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Cat

# Determination of Heavy Metal Contamination in Premium and Supermarket Brands of Extruded Feline and Canine Food in the South African Market

Kerusha Kalicharan[1] | Sooraj Baijnath[2] | Sanil Singh[3] | Thishana Singh[1]

[1]School of Chemistry and Physics, College of Agriculture, Engineering and Science, University of Kwa-Zulu Natal, Durban, South Africa | [2]Wits Integrated Molecular Physiology Research Initiative, Wits Health Consortium (PTY) Ltd, School of Physiology, Faculty of Health Sciences, University of The Witwatersrand, Johannesburg, South Africa | [3]Discipline of Pharmaceutical Sciences, School of Health Sciences, College of Health Sciences, University of KwaZulu-Natal, Durban, South Africa

**Correspondence:** Thishana Singh (singht1@ukzn.ac.za)

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## ABSTRACT

The recent increase in pet food recalls due to contamination and the increased risk of disease has highlighted the need for the screening of canine and feline pelleted food. Heavy metals, an often-overlooked contaminant, has been highlighted for its role in the development of companion animal disease. Therefore, it is imperative that heavy metal content in these commercially available pet foods is investigated. In this study, premium ($n = 14$) and supermarket brands ($n = 17$) of extruded cat and dog food were analyzed for the presence of As, Cd, Co, Cu, Fe, Pb, Hg, Ni and Zn using ICP-OES and Hg by HGAAS. Collectively, extruded dog food brands produced mean concentrations of 7.47 (As), 6.23 (Cd), 4.01 (Co), 16.72 (Ni), 3.99 (Pb), 0.47 (Hg), 35.59 (Cu), 529.53 (Fe) and 25.25 (Zn) mg/kg, whilst cat food brands contained 2.92 (As), 3.15 (Cd), 2.44 (Co), 4.26 (Ni), 7.24 (Pb), 0.16 (Hg), 38.08 (Cu), 389.14 (Fe) and 195.12 (Zn) mg/kg. Canine brands exceeded maximum tolerable limits (MTLs) more than feline with red meat proteins containing higher total heavy metal levels followed by poultry, fish and meat medley formulations. Furthermore, premium brands displayed higher levels of heavy metals exceeding MTLs than supermarket brands which were lower priced.

## 1 | Introduction

In South Africa, pet food revenue has risen exponentially to 226.70 million US dollars in 2024 with a revenue change of 16.2% (Statista 2024). Owners look for affordable, nutritional diets based on cost, recommendations and the dietary needs of their pets, from among the many brands that are readily accessible (Singh et al. 2017; Weaver 2012; Zicker 2008). The consumption of convenience pet food, such as kibble, has been linked to various ailments in pets (Raghavan et al. 2006). In 2018–2019, the Food and Drug Administration (FDA) received multiple reports regarding pet food contamination resulting in several recalls (Dunham-Cheatham et al. 2019; Yukawa et al. 2019). Ingestion of kibble formulations containing contaminated constituents, such as animal proteins, increases the risk of heavy metal exposure. Since animal proteins make up a significant portion of kibble formulations, they were identified as important sources of heavy metals for this study. Quality kibble manufacture must be prioritized for safer consumption, particularly with regard to diets that involve frequent feedings (Funaba et al. 2005).

While several studies have investigated kibble palatability, there are few studies that focus on ingredient interactions at various stages of during manufacture and the overall nutritional value of kibble, with a focus on heavy metal content (Gibson and Sajid 2013). As contaminants, heavy metals are implicated in the development of several disease pathologies, due to both during short-term and long-term exposure. Kibble formulations do incorporate essential heavy metals or trace elements such as Fe, Cu and Zn (micro-nutrients) that are necessary for proper growth and development. However, exposure to feeds which exceed maximum tolerable levels (MTLs) can lead to severe toxicity.

For example, zinc deficiencies can be linked to skin and reproductive disorders, as well as impact fatty acid metabolism (Pereira et al. 2021). High concentrations of Cu and Fe (oxidants) contribute to the production of reactive oxygen species resulting in free radicals that damage cell membranes, oxidize cellular proteins and reduce product shelf-life (Abd-Elhakim et al. 2016). Non-essential heavy metals, such as Cd, As, Pb and Hg, are toxic and have severe neurological implications (Kim et al. 2018). Excessive consumption of Pb is concerning since it has been linked to neurological diseases, gastrointestinal symptoms, hematopoietic system damage, renal damage and haemolysis (Berny et al. 1992; Zook 1972).

In recent studies, lead-shot game meat trimmings were found to pose higher risks of lead intoxication (Hogasen et al., 2016). Kim et al. (2018) revealed that fish-based dry dog food contained greater concentrations of Hg, Cd and As in comparison to red meat or poultry-based diets. Dogs that are exposed to As may develop ulcerative dermatitis and acute symptoms of Cr poisoning which are diarrhoea and lethargy (Evinger and Blakemore 1984).

In addition, naturally occurring water systems are rich in methylmercury, which biomagnifies in the food chain, particularly in fish, which are included in some pet food formulations (Luippold and Gustin 2016). Livestock and poultry are exposed to heavy metals via diet, intense agricultural practices and anthropogenic activities that lead to bioaccumulation (Mottalib et al. 2016). Methylmercury toxicity in cats can result in symptoms such as anorexia, hypothyroidism, weight loss and nervous system impairment (Grubes et al. 1978).

The species, age and geographic location of the animals—fish, cattle and poultry—used to produce pet food all affect the amount of heavy metals present in their proteins. The cumulative effect of heavy metals in protein, feed dyes, cheap substitutions and the extrusion process contribute to significant heavy metal exposure, where dietary intake can exceed the limits specified by the FDA, National Research Council (NRC) and the European Pet Food Industry Federation (FEDIAF) (Abd-Elhakim et al. 2016; Kim et al. 2018).

Most pet food brands contain animal by-products and fillers in their top five ingredients. According to Dunham-Cheatham et al. (2019), fillers are added to pet food to increase its fibre content but have little nutritional value. Due to their grain-based nature, fillers tend to absorb heavy metals from the soil and from intensive agricultural methods, such as the use of fungicides and pesticides (Fan et al. 2017). By-products, or leftover meat from protein sources (excluding muscle meat), are considered unsuitable for human consumption and often contain fatty tissues and diseased tumours that are possible sites for heavy metal accumulation.

The absence of stricter laws and regulations allow for the misrepresentation of pet food nutritive values as a result of poor-quality ingredients (Okuma and Hellberg 2015). Despite the known toxicity of heavy metals, there are a few studies that discuss exposure levels via ingestion for cats and dogs (Abd-Elhakim et al. 2016; Davies et al. 2017; Duran, Tuzen, and Soylak 2010; Kim et al. 2018; Mumma et al. 1986; Squadrone et al. 2017). At present, there is a paucity of research studies and literature on heavy metal exposure via extruded cat and dog food in the South African market. This brings about the need to investigate the extent of heavy metal contamination in pet foods in South Africa and the potential impact of exposure.

The aim of the current study was to investigate heavy metal concentrations (essential and unessential) in premium and supermarket brands of extruded feline and canine food available in the South African market by microwave digestion and ICP-OES analysis. The objectives of the study were to quantify the heavy metal content in selected feline and canine kibble in South Africa, by a quartering sampling method with comparison to MTLs (see Table S2).

## 2 | Materials and Methods

### 2.1 | Materials

Thirty-one samples of extruded cat food (CF) and dog food (DF) were purchased comprising 14 premium brands (PB) and 17 supermarket brands (SB). These brands were selected based on popularity at the supermarket and consumer preference. All brands contained varying amounts of protein (fish, poultry, red meat, special diet and medley of meat). Concentrated nitric acid (70%) purchased from ACE chemicals (South Africa) was diluted to digest all samples in triplicate. Double distilled water (Aquatron Water Still A4000d) was used for all dilutions. Multi-element standards were prepared from 1000 ppm mono-element stock solutions purchased from LabChem and Polychem supplies (South Africa). A 1 ppm Hg standard was prepared separately for HGAAS cold vapour analysis.

### 2.2 | Sample Preparation and Digestion

The kibble samples were quartered, and a grab sample of ~250 g was taken from sub-samples (Campos and Campos 2017). Each sample was milled individually to prevent cross-contamination and stored in labelled re-sealable plastic bags for acid digestion. A grab sample of ~0.3 g of each milled sample was weighed into Teflon vials in triplicate. A 7-mL volume of 1 M nitric acid was added to each vial and left to pre-digest for 1 h at room temperature in the fume hood (Noël et al. 2005). All samples were subjected to a 15-min ramp to 180°C, digested for 10 min and cooled for a further 15 min using a CEM Mars 6 microwave

**TABLE 1** | Operating conditions for Perkin Elmer Optima 5300DV ICP-OES.

| Condition | Rate |
|---|---|
| Sample throughput | 1-5 min/sample |
| Sample volume | 1-2 mL/min |
| Plasma gas flow rate | 15 L/min |
| Carrier gas flow rate | 0.24/min |

**TABLE 2** | LOD, LOQ and linearity for ICP-OES heavy metal analysis in extruded cat and dog food samples available in the South African market by microwave digestion.

| Element | LOD (mg/kg) | LOQ (mg/kg) | Linearity/$R^2$ |
|---|---|---|---|
| As | 0.01169 | 0.03542 | 0.9967 |
| Cd | 0.00415 | 0.01258 | 0.9981 |
| Co | 0.01297 | 0.03932 | 0.9982 |
| Cu | 0.00021 | 0.00005 | 0.9982 |
| Zn | 0.00012 | 0.00466 | 0.9968 |
| Fe | 0.00107 | 0.00325 | 0.9918 |
| Ni | 0.02734 | 0.08286 | 0.9977 |
| Pb | 0.46262 | 1.40188 | 0.9960 |

digestion system. The samples were filtered using a 0.45-μm Nylon filter and diluted to 25 mL with double distilled water.

#### 2.2.1 | ICP-OES Analysis

Diluted samples were further filtered through a 0.45-μm Nylon filter into 15 mL ICP vials. A five-point calibration was prepared for elements; Cu, Cd, Fe, Co, Ni, Pb, As and Zn using multi-element standards. All analyses for heavy metal quantification were completed using a Perkin Elmer Optima 5300DV ICP-OES spectrometer system for simultaneous detection with operating conditions in Table 1.

#### 2.2.2 | Quality Control

A procedural blank was prepared and analyzed with the samples. Emission lines were selected based on correlation coefficients >0.99 and detection of analyte in the samples. The limit of detection (LOD) and limit of quantification (LOQ) were calculated using the standard error of the calibration slope. All samples and analyses were performed in triplicate, and the mean results were presented. The results for the LOD, LOQ and $R^2$ have been presented in Table 2.

#### 2.2.3 | Mercury Analysis by HGAAS

A Perkin Elmer A Analyst 200 atomic absorption spectrometer equipped with a PerkinElmer (Perkin Elmer, CT, USA) mercury hydride system (MHS 15) using a sodium borohydride reductant was used for Hg analysis. A hollow cathode lamp was used at a wavelength of 253.7 nm for Hg detection. A five-point calibration curve was prepared using a 1 ppm Hg solution as per the recommended analytical conditions shown in Table 3 with the corresponding Linearity data represented in Table 4. Each sample (5 mL) was inserted into the hydride system, and readings were taken after 10 s in triplicate.

**TABLE 3** | Recommended analytical conditions for Hg calibration for HGAAS analysis.

| | |
|---|---|
| Calibration solution | 1 mg Hg/L in 1.5 % $HNO_3$ and few drops of 5% $KMnO_4$ |
| Aliquots for calibration | 100, 200, 300, 400, 500 µL |
| Diluent | 1.5% (V/V) nitric acid |
| Reductant solution | 3% $NaBH_4$ in 1 % NaOH solution |

**TABLE 4** | Linearity data for multi-element heavy metal analysis by ICP-OES for extruded cat and dog food.

| Element | Wavelength (nm) | *$m$ | *$c$ | $R^2$ |
|---|---|---|---|---|
| As | 228.812 | 694.46 | 8.7656 | 0.9967 |
| Cd | 228.802 | 1560.3 | 9.494 | 0.9981 |
| Co | 228.616 | 1003.5 | −14.873 | 0.9982 |
| Zn | 213.857 | 2716.9 | 54.641 | 0.9982 |
| Cu | 324.752 | 35607 | 1098.6 | 0.9968 |
| Fe | 259.939 | 4811.5 | −291.6 | 0.9918 |
| Ni | 231.604 | 1076.1 | 6.8733 | 0.9977 |
| Pb | 220.353 | 200.06 | 11.73 | 0.9960 |

*$y$ = Intensity, $m$ = slope, $x$ = concentration and c = y-intercept.

## 3 | Results

The results obtained in this study is presented in the Discussion below.

## 4 | Discussion

Extruded diets play an important role in pet nutrition and general well-being, being the most easily accessible form of nutrition for companion pets. It is peremptory that they are free from contaminants that can exhibit adverse effects on canine and feline health. Commercial diets, formulated from natural ingredients, are susceptible to heavy metal exposure from anthropogenic activities and natural sources. Heavy metals in natural ingredients are potentially hazardous and affect food quality and its suitability for immediate and long-term feeding (Demirözü et al. 2003; Leiva et al. 2019; ul Islam et al. 2007). Supermarket brands, sold at cheaper rates, are least recommended by vets than premium brands sold at high costs, presumed to be of higher quality (Fox 2012).

**TABLE 5** | Non-essential metal concentrations (mg/kg) in selected extruded cat and dog food brands available in South Africa.

| | | Extruded cat food | | | Extruded dog food | | |
|---|---|---|---|---|---|---|---|
| Heavy metal | MTL | Mean ± SD | Range min-max | Number of samples exceeding MTL | Mean ± SD | Range Min-max | Number of samples exceeding MTL |
| Arsenic | 12.5[a] | 2.92 ± 1.21 | 0.06–4.58 | — | 7.47 ± 9.58 | 2.43–41.08 | 1 |
| Cadmium | 10[b] | 3.15 ± 0.35 | 2.62–3.72 | — | 6.23 ± 4.94 | 4.23–23.87 | 1 |
| Cobalt | 2.5[b] | 2.44 ± 0.56 | 1.12–3.52 | 7 | 4.01 ± 1.33 | 2.82–8.11 | 15 |
| Nickel | 50[b] | 4.26 ± 1.19 | 2.61–6.84 | — | 16.72 ± 22.77 | 1.43–65.47 | 2 |
| Lead | 10[b] | 7.24 ± 3.67 | 1.19–11.94 | 4 | 3.99 ± 0.69 | 3.23–5.57 | — |
| Mercury | 0.27[b] | 0.16 ± 0.16 | 0.007–0.60 | 2 | 0.47 ± 2.12 | 0.004–7.99 | 10 |

*Note:* Heavy metal concentrations were compared to maximum tolerable levels (MTLs).
[a]National Research Council reference level for the most sensitive mammal.
[b]Reference level for most sensitive mammal according to the Food and Drug Administration.

Non-essential metals pose numerous adversities due to their level of toxicity to both feline and canine health. Although MTLs are available, the hazards associated with instantaneous and continuous exposure through repetitive diets are concerning (see Table S1). In particular, Pb, Cd, As and Hg cause liver toxicity, neurotoxicity, nephrotoxicity and genotoxicity. In this study, seven brands were found exceeding MTLs for Co, four for Pb and two for Hg out of the 16 samples analyzed in the feline range.

The maximum value noted for Co, Pb and Hg were 3.52, 11.94 and 0.60 mg/kg, respectively, for CF samples. Canine brands display a range of heavy metals exceeding MTLs at higher concentrations. The results (Table 5) indicate that dogs consuming popular kibble brands could be at risk of acute and chronic health implications. In the canine range, one sample exceeded the MTL for As, one for Cd, 15 for Co and two for Ni. Mercury levels in extruded dog food are much higher than expected considering associated pathological conditions (Dunham-Cheatham et al. 2019).

Ten brands violated MTLs with the highest containing 26.6 times the MTL for mercury. The SD, mean and relative standard deviation of the overall heavy metal analysis of the dog and cat food samples are presented in Tables S3 and S4.

The complete elimination of toxic metals from kibble is difficult. Exposure levels must be minimized to reduce acute and chronic toxic effects which can result in arthritis, kidney failure, liver diseases, congestive heart disease, deficiencies in pancreatic enzymes and endocrine disfunctions, fungal, viral and bacterial infections (Dunham-Cheatham et al. 2019).

Apart from protein, fat, carbohydrates and vitamins, essential metals are required for sustenance and optimal growth and development performance. Trace metals such as iron, copper and zinc are positively associated with cell signalling, enzymatic reactions and muscle contraction (Duran et al. 2010). The ingestion pathway (aside from dermal and inhalation) can expose pets to a deficit or surplus of nutrients. Pet foods contain essential metals in their formulations that should meet minimal requirements and not exceed tolerable limits, becoming potentially toxic. Raeeszadeh et al. (2022) evaluated the heavy metal content of different meat sources. While the average levels of selenium, nickel, cobalt and chromium in the different meats were within the maximum permitted limits (MPL), and the levels of lead, cadmium, arsenic, zinc, copper, chromium and nickel exceeded the MPL. All metal concentrations in the meats under evaluation were higher than MPL, with the exception of cobalt. This finding also further substantiates the extent to which heavy metal contamination within animal meat can also contribute to high levels of heavy metals in cat and dog kibble since they are the primary sources of protein and the need for surveillance and regulation of this area of feed manufacture.

Essential metal concentrations (Table 6) show accelerated levels of Cu in 14 brands of CF, the maximum concentration being 72.11 mg/kg. All cat food samples contained Fe concentrations below the European Union (EU) MTL nutritional guidelines put forward by the FEDIAF in 2019 (FEDIAF 2024). For Zn, 31.25% of the samples exceeded MTLs for cat food brands, while 86.67% exceeded MTLs in dog food brands, respectively. Although CF did not exceed MTLs for Fe, $n = 1$ brand of DF contained 1588.62 mg/kg. High tolerable limits for essential metals accommodates for the nutritional requirements of cats and dogs. Hence, pet foods in general will contain high amounts of micro-nutrients.

However, an excess of metals (above MTLs) indicates the use of contaminated ingredients that accelerate these concentrations, and hence of sub-standard quality. Studies have shown significant concentrations of heavy metals in primary farm animal species in Sanandaj, Kurdistan province, making it imperative to monitor and eliminate heavy metal pollution (Raeeszadeh et al. 2022).

Figure 1 displays heavy metal levels found in SB and PB of DF and CF. All samples contained total essential metals above the MRL for cats (115.5 mg/kg) and dogs (160.0 mg/kg) (Paulelli 2018). Premium brands of cat food contain higher amounts of heavy metals with over 50% of the data lying above the 75th percentile of CF-SB. The mean of DF-PB is above the maximum values obtained for cat food samples. Dogs are exposed to higher levels of heavy metals than cats with the total heavy metals

**TABLE 6** | Essential metal concentrations (mg/kg) in selected extruded cat and dog food brands available in South Africa.

| Heavy metal | MRL | MTL | Extruded cat food: Mean ± SD | Range min-max | Number of samples exceeding MTL | Extruded dog food: Mean ± SD | Range Min-max | Number of samples exceeding MTL |
|---|---|---|---|---|---|---|---|---|
| Copper | 5/7.5[a] | 28[b] | 38.08 ± 13.82 | 12.92–72.11 | 14 | 35.59 ± 16.03 | 12.63–83.20 | 9 |
| Iron | 80/36[a] | 681.8[b] | 389.14 ± 88.48 | 266.21–583.50 | — | 529.53 ± 309.16 | 213.31–1588.62 | 1 |
| Zinc | 75/72[a] | 227[b] | 195.12 ± 54.60 | 78.81–304.46 | 5 | 25.25 ± 68.21 | 79.86–353.55 | 13 |

[a]Minimum recommended limit for cats/dogs by FEDIAF 2011.
[b]E.U. maximum as per FEDIAF nutritional guidelines 2019.

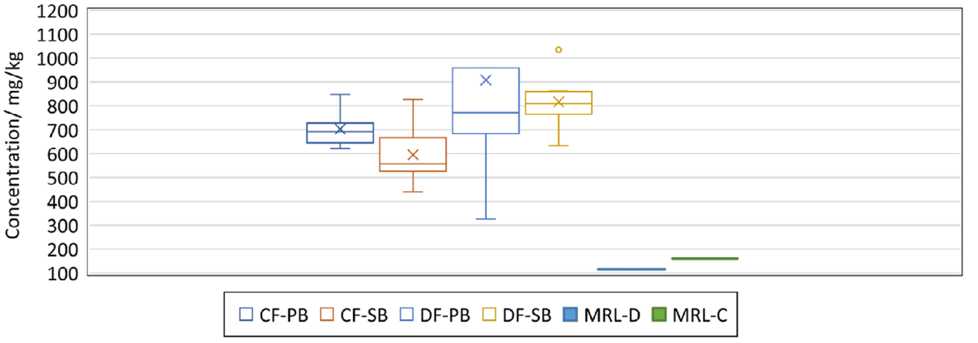


**FIGURE 1** | Total heavy metals (essential and non-essential) in premium (PB) and supermarket (SB) brands of extruded dog (DF) and cat (CF) food in the South African market. Data are present as a median and IQR ($n$ = 7 for CF-PB; 9 for CF-SB; 7 for DF-PB; 8 for DF-SB; MRL-D = 115.5; MRL-C = 160). *Note:* Box and whisker plots depict the total metal exposure in mg/kg of dry matter in extruded cat and dog food in premium and supermarket brands in South Africa.

**TABLE 7** | Total heavy metal concentrations (mg/kg) in selected supermarket (SB) and commercial (PB) brands of dog (DF) and cat food (CF) in South Africa by protein source.

| Brand | Red meat: Mean ± SD | Range min-max | Poultry: Mean ± SD | Range min-max | Fish: Mean ± SD | Range min-max |
|---|---|---|---|---|---|---|
| DF-PB | 1044.95 ± 684.42 | 325.27–1974.3 | 771.36 ± 0.00 | 0.00–771.36 | — | — |
| DF-SB | 812.01 ± 44.27 | 846.94–762.23 | 830.64 ± 166.26 | 633.76–1034.5 | — | — |
| CF-PB | — | — | 668.80 ± 34.79 | 621.28–705.08 | 680.72 ± 0.00 | 0.00–680.72 |
| CF-SB | — | — | 610.91 ± 165.60 | 439.68–826.61 | 539.34 ± 0.00 | 0.00–539.34 |

(THM), essential and non-essential, lying between ~630 and 950 mg/kg. An outlier of 1034.54 mg/kg (SB) was observed in the canine range. Although the minimum requirements of these nutrients are met, food samples should not contain undesirable toxic metals and nutrients in excess. The higher the dietary intake of heavy metals, the larger the bio-accumulation rate commonly associated with the risk of adverse health issues.

The results presented in Table 7 show that premium brands of dog food containing red meat proteins contained higher mean THM concentration than all brands of both cat and dog food analyzed. Supermarket brands of dog food flavoured with poultry meat contained ~830 mg/kg of THM, followed by supermarket brands of dog food containing red meat with ~812 mg/kg. Cat food brands comprising poultry and fish contained THM with concentrations between 539 and 827 mg/kg. Dog food brands for special diets, categorized as other, produced high amounts of THM ~700–775 mg/kg as presented in Table 8. The sources of protein for these brands were not specified on the packaging.

Over-nutrition often leads to toxicity and malfunctions in enzymatic systems, specifically those associated with copper, iron and zinc (Da Silva et al. 2009; McDowell 2003). High amounts of micronutrients, exceeding MTLs, result from fillers comprising a large percentage of pet food formulations (present in the first five ingredients) (Kore et al. 2009).

**TABLE 8** | Total heavy metal concentrations in selected supermarket (SB) and commercial (PB) brands of dog (DF) and cat food (CF) in South Africa by protein source containing a combination of proteins sources.

| | Meat medley[a] | | Other[b] | |
|---|---|---|---|---|
| **Brand** | **Mean ± SD** | **Range min-max** | **Mean ± SD** | **Range min-max** |
| DF-PB | — | — | 705.24 ± 31.16 | 683.2–727.27 |
| DF-SB | — | — | 773.00 ± 0.00 | 0.00–773.00 |
| CF-PB | 588.72 ± 92.572 | 516.11–692.96 | — | — |
| CF-SB | — | — | — | — |

[a]Samples contained a combination of proteins.
[b]Special diets with unspecified protein source.

Moreover, red meat proteins contain myoglobin and haemoglobin, which can accelerate iron levels overall. Fish are exposed to anthropogenic activities, specifically waste disposal, chemical and oil spills becoming more susceptible to heavy metal exposure (Fatima and Usmani 2013).

Heavy metal concentrations in fish proteins are additionally dependent on fish species and source (fresh or salt-water) (Sary and Mohammadi 2012). Carnivorous fish consume smaller fish and crustaceans leading to heavy metal bio-magnification (Ali and Khan 2019).

Exposure to contaminated feed, anthropogenic activities and the natural occurrence of heavy metals equally contributes to high THM in poultry (Mottalib et al. 2016). Therefore, ingredients, such as proteins, should be tested for consumption prior to their inclusion in pet food formulations (Thompson 2008).

Pet food mislabelling and the presence of unspecified proteins/animal derivatives on packaging have been highlighted in recent studies (Maine et al. 2015). Not only are derivatives cheaper alternatives, but fats, kidney and liver tissues are known sites of heavy metal accumulation (Hashemi 2018; Zhuang et al. 2009).

Pets are exposed to heavy metals via dermal, inhalation and ingestion routes. Hence, the cumulative effect of heavy metal exposure is a cause for concern considering ingestion levels highlighted in this study. Routine and targeted tests for toxicity will ensure that feeds promote good health, proper growth and development (Tomza-Marciniak et al. 2012). Aside from the assessment of heavy metals in kibble, the potential health risk and hazard quotient should be evaluated to understand the effects of metal exposure. A study investigated the concentrations of aluminium, cadmium, copper, ferrous iron, Hg, manganese, nickel, lead and zinc in commercially canned and pouched cat foods (salmon, tuna, liver, fish and other aquatic products) and evaluated any possible health risks to kittens and adult cats. With the exception of the mean Fe in all and the Pb levels in salmon and kitten diets, the observed amounts of the metals were lower than the findings from earlier studies. The values of the total target hazard quotient (TTHQ) and target hazard quotient (THQ) did not exceed 1 (Altınok-Yipel et al. 2022). The study shows that heavy metal levels in canned foods and pouched meals may have lower heavy metal levels than those found in extruded cat and dog food thus posing fewer health risks.

While this study highlights the need to investigate heavy metal content in commercially available pet foods, there are a few limitations to be considered. For this study, animal proteins were considered the main contributor to heavy metal levels since they comprise a large percentage of pet food formulations. Since pet foods of different brands were purchased, heavy metal levels observed could be representative of a specific batch and possibly demonstrate batch to batch variation. Additionally, heavy metal exposure to determine the bio-availability of these metals post consumption was not investigated. It is therefore critical that clinical trials are also conducted to evaluate the bioaccessibility of heavy metals and the associated health implications on pets.

## 5 | Conclusion

This study evaluated the concentrations of essential and non-essential metals in selected dry premium ($n = 14$) and supermarket ($n = 17$) cat and dog food brands with varying animal proteins available in South Africa. The results show that all dry cat and dog food brands meet the minimum recommended nutritional requirements for essential metals (Cu, Fe and Zn). Fourteen cat food samples exceeded the MTL for Cu and five for Zn, while nine dog food brands exceeded the MTL for Cu, one for Fe and 13 for Zn. Dog food brands were found to exceed MTLs for non-essential metals more than cat food brands. Ten brands of dog food and two brands of cat food exceeded MTLs for Hg. Ten brands of dog food and seven brands of cat food exceeded MTLs for Cobalt. Dog food brands containing red meat proteins contained higher THM levels followed by poultry, fish and meat medley formulations. Furthermore, PB displayed higher levels of heavy metals exceeding MTLs than SB sold at lower prices. This study highlights the need for regular monitoring to ensure extruded diets sold in South Africa are safe for immediate and prolonged consumption with minimal health risks.

**Author Contributions**

S.B., S.D.S. and T.S. conceived and designed the study. K.K. carried out all experimental procedures, analyzed the initial data and wrote the draft. All authors interpreted the data, revised the manuscript and approved the final version.

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**Conflicts of Interest**

The authors declare no conflicts of interest.

**Data Availability Statement**

There are no additional data available. Supplementary data can be found in the supplementary Information document.

**References**

Abd-Elhakim, Y. M., N. I. El Sharkawy, and G. G. Moustafa. 2016. "An Investigation of Selected Chemical Contaminants in Commercial Pet Foods in Egypt." *Journal of Veterinary Diagnostic Investigation* 28, no. 1: 70–75.

Ali, H., and E. Khan. 2019. "Trophic Transfer, Bioaccumulation, and Biomagnification of Non-Essential Hazardous Heavy Metals and Metalloids in Food Chains/Webs—Concepts and Implications for Wildlife and Human Health." *Human Ecological Risk Assessment: An International Journal* 25, no. 6: 1353–1376.

Altınok-Yipel, F., M. Yipel, and İ. O. Tekeli. 2022. "Health Risk Assessment of Essential and Toxic Metals in Canned/Pouched Food on Kitten and Adult Cats: An Animal Health Risk Assessment Adaptation Assay." *Biological Trace Element Research* 200: 1937–1948. https://doi.org/10.1007/s12011-021-02792-1.

Berny, P. J., L. M. Cote, and W. B. Buck. 1992. "Case Reports of Lead Poisoning in Dogs From the National Animal Poison Control Center and the Centre National D'Informations Toxicologiques, Veterinaires: Anecdotes or Reality?" *Veterinary and Human Toxicology* 34: 26–31.

Campos-M, M., and C. Campos-R. 2017. "Applications of Quartering Method in Soils and Foods." *International Journal of Engineering Research and Application* 7, no. 1: 35–39.

Da Silva, A. S., L. Hoehne, A. A. Tonin, et al. 2009. "Trypanosoma Evansi: Levels of Copper, Iron and Zinc in the Bloodstream of Infected Cats." *Experimental Parasitology* 123, no. 1: 35–38.

Davies, M., R. Alborough, L. Jones, C. Davis, C. Williams, and D. S. Gardner. 2017. "Mineral Analysis of Complete Dog and Cat Foods in the UK and Compliance With European Guidelines." *Scientific Reports* 7, no. 1: 1–9.

Demirözü, B., İ. Saldamlı, B. Gürsel, A. Ucak, F. Çetınyokuş, and N. Yüzbaşı. 2003. "Determination of Some Metals Which Are Important for Food Quality Control in Bread." *Journal of Cereal Science* 37, no. 2: 171–177.

Dunham-Cheatham, S. M., K. Klingler, M. Peacock, M. B. Teglas, and M. S. Gustin. 2019. "What Is in Commercial Cat and Dog Food? The Case for Mercury and Ingredient Testing." *Science of The Total Environment* 684: 276–280.

Duran, A., M. Tuzen, and M. Soylak. 2010. "Trace Element Concentrations of some Pet Foods Commercially Available in Turkey." *Food and Chemical Toxicology* 48, no. 10: 2833–2837.

Evinger, J. V., and J. C. Blakemore. 1984. "Dermatitis in a Dog Associated With Exposure to an Arsenic Compound." *Journal of the American Veterinary Medical Association* 184, no. 10: 1281–1282.

FEDIAF. 2024. *Nutritional Guidelines for Complete and Complementary Pet Food for Cats and Dogs*. https://europeanpetfood.org/wp-content/uploads/2024/09/FEDIAF-Nutritional-Guidelines_2024.pdf.

Fan, Y., T. Zhu, M. Li, J. He, and R. Huang. 2017. "Heavy Metal Contamination in Soil and Brown Rice and Human Health Risk Assessment Near Three Mining Areas in Central China." *Journal of Healthcare Engineering* 2017: 4124302.

Fatima, M., and N. Usmani. 2013. "Histopathology and Bioaccumulation of Heavy Metals (Cr, Ni and Pb) in Fish (*Channa striatus* and *Heteropneustes fossilis*) Tissue: A Study for Toxicity and Ecological Impacts." *Pakistan Journal of Biological Science* 16: 412–420.

Fox, M. W. 2012. *Not Fit for a Dog!: The Truth About Manufactured Dog and Cat Food*. Linden Publishing.

Funaba, M., Y. Oka, S. Kobayashi, et al. 2005. "Evaluation of Meat Meal, Chicken Meal, and Corn Gluten Meal as Dietary Sources of Protein in Dry Cat Food." *Canadian Journal of Veterinary Research* 69, no. 4: 299.

Gibson, M. W., and A. Sajid. 2013. "Pet Food Processing: Understanding Transformations in Starch During Extrusion and Baking." *Cereal Foods World* 58, no. 5: 232–236.

Gruber, T. A., P. Costigan, G. T. Wilkinson, and A. A. Seawright. 1978. "Chronic Methylmercurialism in the Cat." *Australian Veterinary Journal* 54, no. 4: 155–160. https://doi.org/10.1111/j.1751-0813.1978.tb02438.x.

Hashemi, M. 2018. "Heavy Metal Concentrations in Bovine Tissues (Muscle, Liver and Kidney) and Their Relationship With Heavy Metal Contents in Consumed Feed." *Ecotoxicology and Environmental Safety* 154: 263–267.

Høgåsen, H. R., R. Ørnsrud, H. K. Knutsen, and A. Bernhoft. 2016. "Lead Intoxication in Dogs: Risk Assessment of Feeding Dogs Trimmings of Lead-shot Game." *BMC Veterinary Research* 12, no. 1: 152.

Kim, H.-T., J. P. Loftus, S. Mann, and J. J. Wakshlag. 2018. "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)." *Frontiers in Veterinary Science* 5: 264.

Kore, K. B., A. K. Pattanaik, A. Das, and K. Sharma. 2009. "Evaluation of Alternative Cereal Sources in Dog Diets: Effect on Nutrient Utilisation and Hindgut Fermentation Characteristics." *Journal of the Science of Food and Agriculture* 89, no. 13: 2174–2180.

Leiva, A., A. Molina, M. Redondo-Solano, G. Artavia, L. Rojas-Bogantes, and F. Granados-Chinchilla. 2019. "Pet Food Quality Assurance and Safety and Quality Assurance Survey Within the Costa Rican Pet Food Industry." *Animals* 9, no. 11: 980.

Luippold, A., and M. S. Gustin. 2016. "Mercury Concentrations in Wet and Dry Cat and Dog Food." *Animal Feed Science and Technology* 222: 190–193.

Maine, I. R., R. Atterbury, and K.-C. Chang. 2015. "Investigation Into the Animal Species Contents of Popular Wet Pet Foods." *Acta Veterinaria Scandinavica* 57, no. 1: 7.

McDowell, L. 2003. *Minerals in Animal and Human Nutrition* 2nd ed. Elsevier.

Mottalib, M. A., A. Sultana, S. H. Somoal, and M. N. Abser. 2016. "Assessment of Heavy Metals in Tannery Waste-Contaminated Poultry Feed and Their Accumulation in Different Edible Parts of Chicken." *IOSR Journal of Environmental Science Toxicology Food Technology* 10, no. 11: 72–78.

Mumma, R., K. Rashid, B. Shane, et al. 1986. "Toxic and Protective Constituents in Pet Foods." *American Journal of Veterinary Research* 47, no. 7: 1633.

Noël, L., V. Dufailly, N. Lemahieu, C. Vastel, and T. Guerin. 2005. "Simultaneous Analysis of Cadmium, Lead, Mercury, and Arsenic Content in Foodstuffs of Animal Origin by Inductively Coupled Plasma/Mass Spectrometry After Closed Vessel Microwave Digestion: Method Validation." *Journal of AOAC International* 88, no. 6: 1811–1821.

Okuma, T. A., and R. S. Hellberg. 2015. "Identification of Meat Species in Pet Foods Using a Real-Time Polymerase Chain Reaction (PCR) Assay." *Food Control* 50: 9–17.

Paulelli, A. 2018. "Risk Assessement of 22 Chemical Elements in Dry and Canned Pet Foods." *Journal of Consumer Protection and Food Safety* 13: 359–365.

Pereira, A. M., M. R. G. Maia, A. J. M. Fonseca, and A. R. J. Cabrita. 2021. "Zinc in Dog Nutrition, Health and Disease: A Review." *Animals* 11: 978. https://doi.org/10.3390/ani11040978.

Raeeszadeh, M., H. Gravandi, and A. Akbari. 2022. "Determination of Some Heavy Metals Levels in the Meat of Animal Species (Sheep, Beef, Turkey, and Ostrich) and Carcinogenic Health Risk Assessment in Kurdistan Province in the West of Iran." *Environmental Science and Pollution Research* 29: 62248–62258. https://doi.org/10.1007/s11356-022-19589-x.

Raghavan, M., N. W. Glickman, and L. T. Glickman. 2006. "The Effect of Ingredients in Dry Dog Foods on the Risk of Gastric Dilatation-Volvulus in Dogs." *Journal of the American Animal Hospital Association* 42, no. 1: 28–36.

Sary, A. A., and M. Mohammadi. 2012. "Mercury Concentrations in Commercial Fish From Freshwater and Saltwater." *Bulletin of Environmental Contamination and Toxicology* 88, no. 2: 162–165.

Singh, S. D., S. Baijnath, and A. A. Chuturgoon. 2017. "A Comparison of Mycotoxin Contamination of Premium and Grocery Brands of Pelleted Cat Food in South Africa." *Journal of the South African Veterinary Association* 88: 1–4.

Squadrone, S., P. Brizio, G. Simone, A. Benedetto, G. Monaco, and M. C. Abete. 2017. "Presence of Arsenic in PET Food: A Real Hazard." *Veterinaria Italiana* 53: 303–307.

Statista. 2024. "Pat Food—South Africa." https://www.statista.com/outlook/emo/food/pet-food/south-africa.

Thompson, A. 2008. "Ingredients: Where Pet Food Starts." *Topics in Companion Animal Medicine* 23, no. 3: 127–132.

Tomza-Marciniak, A., B. Pilarczyk, M. Bąkowska, M. Ligocki, and M. Gaik. 2012. "Lead, Cadmium and Other Metals in Serum of Pet Dogs From an Urban Area of NW Poland." *Biological Trace Element Research* 149, no. 3: 345–351.

ul Islam, E., X.-e. Yang, Z.-l. He, and Q. Mahmood. 2007. "Assessing Potential Dietary Toxicity of Heavy Metals in Selected Vegetables and Food Crops." *Journal of Zhejiang University Science B* 8, no. 1: 1–13.

Vinodhini, R., and M. Narayanan. 2008. "Bioaccumulation of Heavy Metals in Organs of Fresh Water Fish Cyprinus Carpio (Common Carp)." *International Journal of Environmental Science and Technology* 5, no. 2: 179–182.

Weaver, B. 2012. "Pet Food Information: Resources for Making Healthy Choices for Our Best Friends." *Journal of Agricultural and Food Information* 13, no. 4: 362–376.

Yukawa, S., I. Uchida, Y. Tamura, S. Ohshima, and T. Hasegawa. 2019. "Characterisation of Antibiotic Resistance of Salmonella Isolated From Dog Treats in Japan." *Epidemiology* 147: e102.

Zhuang, P., Z. Huiling, and S. Wensheng. 2009. "Biotransfer of Heavy Metals Along a Soil-Plant-Insect-Chicken Food Chain: Field Study." *Journal of Environmental Sciences* 21, no. 6: 849–853.

Zicker, S. C. 2008. "Evaluating Pet Foods: How Confident Are You When You Recommend a Commercial Pet Food?" *Topics in Companion Animal Medicine* 23, no. 3: 121–126.

Zook, B. C. 1972. "The Pathologic Anatomy of Lead Poisoning in Dogs." *Veterinary Pathology* 9: 310–327. https://doi.org/10.1177/030098587200900503.

## Supporting Information

Additional supporting information can be found online in the Supporting Information section.