table 1 for OCPs, PCBs and PBDEs and Supplementary Table 2 for PAHs.

A simplified flow chart of the extraction and clean-up procedure is presented in Fig. 1.

Method Validation

Prior to the analytical procedures, the method was validated in accordance with the guidelines established by Eurachem (Magnusson and Ornemark 2014) and the European Commission's Directorate-General for Health and Food Safety (SANTE/11312/2021). Validation parameters included selectivity, linearity, accuracy, precision, as well as limits of detection (LOD) and quantification (LOQ). A pooled sample comprising homogenized ovarian, uterine, and testicular tissues was employed for method validation. Linearity was assessed using eight concentration levels (0.5, 1, 2.5, 5, 10, 25, 50, 100 µg/kg). To evaluate matrix effects, the ratio of matrix-based to solvent-based calibration curves was calculated for each analyte. LOD and LOQ were established for all target compounds, based on signal-to-noise ratios of three and ten, respectively. Precision was assessed over four consecutive days using six replicates at six different concentration levels, with results expressed as relative standard deviation (RSD%). Accuracy was evaluated by recovery studies at three spiking levels (10, 50, and 100 µg/kg), with ten replicates conducted per level. The 10 µg/kg level was strategically selected to demonstrate method performance at a concentration close to the LOQs of the majority of the target analytes, which is a recognized approach for validating multi-analyte methods where a single, universal LOQ-level spike is not practicable.

Statistical Analyses

The statistical analyses were carried out using the Stata/MP 14 package program. Before significance tests, the results were checked by Shapiro Wilk test for normality and Levene's test for homogeneity of variances among parametric test assumptions. Since parametric test assumptions were not available, Kruskal Wallis test was used to statistically evaluate the difference between groups for each variable. When the difference between the groups was significant, Dunn's multiple comparison test was applied as a post-hoc test. Differences between the groups were compared with the chi-square test. For values found below the measurement limit (< LOQ), the half value of the measurement limit of each analyte was used in the calculations. $P < 0.05$ criterion was considered in all statistical decisions.

Results

Method Validation

The retention times and quantifying and identifying ions determined for OCPs, PCBs and PBDEs in the method validation study are given in Supplementary Tables 1 and for PAHs in Supplementary Table 2.

In Supplementary Tables 3 and 4, the spike samples for linearity calculation were made with 8 concentrations between 5 and 200 µg/kg and the correlation coefficients (r2) from these samples are all greater than 0.99. LOD and LOQ values were calculated as 0.16–0.37 µg/kg and 0.49–1.11 µg/kg for OCPs; 0.16–0.36 µg/kg and 0.53–1.09 µg/kg for PCBs; 0.12–0.31 µg/kg and 0.37–0.92 µg/kg for PBDEs, respectively. The calculated RSD% values for intermediate precision and reproducibility were all < 13% (Suppl. Table 3).

Validation data for PAHs are shown in Supplementary Table 4. LOD and LOQ values were calculated as 0.22–0.79 µg/kg and 0.66–2.37 µg/kg, respectively. All RSD% values calculated for intermediate precision and reproducibility were < 12% (Suppl. Table 4).

Matrix effects were evaluated for all target analytes by comparing the slopes of the matrix-matched calibration curves to those of the solvent-based calibration curves. The calculated matrix effect values ranged from 88.5% to 99.1%, indicating predominantly negligible effects. These values are within the acceptable range for complex biological matrices using GC-MS analysis, demonstrating that the sample preparation and clean-up procedure effectively mitigated potential matrix interferences.

Endocrine Disrupting Compounds Detected in Reproductive Organs

The arithmetic mean and frequency of detection of target contaminants detected in cat genital organs are given in Table 1. Alpha-hexachlorohexane (α-HCH), beta-hexachlorohexane (β-HCH), hexachlorobenzene (HCB), heptachlor, alpha-endosulfan, dieldrin, *4–4'* -DDD, *2'4* -DDT, methoxychlor, PCB52, PCB118, PCB138, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(*1*,*2*,*3*,*c*, *d*)pyrene, dibenz(a, h)anthracene and benzo (g, h,i) perylene and PBDEs except PBDE28 and PBDE154 were not found. Therefore, they are not shown in Table 1.

Table 1 Arithmetic mean, standard error, minimum and maximum concentrations and detection rates (frequency) of target contaminants detected in Cat genital organs

Target Analyte	Ovarium ($n=50$)		Uterus ($n=50$)		Testis ($n=50$)	
	Concentration (µg/kg)	Frequency (%)	Concentration (µg/kg)	Frequency (%)	Concentration (µg/kg)	Frequency (%)
Lindane	1.79 ± 0.89[b] (< LOQ-11.23)	6	5.18 ± 2.2[a] (< LOQ-33.10)	6	< LOQ	0
Aldrin	< LOQ	0	< LOQ	0	13.93 ± 6.34 (< LOQ-84.04)	6
4–4'-DDE	152.46 ± 34.56[b] (< LOQ-450.55)	80	73.25 ± 18.34[c] (< LOQ-762.19)	40	438.55 ± 201.34[a] (< LOQ-4357.04)	70
4–4'-DDT	82.83 ± 23.46[a] (< LOQ-685.77)	62	23.09 ± 12.35[b] (< LOQ-162.31)	56	12.78 ± 5.49[b] (< LOQ-47.04)	70
Total DDTs	235.29 ± 76.89[b] (LOQ-994.09)	94	96.34 ± 79.86[c] (< LOQ-762.33)	82	451.33 ± 256.32[a] (< LOQ-4357.18)	94
PCB28	1.78 ± 0.68[b] (< LOQ-13.5)	6	1.39 ± 0.42[b] (< LOQ-5.40)	6	3.34 ± 1.98[a] (< LOQ-17.85)	32
PCB101	< LOQ	0	< LOQ	0	0.85 ± 0.23 (< LOQ-4.89)	6
PCB153	< LOQ	0	< LOQ	0	1.47 ± 0.98 (< LOQ-6.43)	50
PCB180	< LOQ	0	< LOQ	0	6.18 ± 2.45 (< LOQ-40.33)	20
Total PCBs	2.68 ± 1.21[b] (< LOQ-14.40)	6	2.29 ± 1.10[b] (< LOQ-6.30)	6	11.85 ± 5.64[a] (< LOQ-45.95)	50
PBDE28	< LOQ	0	< LOQ	0	0.73 ± 0.61 (< LOQ-5.67)	20
PBDE154	< LOQ	0	< LOQ	0	2.25 ± 1.15 (< LOQ-21.23)	18
Total PBDEs	< LOQ	0	< LOQ	0	2.98 ± 1.62 (< LOQ-21.37)	20
Naphthalene	274.51 ± 132.45 (< LOQ-1362.94)	82	275.34 ± 137.43 (< LOQ-774.09)	82	235.58 ± 126.31 (< LOQ-951.35)	62
Acenaphthylene	< LOQ	0	< LOQ	0	10.97 ± 5.21 (< LOQ-100.65	18
Acenaphthene	17.00 ± 6.35[b] (< LOQ-101.93	18	15.55 ± 7.23[b] (< LOQ-99.12)	18	39.98 ± 18.49[a] (< LOQ-309.57)	50
Fluorene	6.55 ± 2.43[b] (< LOQ-48.98)	12	6.21 ± 3.24[b] (< LOQ-55.34)	12	23.93 ± 11.73[a] (< LOQ-187.20)	18
Phenanthrene	34.95 ± 13.45[a] (< LOQ-498.99)	12	34.39 ± 14.12[a] (< LOQ-519.19)	12	7.42 ± 3.65[b] (< LOQ-94.39)	6
Anthracene	34.29 ± 12.65[a] (< LOQ-425.54)	12	30.28 ± 15.24[a] (< LOQ-396.47)	12	13.76 ± 5.87[b] (< LOQ-123.23)	12
Fluoranthene	4.12 ± 2.12 (< LOQ-42.26)	12	3.82 ± 1.92 (< LOQ-38.76)	12	< LOQ	0
Pyrene	3.30 ± 1.21 (< LOQ-26.72	6	3.53 ± 1.75 (< LOQ-32.56)	6	< LOQ	0
Benzo[a]piren	49.46 ± 24.83 (< LOQ-587.98)	12	49.39 ± 21.36 (< LOQ-741.90)	12	< LOQ	0
Total PAHs	426.77 ± 241.53[a] (< LOQ-1380.52)	78	421.10 ± 202.31[a] (< LOQ-1836.50)	82	337.28 ± 149.65[b] (< LOQ-968.93)	82

[a,b] For each target analyte, significant differences ($p<0.05$) between organs (within a row) are indicated by different superscript letters

In the statistical evaluation, the concentration of lindane in the uterus was significantly higher than in the ovary, the concentration of total-DDT and total PCB in the testis was higher than in the ovary and uterus, and the concentration of total DDT in the ovary was higher than in the uterus ($P<0.05$). Total PAH concentration was higher in ovary and uterus than in testis ($P<0.05$).

The most frequently detected compound in cat genital organs was naphthene in the ovary and uterus (82%), followed by *4.4'*-DDE in the ovary (Fig. 2). However, when evaluated in terms of compound class (Fig. 3), the most

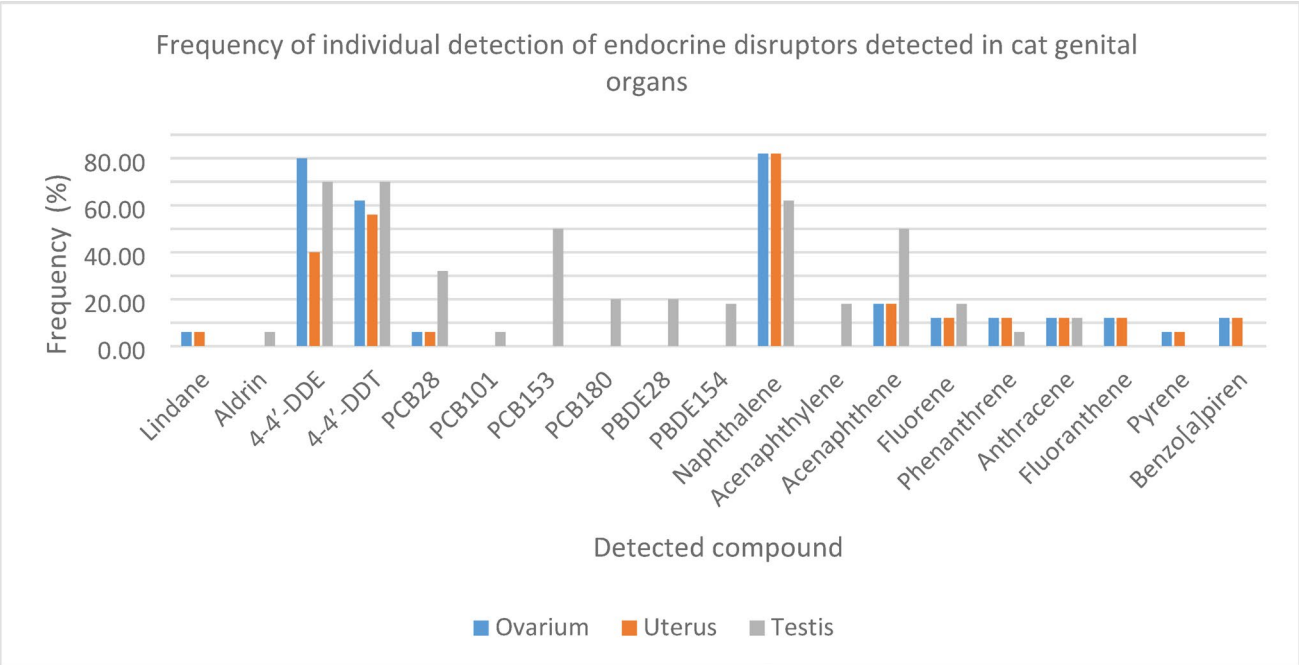


Fig. 2 Individual frequency of detection of endocrine disrupting compounds detected in cat genital organs

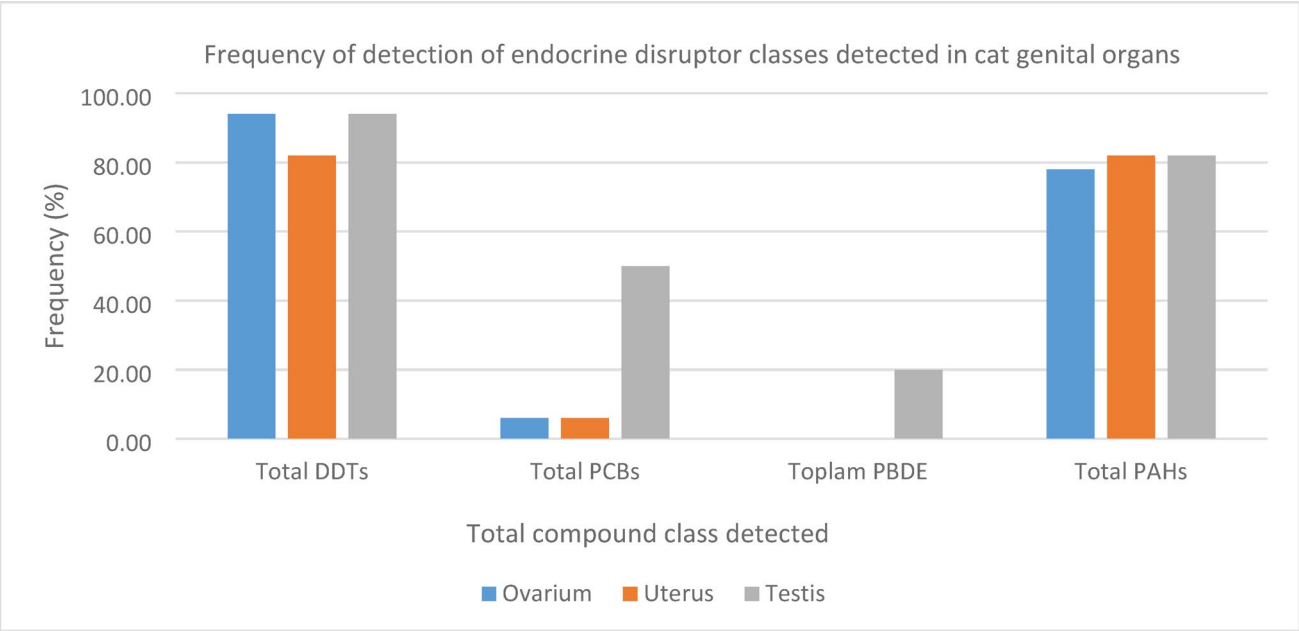


Fig. 3 Frequency of detection of endocrine disrupting compound classes detected in cat genital organs

common compound class was total DDT in ovary and testis with 94%, followed by total DDT in the uterus with 82% and total PAH in testis with 82%. The highest concentrations of pollutants were found in the testis with total DDT and its metabolite *4,4'*-DDE, followed by total PAH compounds in the ovary and uterus (Fig. 4).

According to the anamnesis findings, it was determined that 32 of the houses where cats were housed were smoking and 18 were not smoking. The classification made accordingly is given in Table 2, the graph of detection frequency is shown in Fig. 5 and the concentration graph is shown in Fig. 6. The concentrations of gamma-HCH (lindane), total DDT and total PAHs in the genital organs of cats in smoking houses were significantly higher ($P<0.05$) than in non-smoking houses.

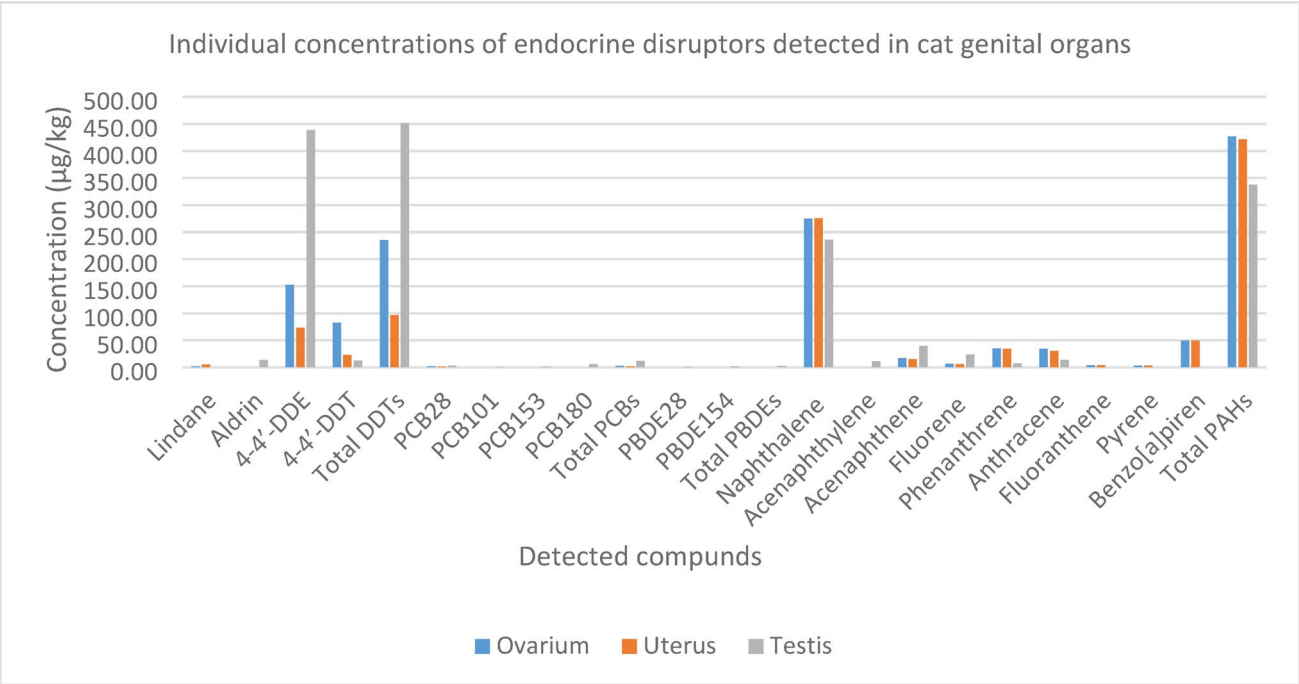


Fig. 4 Individual concentrations of endocrine disrupting compounds detected in cat genital organs

Table 2 Detection rates and mean concentrations (mean and standard error) of persistent organic pollutants detected in the genital organs of cats housed in smoking and non-smoking households

Analyte		Ovary		Uterus		Testis	
		Smoking environment ($n=32$)	Non-smoking environment ($n=18$)	Smoking environment ($n=32$)	Non-smoking environment ($n=18$)	Smoking environment ($n=20$)	Non-smoking environment ($n=30$)
Lindane	Concentration	2.67 ± 0.76^{b} (<LOQ-11.23)	< LOQ	8.41 ± 2.46^{a} (<LOQ-33.10)	< LOQ	< LOQ	< LOQ
	Frequency	9.37	0	9.37	0	0	0
Aldrin	Concentration	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ	22.96 ± 6.74 (<LOQ-84.04)
	Frequency	0	0	0	0	0	9.37
Total DDTs	Concentration	331.15 ± 121.32^{b} (<7.74-994.09)	75.53 ± 24.34^{d} (<LOQ-160.90)	136.04 ± 43.82^{c} (<LOQ-762.33)	36.79 ± 7.81^{e} (<LOQ-102.22)	905.18 ± 309.67^{a} (<3.10-4357.18	133.63 ± 42.74^{c} (<LOQ-452.03)
	Frequency	100	88	96.87	67.13	100	88
Total PCBs	Concentration	3.09 ± 1.81^{b} (<LOQ-14.40)	< LOQ	2.29 ± 0.94^{b} (<LOQ-6.30)	2.30 ± 0.59^{b} (<LOQ-5.68)	14.88 ± 3.42^{a} (<3.96–45.95)	9.73 ± 3.21^{a} (<LOQ-38.70)
	Frequency	9.37	0	6.25	5.55	100	16.67
Total PBDEs	Concentration	< LOQ	< LOQ	< LOQ	< LOQ	2.14 ± 0.36 (<LOQ-5.81)	3.57 ± 1.23 (<LOQ-21.37)
	Frequency	0	0	0	0	20	20
Total PAHs	Concentration	562.00 ± 298.42^{a} (<294.46-1380.52)	156.31 ± 49.43^{b} (<LOQ-384.45)	551.54 ± 302.34^{a} (<LOQ-1836.50)	138.49 ± 36.98^{b} (<LOQ-393.90)	539.14 ± 229.98^{a} (<LOQ-968.93)	195.99 ± 49.59^{b} (<LOQ-739.73)
	Frequency	100	56	93.75	61.12	90	76.67

[a,b,c] For each target analyte, significant differences ($p<0.05$) between organs (within a row) are indicated by different superscript letters.

When the food consumption habits of the cats were evaluated according to the anamnesis taken, it was determined that 29 female and male cats consumed canned meat or fish at least once every 15 days or more, and 21 female and male cats rarely consumed them, and the classification made accordingly and the target analytes detected are given in Table 3; Fig. 7. Thus, total DDT and total PAH concentrations detected in cats that consumed canned meat or fish at least once every 15 days or more were significantly higher ($P<0.05$) than the concentrations of compounds detected

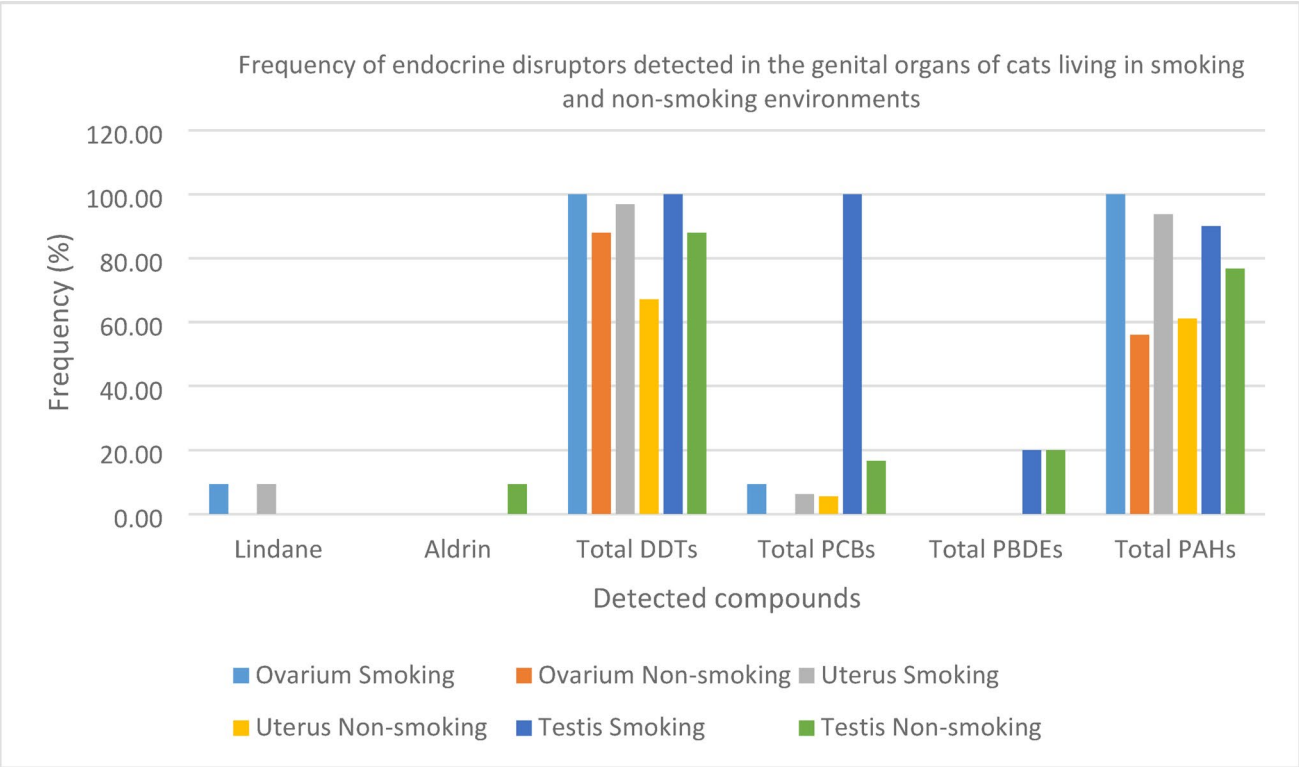


Fig. 5 Frequency of endocrine disrupting pollutants detected in the genital organs of cats living in smoking and non-smoking environments

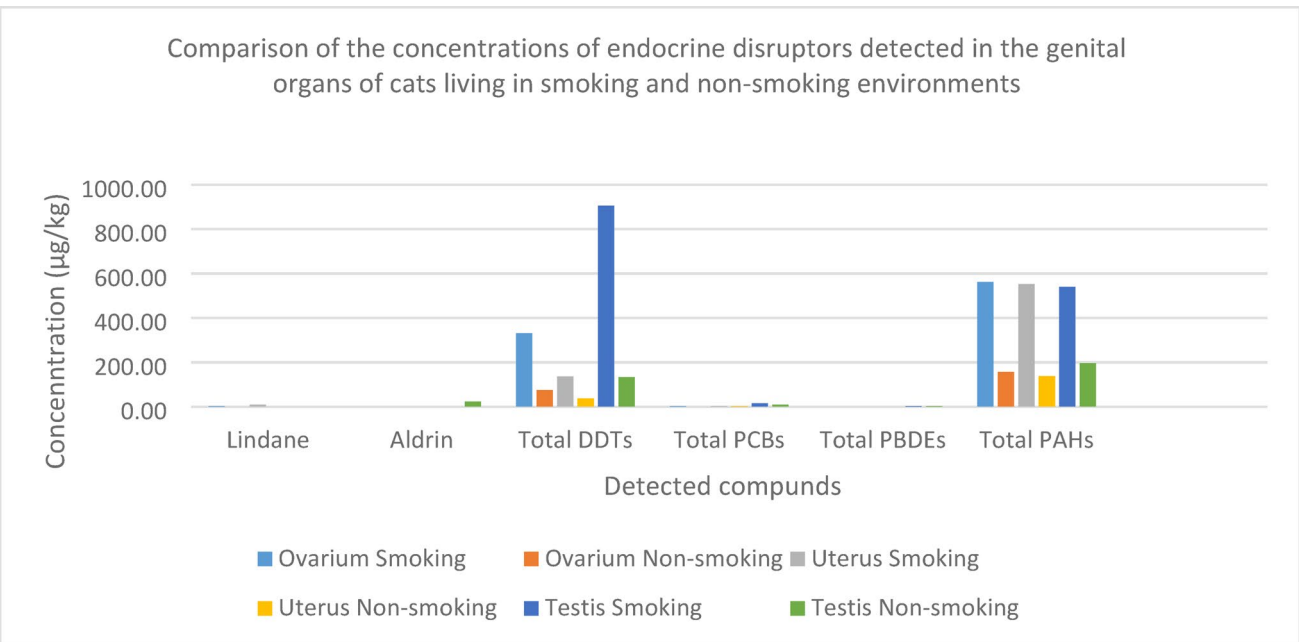


Fig. 6 Comparison of the concentrations of pollutants detected in the genital organs of cats living in smoking and non-smoking environments

Table 3 Detection rate and mean concentrations (mean and standard error) of persistent organic pollutants detected in the genital organs of cats consuming canned meat or fish at least once every 15 days or more and cats consuming rarely (one month or more) or not at all

Target analyte		Ovary		Uterus		Testis	
		Consuming canned meat ($n=29$)	Does not consume canned meat ($n=21$)	Consuming canned meat ($n=29$)	Does not consume canned ($n=21$)	Consuming canned meat ($n=29$)	Does not consume canned ($n=21$)
Lindane	Concentration	2.44 ± 1.02^{b} (<LOQ-11.23)	0.96 ± 0.36^{b} (<LOQ-4.74)	10.72 ± 3.36^{a} (<LOQ-33.10)	< LOQ	< LOQ	< LOQ
	Frequency	6.9	4,76	10.34	0	0	0
Aldrin	Concentration	< LOQ	< LOQ	< LOQ	< LOQ	19.31 ± 7.84 (<LOQ-34.04)	< LOQ
	Frequency	0	0	0	0	10.34	0
Total DDTs	Concentration	345.50 ± 124.32^{b} (<LOQ-994.09	93.60 ± 43.21^{d} (<LOQ-316.79)	171.95 ± 87.98^{c} (<LOQ-762.33)	30.18 ± 17.56^{e} (<LOQ-102.22)	571.16 ± 265.45^{a} (<LOQ-4357.18)	163.74 ± 49.89^{c} (<LOQ-452.03)
	Frequency	96.55	90.48	93.10	66.67	96.55	90.48
Total PCBs	Concentration	3.61 ± 1.52^{b} (<LOQ-14.40)	< LOQ	2.53 ± 1.12^{b} (<LOQ-5.68)	2.09 ± 1.09^{b} (<LOQ-6.30)	15.40 ± 3.78^{a} (<LOQ-45.95)	3.33 ± 1.78^{b} (<LOQ-7.02)
	Frequency	10.34	0	6.90	4.76	68.97	23.81
Total PBDEs	Concentration	< LOQ	< LOQ	< LOQ	< LOQ	4.01 ± 1.98^{a} (<LOQ-21.37)	0.50 ± 0.21^{b} (<LOQ-1.39)
	Frequency	0	0	0	0	24.14	11.12
Toplam PAH	Concentration	609.03 ± 352.12^{a} (<LOQ-1380.52	116.20 ± 65.43^{c} (<LOQ-439.89	590.39 ± 354.87^{a} (<LOQ-1836.50)	130.89 ± 67.45^{c} (<LOQ-393.90	445.28 ± 203.56^{b} (<LOQ-968.93)	78.09 ± 42.61^{d} (<LOQ-182.23)
	Frequency	86.21	66.67	86.21	76.19	89.66	71.43

[a,b,c] For each target analyte, significant differences ($p<0.05$) between organs (within a row) are indicated by different superscript letters

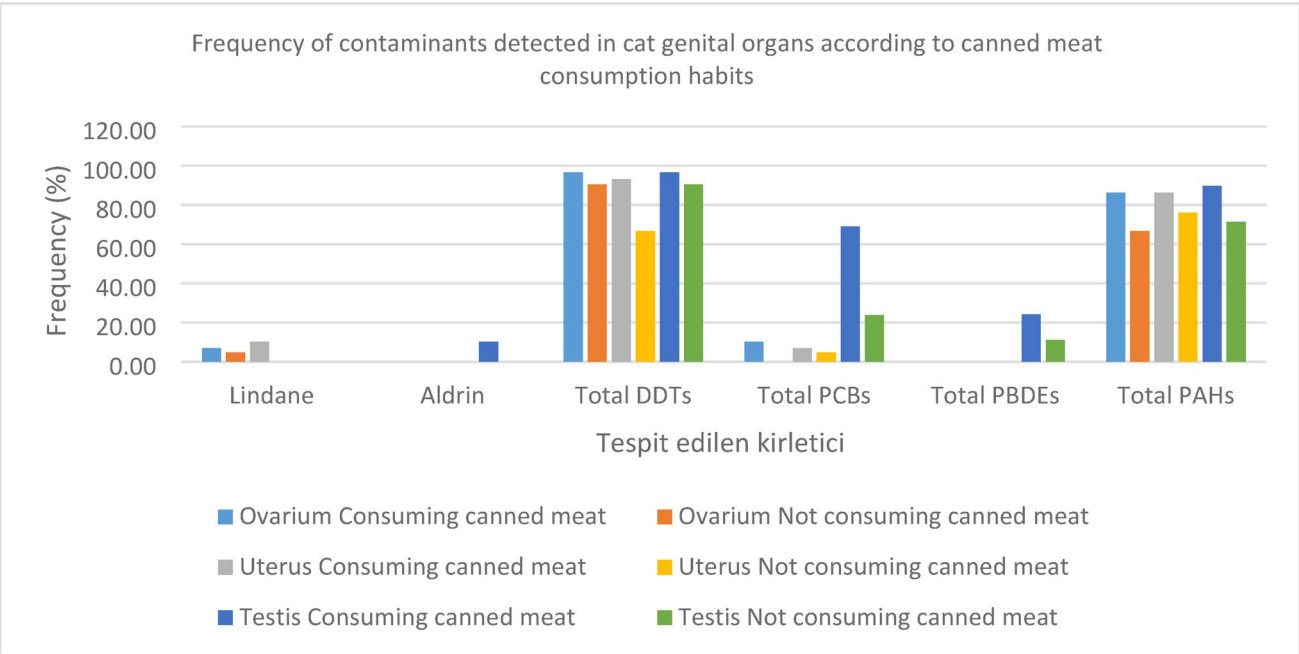


Fig. 7 Frequency of contaminants detected in cat genital organs according to canned meat consumption habits

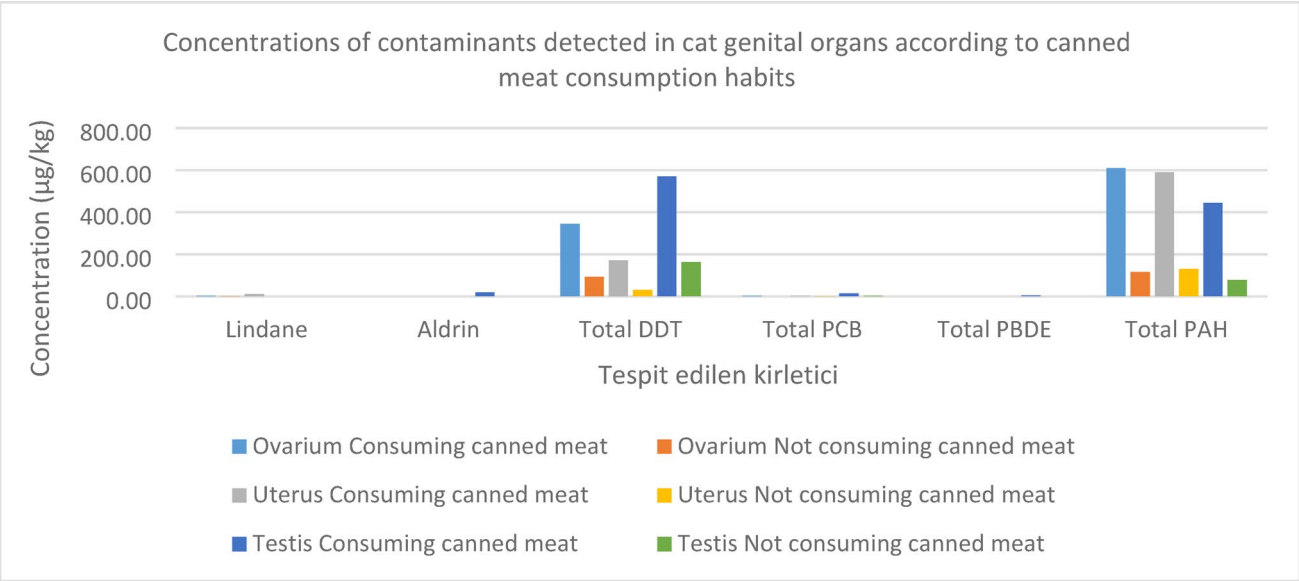


Fig. 8 Concentrations of contaminants detected in cat genital organs according to canned meat consumption habits

in the genital organs of cats that never or rarely consumed these foods (Fig. 8).

Discussion

All target analytes were analyzed at the µg/kg level and recovery rates were between 90.2% (naphthalene) and 99.1% (benzo-a-pyrene); RSD values for intermediate precision and reproducibility were below 13%. According to SANTE guidance, if target analytes are determined in µg/kg units, retrieval rates should be between 50 and 120% and RSD values below 15%. The evaluation of matrix effects is crucial in residue analysis of complex biological tissues like reproductive organs, as co-extracted compounds can significantly influence the ionization efficiency and accuracy of quantification. The observed matrix effects in this study validate the effectiveness of our sample clean-up protocol using PSA and C18 sorbents. Consequently, the use of matrix-matched calibration standards was essential to compensate for these effects and ensure the accuracy of the reported concentrations., Thus, the analytical method was considered sufficient to achieve the study's aims, as it reliably measured the residues of OCPs, PCBs, PBDEs, and PAHs in the genital organs of cats at very low levels.

Although the use of OCPs was banned many years ago, their residues are still found in living tissues and also in the environment because they remain undegraded in the environment for a long time (Sâri and Esen 2022). Due to their cheap production, DDT, HCH, Aldrin and Dieldrin are still used in some undeveloped countries to combat common vector-borne diseases (Jayaraj et al. 2016). Although the use of DDT was completely banned in Turkey in 1982 (Agar et al. 1991), it is still found in many ecosystems today due to its high lipophilic properties and high bioaccumulation and bio-magnification potential (Atmaca et al. 2019). Our finding that *4,4'*-DDE is the dominant contaminant is consistent with the results of previous local studies of river sediments in Turkey (Kuzukiran et al. 2016, 2019) and of human placentas (Yurdakök- Dikmen et al. 2022).

It has been suggested that the biological half-lives of DDT and its compounds are *4,4'*-DDE > *4,4'*-DDT > *4,4'*-DDD, and that higher *4,4'*-DDD or total DDT/*4,4'*-DDE ratios indicate more recent exposure, whereas DDD lower than total DDT and total DDT/DDE ratios are associated with past exposure (Aguilar 1984). Similarly, the total DDT/DDE ratio may be an indicator of the time of exposure to DDT and that a total DDT/DDE ratio of 5 or more indicates past exposure (Mekonen et al. 2021). When concentrations are expressed on a lipid basis, it has been reported that there is a direct correlation between DDT and DDE levels in blood and adipose tissue (Uyar et al. 2024), whereas on a wet tissue basis, the concentration of DDT in adipose tissue may be approximately 280 times higher than in blood. However, since DDT and DDE are widely stored in adipose tissue and released slowly from storage areas, no correlation was reported between tissue levels and short-term exposure time (Anderson 1985). According to these reports, the fact that DDD was not found in the present study and the total DDT/*4,4'*-DDE ratio (235/152) was low. This situation reflects past exposure and indicates that the contamination is not new.

It was found that the genital organs of cats housed in smoking environments contained significantly higher

concentrations of DDT compounds than cats housed in non-smoking environments. This is consistent with studies showing that there is a positive correlation between smoking and DDT content in women's milk (Vuori et al. 1977) and that smoking increases exposure to DDT compounds and that they can accumulate in human adipose tissue (Domanski et al. 1977). This is also consistent with the fact that DDT compounds in the genital organs of cats that consumed canned meat or fish at least once every 15 days or more were significantly higher than DDT compounds detected in the genital organs of cats that rarely (one month or more) or never consumed such foods (Zhang et al. 2025).

Total DDT concentration in the testes was significantly higher than in the ovaries and uterus (Table 1). This may be explained by the fact that male cats kept in smoking environments were exposed to more DDT (Table 2) and consumed more commercial canned food (Table 3). However, the total DDT concentration in the ovary was found to be higher than in the uterus, even when collected from the same female cats. The frequency of DDT was the same in the testis and ovary but slightly lower in the uterus. The higher concentration of lipophilic DDT compounds in the ovaries compared to the uteri, even from the same animal, could potentially be attributed to differences in the lipid composition between these reproductive tissues. Further analysis of tissue lipid content would be valuable to confirm this hypothesis. To our knowledge, there are no studies on DDT or similar fat-soluble compounds that can explain this. However, in a study of 93 normal cats without any disease, it was found by ultrasonography that the ovaries of the cats were 7.1–13.9 mm in diameter, the cornu uterine 1–5.8 mm in diameter and the uterus 1.5–5.3 mm in diameter (Gatel et al. 2020). It is thought that this may be explained by the fact that the size of the ovaries is larger than the uterus and opens more space for endocrine compounds than the uterus, or it may be due to the estrous cycle period of cats. Another study of women showed that blood flow to the uterus and ovaries can change during menstruation. It was also reported that increased levels of the hormone dehydroepiandrosterone (DHEA) in women who do not ovulate can cause resistance to endometrial arterial blood flow (Dogan et al. 2016). A similar phenomenon is thought to occur in cats. To the best of our knowledge, there is no information on whether this phenomenon is present in cats. Therefore, further research is clearly needed to determine why DDT compounds are more abundant in feline ovaries than in the uterus.

According to the results of the report published by the European Food Safety Agency (EFSA) in 2010, it was stated that PCB153 and PCB138 were the most common among other PCB species (Scientific Report of EFSA 2010). The frequency of PCBs in the genital organs of male cats was PCB153 > PCB28 > PCB180 > PCB101. It is estimated that the reason for the differences is that EFSA made this evaluation only in the member countries of the European Union and did not include other countries such as Turkey. Each country has its own dynamics and characteristics and it is thought that different results may be encountered in industrially developed countries such as the European Union. It was reported that PCB28 was the most commonly detected compound in the placentas of women giving birth in Ankara-Turkey, followed by PCB 52 (Yurdakök-Dikmen et al. 2022). Another study in Turkey reported that PCBs were not detected in honey samples collected from Ankara, but that PCB28 was the most common compound found in propolis, followed by PCBs 52 and 153 (Simşek et al. 2021). A study of adipose tissue from cats and dogs in Italy concluded that PCB138, PCB153 and PCB180 were the dominant PCBs (Storelli et al. 2009).

A study in Japan found that, PCB and other organohalogenic pollutants were found in the blood of wild and domestic animals (including cats and dogs) and PCB 153 was found in the highest concentration in cats and PCB 180 in dogs. The high frequency of PCB153 is thought to be due to factors such as the use of plastic carrier bags, tap water consumption, laminate parquet in the house where they stayed, the preference of plastic products as cat toys, food composition, yoghurt consumption for probiotic purposes, exposure to cigarette smoke, and high frequency of canned meat consumption (Zhang et al. 2025). It was observed that the frequency of PCB indicators was significantly higher in the genital organs of male cats than in female genital organs. It is estimated that female cats may transfer these EDCs to their offspring intrauterinally or transfer them to their offspring through milk during lactation periods (Krogenæs et al. 2014). In addition, the lower frequency of detection of PCBs observed in female cat genital organs compared to male cat genital organs may be associated with lower exposure status (Mizukawa et al. 2013) It is thought that PCB levels may be higher in the dry or wet food composition consumed by male cats than in the food composition consumed by females. The higher PCB concentrations in the testes may be explained by the fact that one or more PCB congeners were found in all cats kept in smoking environments (Table 2) and the consumption of canned meat (Table 3).

PBDEs are known as a source of concern especially for young children and cats. It has been reported that terrestrial carnivores can metabolize organohalogen compounds more easily than marine mammals. Moreover, a study found higher levels of PBDE and its metabolites in the blood of cats compared to other carnivores. In addition, the finding of high amounts of PBDE metabolites in the blood of cats suggests that these compounds are also ingested as a result of the consumption of seafood. In contrast, lower levels

of these compounds were found in the blood of dogs, suggesting that either dogs may metabolize these compounds faster or dogs may be exposed to these compounds in lower amounts (Mizukawa et al. 2013; Nomiyama et al. 2024). Another study was reported that PBDE85 was found in only one propolis sample (Şimşek et al. 2021), PBDEs were not found in honey collected from another province of Turkey, Kahramanmaraş (Erdoğrul 2007), and PBDEs were found at very low levels in environmental samples (Kuzukiran and Filazi 2016; Kuzukıran et al. 2016; Sevin et al. 2018). Similarly, only PBDE47 was found in the placentas of women living in Ankara who gave birth (Yurdakök-Dikmen et al. 2022). This may be a result of no PBDE production in Turkey or less importation of PBDE-containing products.

In the study, the frequency of PBDEs detected in cat genital organs according to canned meat consumption habits was observed around 20% in male cats. In addition, this rate was also observed around 20% in male cats in smoking environment. This suggests that male cats are more likely to be exposed to PBDEs through their dietary composition, i.e. seafood dietary composition, than females (Mizukawa et al. 2013; Nomiyama et al. 2014) and consequently exposed to these endocrine disruptors. In addition, considering that PBDE compounds are distributed by binding to house dust (Chow et al. 2015; Dye et al. 2007); in this case, it can be said that the amount of PBDEs in the dust of the environments where male cats were found in this study was higher. It should also be taken into account that females can transfer significant amounts of endocrine disrupting substances to the foetus during pregnancy and lactation periods (Haave et al. 2003).

To trace the origin of combustion-related PAHs, diagnostic ratios of parent PAHs have been widely applied (Budzinski et al. 1997). Specifically, compounds with molecular weights of 178 and 202 are frequently used to differentiate between combustion and petroleum-derived sources (Soclo et al. 2000). For molecular weight 178, the anthracene to anthracene plus phenanthrene ratio (An/178) is typically used, with values below 0.10 suggesting petroleum origin, while values above 0.10 are indicative of combustion processes (Budzinski et al. 1997). In the current study, the An/178 ratio was calculated as $34.29 / (34.29 + 35.95) = 0.48$, clearly exceeding the 0.10 threshold. This suggests that the PAH contamination likely originated from sources such as diesel, shale oil, coal, or certain crude oil derivatives. Similarly, for molecular weight 202, the fluoranthene to fluoranthene plus pyrene ratio (Fl/Fl+Py) is widely accepted as a reliable indicator, with a value of 0.50 commonly used as the cutoff between petroleum and combustion origins (Budzinski et al. 1997). Ratios below 0.50 are typically associated with petroleum products, whereas values above this threshold point toward kerosene, peat, coal, wood combustion, or creosote. In this study, the Fl/Fl+Py ratio was found to be $4.12 / (4.12 + 3.30) = 0.55$. This value supports the inference that the PAHs identified may have originated from kerosene, biomass (e.g., grass), coal, or wood combustion sources.

It was found that the total PAH ratio was high in cats consuming canned meat. Ruiz-Suárez et al. (2015) detected naphthalene, acenaphthene, phenanthrene, fluoranthrene and pyrene in 100% of both cat and dog feed samples. Our findings are consistent with the study of Ruiz-Suárez et al. (2015). In a study by Yamamato et al. (2015), PAH concentrations in hair samples of 20 smokers and 20 non-smokers were analyzed and it was reported that naphthalene, acenaphthene, fluorene, phenanthrene, anthracene, pyrene, fluoranthene were detected in all hair samples in the concentration range of 10–250 ng/g. It was reported that naphthalene, anthracene and total PAH substance contents were higher in the hair samples of smokers compared to non-smokers and especially benzo(a)pyrene, which is known to be carcinogenic, was found to have a relatively higher content in the hair samples of smokers (Yamamato et al. 2015). It can be said that there is a parallelism between the high total PAH ratio in the genital organs of cats living in smoking households and the study of Yamamato et al. (2015). In addition, it is stated that these endocrine disrupting substances are lipophilic in nature and as a result, they are stored in human body tissues, such as milk and placenta, and moreover, they can enter the circulatory system of the foetus through the umbilical cord (Yu et al. 2011). These substances have been suggested to cause prenatal and postnatal toxicity as well as high cancer risk (Navarrete-Meneses et al. 2024), disruption of hormonal balance and adverse neurodevelopmental effects (Archibong et al. 2002). It was stated that inhalation of 25–200 $\mu g/m^3$ benzo(a)pyrene in the air by the mother caused foetal loss and low birth weight (Archibong et al. 2002). In the present study, the frequency of detection of PAH compounds in both male and female cat genital organs was between 80 and 100% in those who were in a smoking environment, and between 80 and 90% in the tissues of those who had the habit of consuming canned meat. Accordingly, it is estimated that PAHs in cigarette smoke may contaminate living organisms through inhalation. In addition, it has been suggested that PAH compounds are also formed as a result of cooking methods used in canned meat production. On the other hand, it is seen that the frequency of detection of PAH compounds in the genital organs of cats, which consume canned meat less frequently and are housed in non-smoking environments, is also significantly higher. The reason for this is thought to be intrauterine transmission from the mother to the offspring during fetal development and as a result of the diet composition consumed.

When the relationship between the concentration of PAHs between the organs was examined, it was observed

that, unlike other EDCs, female cats accumulated PAHs at higher concentrations in the ovaries and uterus than in the testes of male cats. The fact that there was no difference between frequency levels but higher concentrations were found in female cats may be explained by the higher consumption of canned meat and meat products in female cats whose genital organs were removed in the study. Although this may also be explained by the fact that female cats are exposed to more cigarettes at home, the medical history form did not include a question about the amount of smoking at home. This was considered a shortcoming of the study, and no claim was made in this regard.

such a claim could not be put forward since there was no question on the anamnesis card about how much smoking was done at home and this was considered as a deficiency. In human studies, it has been suggested that women express genes encoding PAH metabolizing enzymes (CYP1A1) more and therefore the high enzymatic capacity of women increases their susceptibility to DNA adduct formation and lung cancer and therefore they metabolize them more slowly than men (Keir et al. 2021). Although there is no similar study in cats, this could be considered as a reason why female cats accumulate PAHs more.

Conclusions

In this study, in which consent forms were obtained from the owners of male and female cats brought to veterinary clinics for neutering, the ovaries and uteruses of female cats and the testes of male cats were taken and analyzed for the residues of certain endocrine compounds and thus, the exposure of cats, especially those housed in domestic environments, to environmental pollution was investigated. A total of 42 endocrine disruptors were analyzed by GC-MS, including OCPs, indicator PCBs and PCB118 representing ND-PCBs, PAHs considered as a priority by the United States Environmental Protection Agency (USEPA) and PBDEs recommended for monitoring in the European Commission Water Framework Directive. DDTs were found most frequently in cat genital organs, followed by PAHs. PCBs were found mostly in the testes, while PBDEs were detected with the lowest frequency and concentration. Cats in smoking environments and cats consuming meat products were found to be exposed to more DDT compounds. However, the total DDT concentration in the ovary was higher than in the uterus, even if they were taken from the same female cats. It was found that the concentration of PAHs in the organs of female cats accumulated at higher concentrations than in the testes of male cats and this was due to the fact that female cats consumed more canned meat and meat products.

As a result, it is seen that cats kept in the home environment may also be exposed to certain endocrine disrupting compounds and their sources may include smoking and consumed foods. The detected compounds may cause various adverse diseases in cats kept at home, and thus, it is considered important for cat owners to reduce such pollution sources as much as possible in order to protect both their own health and their pets. Considering that people may also be exposed to the hazards that cats are exposed to, it is concluded that this study can be an example of a single health approach.

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Author Contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by B.Cagmel-Turhal and A.Filazi. The first draft of the manuscript was written by B.Cagmel Turhal and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability Data will be made available on request.

Declarations

Competing Interests The authors have no relevant financial or non-financial interests to disclose.

Ethical Approval All procedures involving animal tissues were in accordance with the ethical standards of the institution and approved by the Ankara University Animal Experiments Local Ethics Committee (decision number 2022-2-15).

Consent to Participate Permission to participate was obtained from the owners of all cats included in the study.

References

Acaröz U, Kuzukıran O, Karatekeli S, İnce S, Filazi A (2020) Determination of organic chlorinated Pesticide, polybrominated Diphenyl ethers and polychlorinated biphenyl compounds in water samples from Eğirdir lake and surrounding spring waters. Bitlis Eren Univ J Sci 9:967–974. https://doi.org/10.17798/bitlisfen.676299

Adewunmi Adekunle A, Brahami Y, Coulibaly ML, Courtellemont R, Meghnefi F, Fofana I (2025) Bio-based hydrocarbon and gas-to-liquid (GTL) insulating liquids for power transformers: a

comprehensive review. Transformers Mag 12:104–117. https://hrcak.srce.hr/327390

Agar S, Aydınoğlu H, Temel O, İkizünal K, Ece H (1991) History of pesticide use, its present and future (Turkish). Turk Entomol Derg 15:247–256

Aguilar A (1984) Relationship of DDE/ΣDDT in marine mammals to the chronology of DDT input into the ecosystem. Can J Fish Aquat Sci 41:840–844. https://doi.org/10.1139/f84-10

Aksoy A, Dervisoglu M, Guvenc D, Gul O, Yazici F, Atmaca E (2013) Levels of organochlorine pesticide residues in butter samples collected from the black sea region of Turkey. Bull Environ Contam Toxicol 90:110–115. https://doi.org/10.1007/s00128-012-0872-8

Ali N, Malik RN, Mehdi T, Eqani SAMAS, Javeed A, Neels H, Covaci A (2013) Organohalogenated contaminants (OHCs) in the serum and hair of pet cats and dogs: biosentinels of indoor pollution. Sci Total Environ 449:29–36. https://doi.org/10.1016/j.scitotenv.2013.01.037

Anderson HA (1985) Utilization of adipose tissue biopsy in characterizing human halogenated hydrocarbon exposure. Environ Health Perspect 60:127–131. https://doi.org/10.1289/ehp.8560127

Archibong AE, Inyang F, Ramesh A, Greenwood M, Nayyar T, Kopsombut P et al (2002) Alteration of pregnancy related hormones and fetal survival in F-344 rats exposed by inhalation to benzo (a) pyrene. Reprod Toxicol 16:801–808. https://doi.org/10.1016/S0890-6238(02)00058-8

Atmaca E, Das YK, Yavuz O, Aksoy A (2019) An evaluation of the levels of organochlorine compounds (OCPs and PCBs) in cultured freshwater and wild sea fish eggs as an exposure biomarker for environmental contamination. Environ Sci Pollut Res 26:7005–7012. https://doi.org/10.1007/s11356-019-04207-0

Budzinski H, Jones I, Bellocq J, Pierard C, Garrigues PH (1997) Evaluation of sediment contamination by polycyclic aromatic hydrocarbons in the Gironde estuary. Mar Chem 58:85–97. https://doi.org/10.1016/S0304-4203(97)00028-5

Chow K, Hearn LK, Zuber M, Beatty JA, Mueller JF, Barrs VR (2015) Evaluation of polybrominated Diphenyl ethers (PBDEs) in matched Cat Sera and house dust samples: investigation of a potential link between PBDEs and spontaneous feline hyperthyroidism. Environ Res 136:173–179. https://doi.org/10.1016/j.envres.2014.09.027

Dogan O, Yildiz A, Temizkan O, Pulatoglu C (2016) Comparison of uterine, endometrial and ovarian blood flow by transvaginal color doppler ultrasound in ovulatory and anovulatory cycles. Ginekol Pol 87:581–584. https://doi.org/10.5603/GP.2016.0048

Domanski JJ, Nelson LA, Guthrie FE, Domanski RE, Mark R, Postlethwait RW (1977) Relation between smoking and levels of DDT and dieldrin in human fat. Arch Environ Health Int J 32:196–199

Dye JA, Venier M, Zhu L, Ward CR, Hites RA, Birnbaum LS (2007) Elevated PBDE levels in pet cats: sentinels for humans? Environ Sci Technol 41:6350–6356

Erdoğrul Ö (2007) Levels of selected pesticides in honey samples from Kahramanmaraş. Turk Food Control 18:866–871. https://doi.org/10.1016/j.foodcont.2006.04.010

Gatel L, Rault DN, Chalvet-Monfray K, De Rooster H, Levy X, Chiers K, Saunders JH (2020) Ultrasonography of the normal reproductive tract of the female domestic Cat. Theriogenology 142:328–337. https://doi.org/10.1016/j.theriogenology.2019.10.016

Haave M, Ropstad E, Derocher AE, Lie E, Dahl E, Wiig Ø et al (2003) Polychlorinated biphenyls and reproductive hormones in female Polar bears at Svalbard. Environ Health Perspect 111:431–436. https://doi.org/10.1289/ehp.5553

He J, Xu J, Zheng M, Pan K, Yang L, Ma L et al (2024) Thyroid dysfunction caused by exposure to environmental endocrine disruptors and the underlying mechanism: a review. Chem Biol Interact 391:110909. https://doi.org/10.1016/j.cbi.2023.110909

Jayaraj R, Megha P, Sreedev P (2016) Organochlorine pesticides, their toxic effects on living organisms and their fate in the environment. Interdiscip Toxicol 9:90–100. https://doi.org/10.1515/intox-2016-0012

Keir JL, Cakmak S, Blais JM, White PA (2021) The influence of demographic and lifestyle factors on urinary levels of PAH metabolites—empirical analyses of cycle 2 (2009–2011) CHMS data. J Expo Sci Environ Epidemiol 31:386–397. https://doi.org/10.1038/s41370-021-00319-2

Krogenæs AK, Ropstad E, Gutleb AC, Hårdnes N, Berg V, Dahl E, Fowler PA (2014) In utero exposure to environmentally relevant concentrations of PCB 153 and PCB 118 disrupts fetal testis development in sheep. J Toxicol Environ Health A 77:628–649. https://doi.org/10.1080/15287394.2014.887428

Kunisue T, Nakanishi S, Watanabe M, Abe T, Nakatsu S, Kawauchi S et al (2005) Contamination status and accumulation features of persistent organochlorines in pet dogs and cats from Japan. Environ Pollut 136:465–476. https://doi.org/10.1016/j.envpol.2005.01.009

Kuzukiran O, Filazi A (2016) Determination of selected polychlorinated biphenyl residues in meat products by quechers method coupled with gas chromatography–mass spectrometry. Food Anal Methods 9:1867–1875. https://doi.org/10.1007/s12161-015-0366-z

Kuzukiran O, Yurdakok-Dikmen B, Filazi A, Sevin S, Aydin FG, Tutun H (2016) Determination of polychlorinated biphenyls in marine sediments by ultrasound-assisted isolation and dispersive liquid–liquid Microextraction and gas chromatography–mass spectrometry. Anal Lett 49:2525–2536

Kuzukiran Ö, Filazi A, Arslan P, Dikmen BY, Tavşanoğlu ÜN (2019) Determination of persistent organic pollutants in water and sediment samples from Kızılırmak river. Kocatepe Vet J 12:430–436. https://doi.org/10.30607/kvj.625858

Ma X, Wang Z, Yu L, Yao W, Xiao L, Yao Z et al (2019) Mirror image between gas–particle partitioning and soil–moss distribution of polybrominated Diphenyl ethers in the Polar regions. Sci Total Environ 656:1199–1206. https://doi.org/10.1016/j.scitotenv.2018.11.455

Magnusson B, Ornemark U (2014) Eurachem guide: the fitness for purpose of analytical methods—a laboratory guide to method validation and related topics, 2nd edn. Accessed 3 Oct 2020. http://www.eurachem.org

Mekonen S, Ambelu A, Wondafrash M, Kolsteren P, Spanoghe P (2021) Exposure of infants to organochlorine pesticides from breast milk consumption in Southwestern Ethiopia. Sci Rep 11:22053. https://doi.org/10.1038/s41598-021-01556-w

Mizukawa H, Nomiyama K, Nakatsu S, Yachimori S, Hayashi T, Tashiro Y et al (2013) Species-specific differences in the accumulation features of organohalogen contaminants and their metabolites in the blood of Japanese terrestrial mammals. Environ Pollut 174:28–37. https://doi.org/10.1016/j.envpol.2012.11.006

Navarrete-Meneses MDP, Salas-Labadía C, Gómez-Chávez F, Pérez-Vera P (2024) Environmental pollution and risk of childhood cancer: a scoping review of evidence from the last decade. Int J Mol Sci 25:3284. https://doi.org/10.3390/ijms25063284

Nomiyama K, Kanbara C, Ochiai M, Eguchi A, Mizukawa H, Isobe T et al (2014) Halogenated phenolic contaminants in the blood of marine mammals from Japanese coastal waters. Mar Environ Res 93:15–22. https://doi.org/10.1016/j.marenvres.2013.10.003

Nomiyama K, Sato R, Sato F, Eguchi A (2024) Accumulation of persistent organic pollutants in the kidneys of pet cats (*Felis silvestris* catus) and the potential implications for their health. Sci Total Environ 933:173212. https://doi.org/10.1016/j.scitotenv.2024.173212

Parent AS, Damdimopoulou P, Johansson HK, Bouftas N, Draskau MK, Franssen D et al (2025) Endocrine-disrupting chemicals and

female reproductive health: a growing concern. Nat Rev Endocrinol https://doi.org/10.1038/s41574-024-01049-5

Pei J, Yao H, Wang H, Li H, Lu S, Zhang X, Xiang X (2018) Polybrominated Diphenyl ethers (PBDEs) in water, surface sediment, and suspended particulate matter from the yellow River, China: levels, spatial and seasonal distribution, and source contribution. Mar Pollut Bull 129:106–113. https://doi.org/10.1016/j.marpolbul.2018.02.023

Reincke M, Arlt W, Damdimopoulou P, Köhrle J, Bertherat J (2024) Endocrine disrupting chemicals are a threat to hormone health: a commentary on behalf of the ESE. Nat Rev Endocrinol 20:187–188. https://doi.org/10.1038/s41574-024-00958-9

Ruiz-Suárez N, Camacho M, Boada LD et al (2015) The assessment of daily dietary intake reveals the existence of a different pattern of bioaccumulation of chlorinated pollutants between domestic dogs and cats. Sci Total Environ 530–531:45–52. https://doi.org/10.1016/j.scitotenv.2015.05.088

Ruiz-Suárez N, Rial C, Boada LD, Henríquez-Hernández LA, Valeron PF, Camacho M et al (2016) Are pet dogs good sentinels of human exposure to environmental polycyclic aromatic hydrocarbons, organochlorine pesticides and polychlorinated biphenyls? J Appl Anim Res 44:135–145. https://doi.org/10.1080/09712119.2015.1013969

SANTE/11312/2021 (2021) Analytical quality control and method validation procedures for pesticide residues analysis in food and feed. Accessed 25 May 2025. https://www.eurl-pesticides.eu/docs/public/tmplt_article.asp?CntID=727

Sari MF, Esen F (2022) Atmospheric concentration, spatial variations, and source identification of persistent organic pollutants in urban and semi-urban areas using passive air samplers in Bursa, Turkey. Environ Sci Pollut Res 29:1–11. https://doi.org/10.1007/s11356-021-18485-6

Scientific Report of EFSA (2010) Results of the monitoring of non dioxin-like PCBs in food and feed. EFSA J 8:1701. https://doi.org/10.2903/j.efsa.2010.1701

Sevin S, Kuzukiran O, Yurdakok-Dikmen B, Tutun H, Aydin FG, Filazi A (2018) Selected persistent organic pollutants levels in the Ankara river by months. Environ Monit Assess 190:1–7. https://doi.org/10.1007/s10661-017-6405-6

Simsek I, Kuzukiran O, Yurdakok-Dikmen B, Snoj T, Filazi A (2020) Determination of persistent organic pollutants (POPs) in propolis by solid-phase extraction (SPE) and gas chromatography–mass spectrometry (GC-MS). Anal Lett 54:1668–1682. https://doi.org/10.1080/00032719.2020.1825463

Simsek I, Kuzukiran O, Yurdakok-Dikmen B, Sireli UT, Beykaya M, Filazi A (2021) Comparison of selected lipophilic compound residues in honey and propolis. J Food Compos Anal 102:104068. https://doi.org/10.1016/j.jfca.2021.104068

Şimşek I, Bilgili A (2022) Investigation of monthly residues of polycyclic aromatic hydrocarbons in water and sediment samples from Kirikkale Kizilirmak river basin. Environ Monit Assess 194:683. https://doi.org/10.1007/s10661-022-10334-9

Soclo HH, Garrigues PH, Ewald M (2000) Origin of polycyclic aromatic hydrocarbons (PAHs) in coastal marine sediments: case studies in Cotonou (Benin) and Aquitaine (France) areas. Mar Pollut Bull 40:387–396. https://doi.org/10.1016/S0025-326X(99)00234-7

Storelli MM, Storelli A, Barone G et al (2009) Accumulation of polychlorinated biphenyls and organochlorine pesticide in pet cats and dogs: assessment of toxicological status. Sci Total Environ 408:64–68. https://doi.org/10.1016/j.scitotenv.2009.09.006

US Environmental Protection Agency (EPA) (2024) Research on endocrine disruptors. Accessed 25 May 2025. https://www.epa.gov/chemical-research/research-endocrine-disruptors

Uyar R, Turgut Y, Çelik HT, Ünal MA, Kuzukıran Ö, Özyüncü Ö et al (2024) Effects of DDT and DDE on placental cholinergic receptors. Reprod Toxicol 126:108588. https://doi.org/10.1016/j.reprotox.2024.108588

Vuori E, Tyllinen H, Kuitunen P, Paganus A (1977) The occurrence and origin of DDT in human milk. Acta Paediatr 66:761–765. https://doi.org/10.1111/j.1651-2227.1977.tb07984.x

WHO (2022) World Health Organization. Food safety, persistent organic pollutants. Accessed 25 May 2025. https://www.who.int/news-room/fact-sheets/detail/food-safety

WHO/IPCS (World Health Organization, International Programme on Chemical Safety) (2002) Global Assessment of the State-of-the-Science of Endocrine Disruptors. WHO/PCS/EDC/02.2. https://iris.who.int/bitstream/handle/10665/67357/WHO_PCS_EDC_02.2.pdf?sequence=1. Accessed 25 May 2025

Yamamoto Y, Ishizaki A, Kataoka H (2015) Biomonitoring method for the determination of polycyclic aromatic hydrocarbons in hair by online in-tube solid-phase Microextraction coupled with high performance liquid chromatography and fluorescence detection. J Chromatogr B 1000:187–191. https://doi.org/10.1016/j.jchromb.2015.07.031

Yavuz O, Arslan HH, Esin C, Das YK, Aksoy A (2018) Determination of plasma concentrations of organochlorine pesticides and polychlorinated biphenyls in pet cats and dogs. Toxicol Ind Health 34:541–553

Yavuz O, Arslan HH, Tokur O, Marangoz O, Ozturk ZN, Mushtaq S (2024) Monitoring of environmental persistent organic pollutants in hair samples of cats and dogs. Toxicol Ind Health 34:541–553. https://doi.org/10.1177/0748233718768050

Yu Y, Wang X, Wang B, Tao S, Liu W, Wang X et al (2011) Polycyclic aromatic hydrocarbon residues in human milk, placenta, and umbilical cord blood in Beijing, China. Environ Sci Technol 45:10235–10242. https://doi.org/10.1021/es202796k

Yurdakok-Dikmen B, Kuzukiran O, Uyar R, Boztepe UG, Çelik HT, Ozyuncu O et al (2022) Live in same region, respond differently: canine and human response to pollutants in placental accumulation. Chemosphere 301:134470. https://doi.org/10.1016/j.chemosphere.2022.134470

Zhang Z, Pan Y, Fang Y, Mao S, Zhou Z, Zhang C et al (2025) Organochlorine pesticides: occurrence and Spatial distribution of residues, toxicity, and toxic mechanisms. Toxicology, https://doi.org/10.1016/j.tox.2024.154134

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