scientific reports

OPEN

Individual and combined contamination of the toxic metals in commercial cat and dog food

Jiaying Du[1], Kerui Zhou[1], Han Jiang[1], Shen Hu[2], Wei Zhang[3], Qiang Zheng[2], Guangteng Zhou[1] & Niya Zhang[1]✉

As the long-term accumulation of toxic metals in food poses significant health risks to pets, there is a growing concern among people regarding toxic metal contamination in pet food. In order to investigate the toxic metals levels in pet food in China, we collected a total of 93 imported cat and dog food from the Chinese market produced in 2021–2022, comprising 45 cat food and 48 dog food, and determined the concentrations of lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg) and arsenic (As) in them. The concentrations of Pb, Cd and Cr were determined by flame atomic absorption spectrometry, while Hg and As were quantified by atomic fluorescence spectrometry. The most contaminated of all samples were Cr and As, which were detected in all samples, followed by Hg, which was detected in 91 samples. In cat food, Cr and As were the most prevalent toxic metals, and Cr and Hg were found in all dog food. Pb was not detected in the canned food, while both cat and dog canned foods showed relatively high contamination rates of Cr, As, and Hg. Cr, Hg and As had the highest contamination levels in dry food. Some samples exceed the limits set by Hygienical Standard for Pet Feed of China (Announcement No. 20 of 2018) regarding Pb and Cr, while other toxic metals remained within acceptable limits. Canned food, however, met all regulatory limits for toxic metals. Across all types of pet food, Cr, Hg, and As were consistently the most prevalent combined contaminants. Analysis of the acute hazard index (aHI) values showed that both cats and dogs face potential dietary exposure risks to the toxic metals investigated, with Cr posing the most significant risk, followed by Pb and As. This study underscores the extensive presence of toxic metal contamination in pet foods, posing a significant risk to pet health due to ongoing exposure to multiple toxic metals.

Keywords Toxic metals, Dog food, Cat food, Combined contamination, Risk assessment

In recent years, there has been an increasing demand for companion pets in a society with a low birth rate and an ageing population. According to statistics, the number of pet dogs and cats in China reached 190 million in 2020, a nearly 3.6-fold increase over the past fifteen years[1]. The pet food industry offers a wide range of food products for dogs and cats, especially wet and dry food[2]. Dry food is the form of small, crunchy nutritionally dense nuggets and is the mainstay of the commercial pet food industry. Wet pet food are usually packed in tins or pouches[3]. The health and well-being of pets is a major concern for pet owners, so the quality and safety of pet food is of paramount importance to pet owners. They are particularly concerned about issues such as mold toxins and toxic metals. EU RASFF reported 34 cases of chemical hazards in pet food, of which 21 cases of heavy metal hazards[4]. Research on the prevalence in food and its impact of heavy metals on pets remain limited.

Heavy metals constitute a broad category of pollutants distinguished by their intensive usage, non-biodegradability, accumulation, and multiplication in the food chain[5]. Lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg) and arsenic (As) are known as the most problematic heavy metals and as toxic heavy metals[6,7]. Toxic metals are one of the most notified hazards in the Rapid Alert System for Food and Feed (RASFF)[8]. Cereals, legumes and tuberous roots and tubers are important plant-origin ingredients in pet food, such as rice, wheat, maize, potato, soybean, while meat, offal and byproducts of poultry, poultry eggs and marine fish are important animal-origin ingredients in pet food. Toxic metals in the soil are associated with mining activities[9]and the application of livestock manure chemical fertilizers[10], which result in uptake and accumulation of Cd, Pb, As and Hg by the crops. Toxic metals contaminate meat and offal from livestock, poultry and fish

[1]Department of Animal Nutrition and Feed Science, College of Animal Science and Technology, Huazhong Agricultural University, Wuhan 430070, Hubei Province, China. [2]Institute of Veterinary Drug of Hubei Province, Wuhan 430070, Hubei Province, China. [3]Institute of Animal Husbandry and Veterinary Medicine, Hubei Academy of Agricultural Sciences, Wuhan, China. ✉email: zhangniya@mail.hzau.edu.cn

via polluted environment, contaminated animal feed, canning process. Aquatic environment is known for the prevalence of toxic metals, which contributes greatly to the accumulation of toxic metal in seafood[11].

Toxic metals are ubiquitous bio-accumulative toxicant in the environment and food chain[12], and they exert toxic effects at very low concentrations[13], posing a priority threat to public health. Exposure to Pb can induce severe toxic effects, impacting almost every organ system[14]. Pb poisoning in dogs can have negative effects on the gastrointestinal tract, nervous system, kidneys, cardiovascular system, and blood[15]. Cd is a pervasive environmental pollutant known for its cumulative toxicity, predominantly accumulating in the liver and kidneys[16]. Cd can induce cancer in animals through various mechanisms, and exposure to it can cause nephrotoxicity and damage to the small intestine[17]. High levels of As exposure can cause kidney disease[18]. Exposure of dogs to As can lead to ulcerative dermatitis[19]. Cr typically exists in two valence states: trivalent chromium [Cr(III)] and hexavalent chromium [Cr(VI)], although Cr(III) is beneficial to animals, but Cr(VI) is highly toxic and can cause a range of diseases[20]. Lethargy, dilated pupils, tearing, and diarrhea are signs of acute Cr poisoning[5]. Santana et al[21]found that exposure of mice to Pb, Cd, and As results in varying degrees of lesions in the renal tubules. Both organic and inorganic Hg are readily accumulated in animals[22], while the organic for, which are mainly found in aquatic animals, has higher toxicity. Methylmercury poisoning in cats can cause clinical signs such as anorexia, weight loss, hypothyroidism and damage to the nervous system[23].

In 2018, China released Hygienical Standard for Pet Feed (Announcement No. 20 of 2018)[24], specifying limits for Pb, Cd, Cr, Hg and As in pet feed (Supplementary Table 1). Directive EC/1881/2006[25] and its subsequent amending document set the limits for Pb, Cd and Hg in feed.

Dogs and cats generally have longer lifespans compared to poultry, livestock, aquaculture animal and laboratory animals, resulting in longer exposure periods to toxic metals, which may lead to a lower toxicity threshold of toxic metals for pets. Therefore, monitoring toxic metal contamination in pet food is particularly crucial. Currently, there is a paucity of information in the literature on toxic metal contamination in pet food. To this end, we investigated the individual and combined occurrence of Pb, Cd, Cr, Hg, and As in imported dog and cat food collected from the Chinese market in 2021–2022, and conducted a health risk assessment.

Materials and methods

Sample collection and preparation

The samples examined in this paper were pet food imports produced between 2021 and 2022, sourced from various locations in supermarket and store chains across Beijing, Shenzhen, and Wuhan. A total of 93 pet food products were sampled, including 32 from the United States, 29 from Spain, 17 from Thailand, 10 from Germany and 5 from New Zealand, with 45 types of cat food and 48 types of dog food. In terms of food form, the samples consisted of 79 dry pet food formulations and 14 canned pet food formulations. After collection, the samples were stored according to the product storage instructions, that is the room with RH 40–60% and temperature 20–23℃. To avoid sample contamination and degradation, the sample determination should be completed as soon as possible. Before analysis, dry food samples were ground using a grinding mill (TAISITE INSTRUMENT, FW100) to ensure that 95% of the ground samples passed a 20 mesh sieve. Canned samples were homogenised using a homogeniser (Precision Labs, HM-7300).

Sample preparation for heavy metal determination

According to the national standard of China, samples for the determination of Pb (GB/T 13,080–2018), Cd (GB/T 13,082–2021), Cr (GB/T 13,088–2006) and As (GB/T 13,079–2006) were digested by the dry ashing method. A 5 g sample (0.0001 g) was charred in a porcelain crucible on a DK-98-II adjustable electric furnace, followed by ashing in a muffle furnace (Nabertherm, L9/11/B170). For Pb and Cd dettermination, 5 mL 6 mol/L HCl (Sinopharm Chemical Reagent Co.Ltd) and 5 mL 6 mol/L HNO_3 (Sinopharm Chemical Reagent Co.Ltd) were added to the ashed samples. For Cr, 5 mL 20% HNO_3 (Sinopharm Chemical Reagent Co.Ltd) was added to the ashed samples. Then the resulting solution was diluted to 50 mL with deionized water, subjected to being mixed and filtered. At the same time, the reagent blank solution was prepared. Samples for As determination were digested with 5 mL 150 g/L $Mg(NO_3)_2$ (Sinopharm Chemical Reagent Co., Ltd), followed by being charried and ashed in a muffle furnace (Nabertherm, L9/11/B170). Then the ashed sample were cooled and dissolved in 10 mL 3 mol/L HCl (Sinopharm Chemical Reagent Co., Ltd), followed by being transferred to a 50 mL volumetric flask, then 2.5 mL 50 g/L thiourea solution (Sinopharm Chemical Reagent Co., Ltd) was added to it, and the above solution was diluted to 50 mL by deionized water, meanwhile the reagent blank solution was prepared.

According to the national standard of China, samples for the determination of Hg (GB/T 13,081–2006) were digested using the microwave digestion method. A sample weighing 0.20–1.0 g (accurate to 0.0001 g) was placed in a digestion vessel along with 2–10 mL of 69%–70% HNO_3 (J.T.BaKer) and 2–4 mL of 30% H_2O_2 (Sinopharm Chemical Reagent Co., Ltd) in a SINEO MASTER 40 microwave digestion system (Shanghai Sineo Microwave Chemistry Technology Co., Ltd) in three heating stages. First, the samples were heated for 10 min until reaching 150℃ at 2100 W. In the second stage, the temperature was maintained at 170℃ for 5 min at 2100 W. In the last stage, the temperature was increased for 35 min to 190℃ at 2100 W. After digestion, the vessel was washed with a nitric acid solution (50 + 450) (J.T.BaKer), and the rinse was collected in a 50 mL volumetric flask and diluted to volume. Simultaneously, a reagent blank solution was prepared.

Sample analysis method

The levels of Pb, Cd and Cr were detected by flame atomic absorption spectrometry (ZEEnit 700 P, Analytik Jena AG) and the wavelengths were determined: Pb: 283.3 nm; Cd: 228.8 nm; Cr: 359.3 nm. The levels of Hg and As were analyzed by atomic fluorescence spectrometry (AFS-8530, Beijing Haiguang Instrument Co., Ltd). Quantification of toxic metals based on standard calibration in samples. Standard solutions of Pb, Cd, Cr, Hg and As (1000 μg/mL) (Guobiao (Beijing) Testing & Certification Co., Ltd) were used to configure standard series solutions, and the calibration curves for Pb, Cd, Cr, Hg and As were plotted. The standard solution has a national certification and accurate content.

The contamination rate of Pb and Cd indicates the proportion of samples where the toxic metal concentrations exceed the corresponding limit of quantification (LOQ). The contamination rate of Cr, Hg, and As indicates the proportion of samples where the toxic metal concentrations exceed the corresponding limit of detection (LOD). The exceedance rate is the proportion of samples where toxic metal concentrations exceed the Hygienical Standard for Pet Feed of China (Announcement No. 20 of 2018). The LOD and LOQ for detection method are presented in Table 1.

Quality control

Each batch of samples consists of 21 samples, each with parallel samples. Every batch also includes blank samples and certified reference materials to ensure the accuracy and stability of the testing. The reliability of the results is evaluated by calculating the recovery rate and precision. The recovery was calculated by spiking the toxic metal standard, the blank sample was not spiked. The recovery rates for Pb, Cr, Cd, Hg, and As were 105.28%, 117.93%, 102.52%, 89.9% and 107.6%, respectively. Standard solutions (Pb (5 mg/kg), Cr (1 mg/kg), Cd (0.5 mg/kg), Hg (8 μg/kg), and As (100 μg/kg)) were detected 4 times, and the relative standard deviation (RSD) was calculated to be in the range of 2.88–4.16%.

Health risk assessment

To assess the health risk of toxic metals in the samples, we calculated the daily intake of food for cats and dogs based on the metabolizable energy (ME) listed on the food labels. For foods that did not provide this information, the ME was estimated using the method described by the NRC[26]. The short-term intake (ESTI; μg/kg/day) and the acute hazard index (aHI) were used to represent the health risk. A simulation was therefore carried out with dogs of different sizes (5 kg, 10 kg and 30 kg) and cats weighing between 2 and 5 kg. The ME for dogs was calculated using the Eq. 95 kcal $\times BW^{0.75}$, while for cats, it was calculated using the Eq. 100 kcal $\times BW^{0.67}$[27].. The ESTI was calculated as follows:

$$\mathrm{ESTI} = \frac{\mathrm{C} \times \mathrm{K}}{\mathrm{BW}}$$

where C represents the highest concentration of each toxic metal in all samples, and K is the calculated daily intake of the sample.

The acute hazard index (aHI) is the ratio between the exposure to a single dose of a toxic substance and the acute reference dose of toxicity for it, was calculated as follows[28]:

$$\mathrm{aHI} = \frac{\mathrm{ESTI}}{\mathrm{ARfD}}$$

where ARfD is the acute reference dose, but it should be emphasised that there are no toxicological reference values for dogs and cats for the heavy metals investigated in the present study. Therefore, in the absence of appropriate reference values for pets, we used the same reference dose (RfD; μg/kg/day) as for mammals.

Data statistics

Microsoft Excel 2016 and PowerPoint 2016 for Windows version 10 were used for statistical analysis. Data were expressed as contamination rate, maximum, minimum and mean.

Results

Contamination of samples with Pb, Cd, Cr, Hg and As

The concentration of Pb, Cd, Cr, Hg and As in 93 samples are shown in Table 2. Cr and As were detected in all samples, with the highest contamination rates, followed by Hg. The contamination rates of Pb and Cr ranked third and fourth, respectively. Among the five metals, Cr has the highest concentration.The highest concentrations of Pb and Cr found in the positive samples were 5.80 mg/kg and 15.47 mg/kg, respectively. These levels exceeded the limits set by the Chinese Hygienic Standard for Pet Feed (Announcement No. 20 of 2018). Specifically, 8.60% of the samples exceeded the allowable Pb limit, while 26.88% surpassed the Cr limit.

The presence of the five toxic metals in cat and dog food is presented in Table 3. Out of the 45 samples of cat food tested, Cr and As were found in the largest number of samples, with all samples being tested for these

Heavy metals	LOD	LOQ
Pb (mg/kg)	NM	2
Cd (mg/kg)	0.08	0.20
Cr (μg/kg)	150	NM
Hg (μg/kg)	0.15	NM
As (mg/kg)	0.010	NM

Table 1. Detection limit and quantification limit of the heavy metal detection methods. Note[a]: “NM” stands for “Not Mentioned”.

Item	Pb (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Hg (mg/kg)	As (mg/kg)
No. of samples	93	93	93	93	93
No. of contaminated samples	39	29	93	91	93
% Contamination rate	41.94	31.18	100.00	97.85	100.00
Legal limits for toxic metals[a]	5	2	5	0.3	10
No. of above legal limit[a] samples	8	0	25	0	0
% above legal limit[a]	8.60	0	26.88	0	0
Minimum concentration[b]	2.07	0.0200	0.48	0.001	0.02
Maximum concentration	5.80	0.279	15.47	0.027	1.89
Mean concentration[c]	3.63	0.138	3.47	0.011	0.21

Table 2. Contamination of Pb, Cd, Cr, Hg and As in all samples. Note[a]: reference value according to the Hygienical Standard for Pet Feed of China (Announcement No. 20 of 2018). [b]: the lowest concentration of the positive samples. [c]: arithmetic mean of all positive samples.

Item	Pb		Cd		Cr		Hg		As	
	Cat food	Dog food	Cat food	Dog food	Cat foods	Dog food	Cat food	Dog food	Cat food	Dog food
No. of samples	45	48	45	48	45	48	45	48	45	48
No. of contaminated samples	19	20	15	14	45	48	43	48	45	48
Contamination rate(%)	42.22	41.67	33.33	29.17	100.00	100.00	95.56	100.00	100.00	100.00
No. of above legal limit[a] samples	4	4	0	0	10	15	0	0	0	0
% above legal limit[a]	8.89	8.33	0	0	22.22	31.25	0	0	0	0
Minimum concentration[b]	2.31	2.07	0.0200	0.0214	0.48	0.82	0.002	0.001	0.02	0.03
Maximum concentration	5.80	5.54	0.253	0.279	15.47	6.67	0.022	0.027	1.64	1.89
Mean concentration[c]	3.93	3.34	0.142	0.134	3.31	3.62	0.011	0.012	0.16	0.26

Table 3. Contamination of Pb, Cd, Cr, Hg and As in cat food and dog food. Note[a]: reference value according to the Hygienical Standard for Pet Feed of China (Announcement No. 20 of 2018). [b]: the lowest concentration of the positive samples. [c]: arithmetic mean of all positive samples.

Item	Pb (mg/kg)		Cd (mg/kg)		Cr (mg/kg)		Hg (mg/kg)		As (mg/kg)	
	Canned food	Dry food	Canned food	Dry food	Canned food	Dry food	Canned food	Dry food	Canned food	Dry food
No. of samples	12	33	12	33	12	33	12	33	12	33
No. of contaminated samples	0	19	2	13	12	33	10	33	12	33
Contamination rate(%)	0	57.58	16.67	39.40	100.00	100.00	83.33	100.00	100.00	100.00
No. of above legal limit[a] samples	0	4	0	0	0	10	0	0	0	0
% above legal limit[a]	0	12.12	0	0	0	30.30	0	0	0	0

Table 4. Contamination of Pb, Cd, Cr, Hg and As in canned and dry cat food. Note[a]: reference value according to the Hygienical Standard for Pet Feed of China (Announcement No. 20 of 2018).

elements. Mercury (Hg) was detected in 97.58% of the samples. In dog food, chromium, mercury, and arsenic were detected in every sample analyzed. Consistent with observations across all samples, Cr has the highest concentrations in both cat and dog food. Furthermore, the average concentrations of Pb and Cd were higher in cat food than in dog food, whereas the average concentrations of Cr and As were lower in cat food than in dog food. Notably, 8.89% of cat food samples and 8.33% of dog food samples exceeded the Pb limit set by Hygienical Standard for Pet Feed of China (Announcement No. 20 of 2018), while 22.22% of cat food samples and 31.25% of dog food samples exceeded the Cr limit.

Tables 4 and 5 analyze the toxic metal content in canned and dry cat food and dog food, respectively. Whether in cat food or dog food, Pb was not detected in the canned food, while Cr, As, and Hg were frequently detected. The contamination rates of Cr, Hg, and As in dry food are the highest, similar to those in canned food. The content of five toxic metals in all the canned samples were below the corresponding limits of the Hygienical Standard for Pet Feed of China (Announcement No. 20 of 2018). However, in dry food samples, some exceeded the limits for Pb and Cr, with the exceedance rates for Pb and Cr being similar in both cat food and dog food.

Item	Pb (mg/kg)		Cd (mg/kg)		Cr (mg/kg)		Hg (mg/kg)		As (mg/kg)	
	Canned food	Dry food	Canned food	Dry food	Canned food	Dry food	Canned food	Dry food	Canned food	Dry food
No. of samples	2	46	2	46	2	46	2	46	2	46
No. of contaminated samples	0	20	0	14	2	46	2	46	2	46
Contamination rate(%)	0	43.48	0	30.43	100.00	100.00	100.00	100.00	100.00	100.00
No. of above legal limit[a] samples	0	4	0	0	0	15	0	0	0	0
% above legal limit[a]	0	8.70	0	0	0	32.61	0	0	0	0

Table 5. Contamination of Pb, Cd, Cr, Hg and As in canned and dry dog food. Note[a]: reference value according to the Hygienical Standard for Pet Feed of China (Announcement No. 20 of 2018).

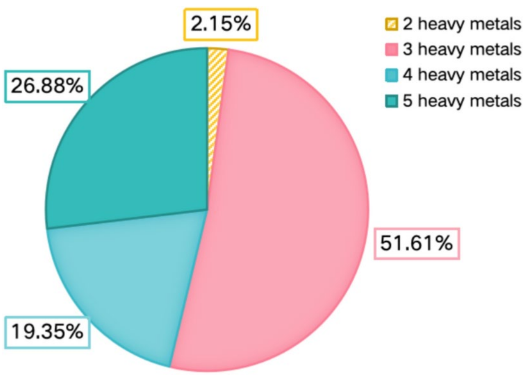

Fig. 1. Combined toxic metal contamination in all samples (n = 93).

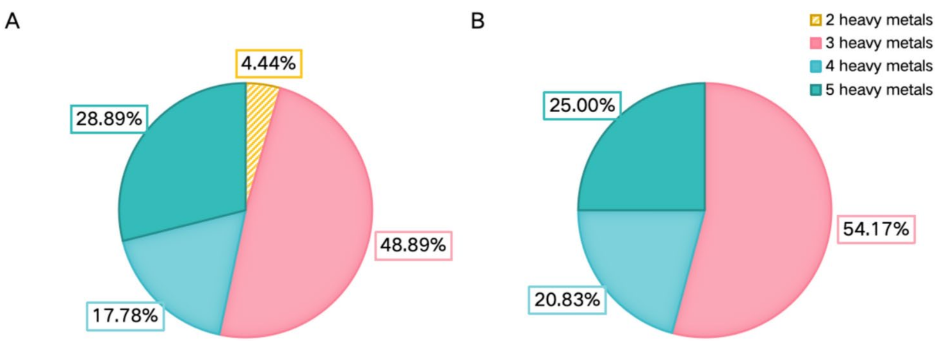

Fig. 2. Combined toxic metal contamination in cat and food.A. Cat food (n=45); B. Dog food (n=48).

Combined contamination of Pb, Cd, Cr, Hg and As in samples

Figure 1 illustrates the presence of Pb, Cd, Cr, Hg, and As in all samples. At least two toxic metals were found in each sample. Specifically, only 2.15% of the samples contained two toxic metals, Cr and As. In contrast, 26.88% of the samples were contaminated with all five toxic metals. The majority of samples were affected by three toxic metals, primarily Cr, Hg, and As. Additionally, 19.35% of the samples were found to contain four toxic metals, with the main contaminants being Pb, Cr, Hg, and As.

The co-occurrence of Pb, Cd, Cr, Hg and As in cat and dog food is shown in Fig. 2A and Fig. 2B, respectively, and shows a similar trend to that of all samples. In cat and dog food, the predominant situation of co-contamination in both cat and dog food was simultaneous contamination by three toxic metals, mainly by Cr, Hg and As. The co-contamination by four metals in cat and dog food was 17.78% and 20.83% respectively, with Pb, Cr, Hg and As being the main contaminants. Notably, in cat food, all samples contained at least two toxic metals, whereas in dog food, all samples contained at least three types of toxic metals.

Figure 3 shows the co-contamination of toxic metals in canned food (**A**) and dry food (**B**) samples. Canned foods were found to be contaminated with at least two and up to four different toxic metals, while dry foods were contaminated with at least three toxic metals. The highest contamination rates were observed with three toxic metals, affecting 71.43% of canned food samples and 48.10% of dry food samples. The primary toxic metals involved were Cr, Hg, and As.

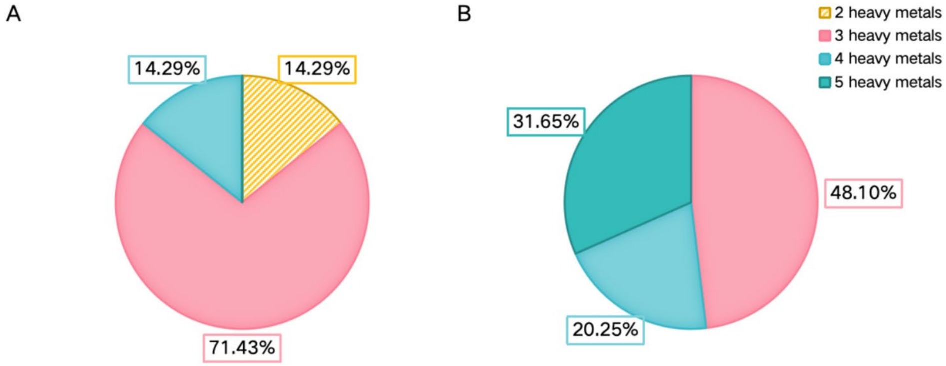

Fig. 3. Combined toxic metal contamination in canned and dry food. A. canned food (n = 14); B. dry food (n = 79).

Heavy metal	RfD[a] (μg/kg/day)	Pet type	Body size (kg)	aHI[b]
Pb	6	Cat	2	21.82
			5	16.13
		Dog	5	17.36
			10	14.60
			30	11.09
Cd	1	Cat	2	5.86
			5	4.33
		Dog	5	5.41
			10	4.55
			30	3.45
Cr	0.3	Cat	2	1040.14
			5	768.73
		Dog	5	404.03
			10	339.75
			30	258.15
Hg	0.1	Cat	2	13.28
			5	9.81
		Dog	5	4.32
			10	3.78
			30	2.88
As	0.3	Cat	2	124.97
			5	92.36
		Dog	5	94.50
			10	88.20
			30	67.20

Table 6. Dietary exposure risk assessment for cats and dogs of different sizes. Note[a]: The reference dose (RfD) is an indicator used to assess the health risks of long-term, low-dose exposure to chemicals, based on the non-carcinogenic daily intake (TDI) reference values provided by the U.S. Environmental Protection Agency (EPA). [b]: The acute hazard indez (aHI) is the ratio between the ESTI and the acute toxicity reference dose, and a value > 1 would indicate that a significant adverse event might occur. This number is dimensionless.

Dietary exposure risk assessment

Table 6 presents the aHI (acute Hazard Index) values for toxic metals, including Pb, Cd, Cr, Hg, and As, in cats and dogs of different body weights. The aHI values for these metals in both species exceed the established safety threshold, with Cr showing the highest aHI value, significantly surpassing the limit. In both cats and dogs, As ranks as the second highest in aHI value, followed by Pb. Notably, the aHI value for As in cats is considerably higher than that in dogs. This study suggests that both cats and dogs face potential dietary exposure risks to the toxic metals investigated, with Cr posing the most significant risk, followed by Pb and As. Additionally, it was observed that cats and dogs with lower body weights tend to exhibit higher aHI values for these toxic metals.

Discussion

Pb, Cd, Cr, Hg, and As are toxic, bio-stable and bio-accumulative pollutants for pets. In this study, Cr, As and were Hg were prevalently present in all samples. Pedrinelli et al[29]reported that in home-prepared diets for dogs and cats, above 90% samples were contaminated with Pb, Cd, Cr and Hg, being consistent with our findings. Interestingly, our study also found that Pb contamination rates were low, yet its concentration was high (5.80 mg/kg). The presence of high Pb concentrations despite low contamination rates suggests a need for careful monitoring and adherence to strict regulatory standards to safeguard pet health. In contrast to the Hygienical Standard for Pet Feed of China (Announcement No. 20 of 2018), where 8.60% of the pet food samples exceeded the Pb limit and 26.88% exceeded the Cr limit, the concentrations of the other three heavy metals were below their respective limits. This trend was consistent across both cat and dog food samples examined in the study. This discrepancy may stem from an accumulation of metal elements in the geographical regions where these raw materials are sourced for pet foods. The origin and cultivation conditions of food ingredients significantly influence the inclusion of trace minerals[30]. The primary ingredients investigated in this study included poultry, fish, cereals, tubers, and meat and bone meal. According to Hossain et al[31], significant Cr pollution was observed in meat bone meal and fish meal. Additionally, studies have reported higher accumulations of Cr and Pb in grains and vegetables[32]. Garrido et al[33]also highlighted that potato tubers from mining areas exceeded the concentration limits for Pb, Cd, and As in commercially sold vegetables by 16-fold, tenfold, and ninefold respectively. In a previous study with commercial pet food conducted in Egypt, cat food, on average, had greater concentrations of the metals Cd, Cr, Pb, and Sn than dog food[34]. It is noteworthy that these findings diverge from those of the current study. In the present investigation, the mean concentrations of Pb and Cd were higher in cat food than in dog food, whereas the mean concentrations of Cr and As were lower in cat food than in dog food. The discrepancy may be attributed to the disparity in the primary constituents of foodstuff, in addition to the provenance of the raw materials. In general, animal-based ingredients are more susceptible to contamination with toxic metals than plant-based ingredients[27]. Moreover, Keshavarzi et al[35]observed that the concentration of toxic metals in the tissues of the three fish species differed due to differences in their feeding habits and accumulation capacity. In this study, the difference in toxic metal concentrations between cat and dog food may be attributed to the fact that cats are carnivores with primary nutritional needs from animal proteins and fats. Therefore, some cat foods may use more animal-based ingredients. In contrast, dogs are omnivores with a more varied diet that includes a significant amount of plant-based foods alongside small amounts of animal-based foods. Cats are more likely than dogs to consume food containing fish proteins, as these are more appealing to cats. Fish is a rich source of protein, but some species may bioaccumulate high levels of toxic metals. The study conducted by Kim[30] revealed that fish-based diets exhibited significantly higher levels of As, Cd and Hg than poultry or red meat-based diets. Consequently, diets containing fish may present a greater risk to health than others. In this study, dry pet food showed a higher rate of toxic metal contamination compared to canned food, with average concentrations of Pb, Cd, Cr, and As being higher in dry food than in canned food. Similar findings were reported by Zafalon et al[27]. Additionally, the content of five toxic elements in canned food met the standard, whereas in dry food, the Pb content of 10.13% samples exceeded the standard, and the Cr content of 31.65% samples exceeded the standard. This indicates that dry food is less safe than canned food. The higher concentrations of serum toxic metals in dogs that received commercial and mixed foods compared with dogs on homemade food may be due to the higher proportion of dry food in the dog diets, as noted by Tomza-Marciniak et al[36]. The observed difference in heavy metal contamination between dry and canned pet food may indeed stem from several factors such as raw materials, processing methods, additives, and packaging materials. Variations in the sources of raw materials appear to be a primary contributing factor. The contamination in dry pet food could also be attributed to processing techniques like puffing, granulating, and baking, which may facilitate the introduction or concentration of heavy metals. Research by Tao et al[37] supports this, noting higher incidences of heavy metal contamination (including Cr, Cd, As, and Hg) in mineral and additive samples used in pet food. Excessive use of these components in dry food formulations could potentially elevate toxic metal levels. Moreover, packaging materials containing toxic metals may leach into the pet food, further exacerbating contamination. For instance, Eti et al[38] found heavy metals (Pb, Cd, Hg, Cr, and Sb) migrating from food contact plastic packaging in Bangladesh, which poses a risk of bioaccumulation over time through repeated exposure.

As natural components of the earth's crust, the penetration of toxic metals is ubiquitous. Due to natural processes and anthropogenic human activities, toxic metals pollute ecosystems such as soil, plants, water and air and maximize the enrichment effect of toxic metals in the environment[39]. In order to ensure that pets receive balanced nutrition, pet food usually contains a variety of ingredients. As a result, the mixed presence of heavy metals is inevitable. In the present study, at least two heavy metals were detected. The highest proportion of samples was contaminated with three toxic metals, the dominant pollutants were Cr, Hg and As, regardless of whether the statistics were calculated based on all samples, on the basis of cat or dog food or on the basis of canned or dry food. In humans, simultaneous exposure to cadmium and inorganic arsenic has been reported to cause more significant kidney damage than exposure to each element alone[40]. Additional studies have demonstrated that simultaneous exposure to higher concentrations of toxic metal mixtures (Cr, Co, Cd, and Pb) can lead to poorer liver function[41]. Wang et al[42] also calculated through modeling that exposure to metal mixtures increases the hyperlipidemia risk. Although there is a paucity of literature on combined heavy metal pollution in pets, it can be reasonably inferred from the damage caused by human exposure to toxic metal mixtures that combined heavy metal pollution can also have adverse effects on pets. Thus, extensive and in-depth studies on the combined and cumulative effects of toxic metals in pet food are needed.

To further assess the risk of cats and dogs ingesting heavy metals from contaminated food, we calculated the aHI. The aHI is an indicator used to evaluate the acute toxicity risk to animals from short-term exposure to chemical substances like heavy metals. A higher value indicates a greater risk of exposure. In this study, both cats and dogs face the potential risk of exposure to toxic metals through their diet, and Cr is the most dangerous factor for the health of cats and dogs among the five heavy metals, while Pb and As also pose significant risks to their health. Additionally, the study observed that lighter-weight cats and dogs may be more sensitive to heavy metal intake due to their relatively smaller body mass, resulting in higher aHI values.

Conclusions

The study found widespread presence of Cr, Hg, and As in imported cat and dog food brands from the Chinese market in 2021–2022. Pb average concentrations were highest overall, followed by Cr, with some samples exceeding the limits set by Hygienical Standard for Pet Feed of China (Announcement No. 20 of 2018). Dry foods are less safe than canned foods. Cr poses the greatest health risk to pets, with significant risks also from Pb and As. Co-contamination of Cr, Hg, and As is common, potentially amplifying their cumulative health impacts. Therefore, more research on combined toxicity is needed to fully understand these risks, emphasizing the need for stricter quality controls in pet food production and safety assessments of packaging materials.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Received: 29 October 2024; Accepted: 9 April 2025
Published online: 17 April 2025

References

1. Lin, Z., Zhang, K., Hu, D., Hu, X. & Hu, H. Exploration of biosecurity and high-quality development of imported pet food at the national gate. *Port Health Control* **27**(05), 38–41 (2022).
2. Witaszak, N., Waśkiewicz, A., Bocianowski, J. & Stępień, Ł. Contamination of pet food with mycobiota and fusarium mycotoxins-focus on dogs and cats. *Toxins* **12**(2), 130. https://doi.org/10.3390/toxins12020130 (2020).
3. Kong X (2021) Pet food and taboos.Zhe Jiang XuMu ShouYi 46(06) 41–42.
4. Zhang S,Cao C,Liu M,Wang Y,Wang M Risks and strategies in pet food safety assessment. China Feed (01) 125–129 https://doi.org/10.15906/j.cnki.cn11-2975/s.2023030006-12 (2024)
5. Altınok-Yipel, F., Yipel, M. & Tekeli, İO. Health risk assessment of essential and toxic metals in canned/pouched food on kitten and adult cats: An animal health risk assessment adaptation assay. *Biol, Trace Elem. Res.* **200**(4), 1937–1948. https://doi.org/10.1007/s12011-021-02792-1 (2022).
6. Rahman, Z. & Singh, V. P. The relative impact of toxic heavy metals (THMs) (arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: an overview. *Environ. Monit. Assess* **191**(7), 419. https://doi.org/10.1007/s10661-019-7528-7 (2019).
7. Hejna, M. et al. Review: Nutritional ecology of heavy metals. *Animal* **12**(10), 2156–2170. https://doi.org/10.1017/S175173111700355X (2018).
8. Pigłowski, M. Heavy metals in notifications of rapid alert system for food and feed. *Int. J. Environ. Res. Public Health* **15**(2), 365. https://doi.org/10.3390/ijerph15020365 (2018).
9. Du, J. et al. Mercury horizontal spatial distribution in paddy field and accumulation of mercury in rice as well as their influencing factors in a typical mining area of Tongren City, Guizhou. *China. J. Environ. Health Sci. Eng.* **19**(2), 1555–1567. https://doi.org/10.1007/s40201-021-00711-z (2021).
10. Wang, F., Wang, Z., Kou, C., Ma, Z. & Zhao, D. Responses of wheat yield, macro- and micro-nutrients, and heavy metals in soil and wheat following the application of manure compost on the North China Plain. *PLoS ONE* **11**(1), e0146453. https://doi.org/10.1371/journal.pone.0146453 (2016).
11. Basyigit, B. & Tekin-Oezan, S. Concentrations of some heavy metals in water, sediment, and tissues of pikeperch (sander lucioperca) from karatas lake related to physico-chemical parameters, fish size, and seasons. *Pol. J. Environ.* **22**(3), 633–644 (2013).
12. Ramachandra, T. V., Sudarshan, P. B., Mahesh, M. K. & Vinay, S. Spatial patterns of heavy metal accumulation in sediments and macrophytes of Bellandur wetland, Bangalore. *J. Environ. Manage.* **206**, 1204–1210. https://doi.org/10.1016/j.jenvman.2017.10.014 (2018).
13. Ali, H., Khan, E. & Sajad, M. A. Phytoremediation of heavy metals–concepts and applications. *Chemosphere* **91**(7), 869–881. https://doi.org/10.1016/j.chemosphere.2013.01.075 (2013).
14. Singh, N., Kumar, A., Gupta, V. K. & Sharma, B. Biochemical and molecular bases of lead-induced toxicity in mammalian systems and possible mitigations. *Chem. Res. Toxicol.* **31**(10), 1009–1021. https://doi.org/10.1021/acs.chemrestox.8b00193 (2018).
15. Høgåsen, H. R., Ørnsrud, R., Knutsen, H. K. & Bernhoft, A. Lead intoxication in dogs: Risk assessment of feeding dogs trimmings of lead-shot game. *BMC Vet. Res.* **12**(1), 152. https://doi.org/10.1186/s12917-016-0771-z (2016).
16. Rani, A., Kumar, A., Lal, A. & Pant, M. Cellular mechanisms of cadmium-induced toxicity: A review. *Int. J. Environ. Health Res.* **24**(4), 378–399. https://doi.org/10.1080/09603123.2013.835032 (2014).
17. Chen, X. et al. Cadmium exposure triggers oxidative stress, necroptosis, Th1/Th2 imbalance and promotes inflammation through the TNF-α/NF-κB pathway in swine small intestine. *J. Hazard Mater.* **421**, 126704. https://doi.org/10.1016/j.jhazmat.2021.126704 (2022).
18. Chen, W. J. et al. Renin-angiotensin-aldosterone system related gene polymorphisms and urinary total arsenic is related to chronic kidney disease. *Toxicol. Appl. Pharmacol.* **279**(2), 95–102. https://doi.org/10.1016/j.taap.2014.05.011 (2014).
19. Evinger, J. V. & Blakemore, J. C. Dermatitis in a dog associated with exposure to an arsenic compound. *J. Am. Vet. Med. Assoc.* **184**(10), 1281–1282 (1984).
20. Luo, M. et al. Effect of selenium nanoparticles against abnormal fatty acid metabolism induced by hexavalent chromium in chicken's liver. *Environ. Sci. Pollut. Res. Int.* **26**(21), 21828–21834. https://doi.org/10.1007/s11356-019-05397-3 (2019).
21. Santana, F. F. V. et al. Toxicology of arsenate, arsenite, cadmium, lead, chromium, and nickel in testes of adult Swiss mice after chronic exposure by intraperitoneal route. *J. Trace Elem. Med. Biol* **80**, 127271. https://doi.org/10.1016/j.jtemb.2023.127271 (2023).
22. Dunham-Cheatham, S. M., Klingler, K., Peacock, M., Teglas, M. B. & Gustin, M. S. What is in commercial cat and dog food? The case for mercury and ingredient testing. *Sci. Total Environ.* **684**, 276–280. https://doi.org/10.1016/j.scitotenv.2019.05.337 (2019).
23. Gruber, T. A., Costigan, P., Wilkinson, G. T. & Seawright, A. A. Chronic methylmercurialism in the cat. *Aust Vet J* **54**(4), 155–160. https://doi.org/10.1111/j.1751-0813.1978.tb02438.x (1978).
24. Announcement of the Ministry of Agriculture and Rural Affairs on the Management of Pet Feed of China (Announcement No. 20 of 2018). National Criterion of China Beijing, China: 2018
25. EC-European Commission (2006) Commission regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. Off J Eur Union L 364:5–24
26. National Research Council et al. Nutrient Requirements of Dogs and Cats. National Academies Press (2006)

27. Zafalon, R. V. A. et al. Toxic element levels in ingredients and commercial pet foods. *Sci. Rep.* **11**(1), 21007. https://doi.org/10.1038/s41598-021-00467-4 (2021).
28. Macías-Montes, A. et al. Risk assessment of the exposure to mycotoxins in dogs and cats through the consumption of commercial dry food. *Sci. Total Environ.* **708**, 134592. https://doi.org/10.1016/j.scitotenv.2019.134592 (2020).
29. Pedrinelli, V. et al. Concentrations of macronutrients, minerals and heavy metals in home-prepared diets for adult dogs and cats. *Sci. Rep.* **9**(1), 13058. https://doi.org/10.1038/s41598-019-49087-z (2019).
30. Kim, H. T., Loftus, J. P., Mann, S. & Wakshlag, J. J. Evaluation of arsenic, cadmium, lead and mercury contamination in over-the-counter available dry dog foods with different animal ingredients (red meat, poultry, and fish). *Front. Vet. Sci.* **5**, 264. https://doi.org/10.3389/fvets.2018.00264 (2018).
31. Hossain, A. M. M. M. et al. Chromium (cr) contamination of poultry from use of tannery-based cr-contaminated feed ingredients and public health and environmental risks. *Asian. J. Water Environ.* **14**(1), 19–28 (2017).
32. Khandare, A. L. et al. Potential health risks associated with the heavy metal content in commonly consumed food from prakasam district of Andhra Pradesh. *India Biol. Trace Elem. Res.* **200**(7), 3453–3461. https://doi.org/10.1007/s12011-021-02918-5 (2022).
33. Garrido, A. E., Strosnider, W. H. J., Wilson, R. T., Condori, J. & Nairn, R. W. Metal-contaminated potato crops and potential human health risk in Bolivian mining highlands. *Environ. Geochem. Health* **39**(3), 681–700. https://doi.org/10.1007/s10653-017-9943-4 (2017).
34. Abd-Elhakim, Y. M., El Sharkawy, N. I. & Moustafa, G. G. An investigation of selected chemical contaminants in commercial pet foods in Egypt. *J. Vet. Diagn. Inves. Inc.* **28**(1), 70–75. https://doi.org/10.1177/1040638715624733 (2016).
35. Keshavarzi, B. et al. Heavy metal contamination and health risk assessment in three commercial fish species in the Persian Gulf. *Mar. Pollut. Bull.* **129**(1), 245–252. https://doi.org/10.1016/j.marpolbul.2018.02.032 (2018).
36. Tomza-Marciniak, A., Pilarczyk, B., Bąkowska, M., Ligocki, M. & Gaik, M. Lead, cadmium and other metals in serum of pet dogs from an urban area of NW Poland. *Biol. Trace Elem. Res.* **149**(3), 345–351. https://doi.org/10.1007/s12011-012-9433-6 (2012).
37. Tao, C. et al. Heavy Metal content in feedstuffs and feeds in Hubei Province. *China. J. Food Prot.* **83**(5), 762–766. https://doi.org/10.4315/0362-028X.JFP-18-539 (2020).
38. Eti, S. A. et al. Assessment of heavy metals migrated from food contact plastic packaging: Bangladesh perspective. *Heliyon* **9**(9), e19667. https://doi.org/10.1016/j.heliyon.2023.e19667 (2023).
39. Chen, Y. G. et al. Impacts of heavy metals and medicinal crops on ecological systems, environmental pollution, cultivation, and production processes in China. *Ecotoxicol Environ Saf* **219**, 112336. https://doi.org/10.1016/j.ecoenv.2021.112336 (2021).
40. Nordberg, G. F. et al. Biomarkers of cadmium and arsenic interactions. *Toxicol Appl Pharmacol* **206**(2), 191–197. https://doi.org/10.1016/j.taap.2004.11.028 (2005).
41. Chang, Z. et al. The relationship between co-exposure to multiple heavy metals and liver damage. *J. Trace Elem. Med. Biol.* **77**, 127128. https://doi.org/10.1016/j.jtemb.2023.127128 (2023).
42. Wang, G. et al. Association between exposure to mixture of heavy metals and hyperlipidemia risk among US adults: A cross-sectional study. *Chemosphere* **344**, 140334. https://doi.org/10.1016/j.chemosphere.2023.140334 (2023).

Author contributions
We thank Niya Zhang for conceiving and designing the experiments, Jiaying Du and Niya Zhang for writing and editing the manuscript, Kerui Zhou and Han Jiang for performing the analyses, Shen Hu, Qiang Zheng and Wei Zhang for analysing the data, and Guangteng Zhou for participating in sample collection and preparation.

Funding
This study was supported by Key Laboratory of Animal Embryo Engineering and Molecular Breeding of Hubei Province and the Fundamental Research Funds for the Central Universities (Project No. 2662022DKYJ006).

Competing interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Additional information
Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-98066-0.

Correspondence and requests for materials should be addressed to N.Z.

Reprints and permissions information is available at www.nature.com/reprints.