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Assessing the Food Safety of Imported Fish via Spectral Quantification of Lead, Cadmium, Zinc, and Nickel: A Comparative Analysis of Canned Tuna, Sardines, and Frozen Fish

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Abstract

Background. Imported canned and frozen fish are becoming an increasingly important source of dietary protein in Iraq, yet recent monitoring data on heavy-metal residues in these products remain limited. Species-specific bioaccumulation, processing conditions, and source-area differences may increase dietary exposure to Pb and Cd.

Objective.This study measured Pb, Cd, Zn, and Ni in canned tuna, canned sardines, and imported frozen fish sold in Iraq, assessed compliance with international maximum residue limits (MRLs), and examined inter-element relationships suggesting common contamination sources.

Methods. A comparative cross-sectional design included 39 products: 25 canned tuna, 7 canned sardines, and 7 frozen fish, analysed in triplicate ($n = 117$). Samples were oven-dried, digested using HNO_3, $HClO_4$, and H_2SO_4, and analysed by flame atomic absorption spectroscopy. Shapiro–Wilk and Levene tests assessed assumptions, Kruskal–Wallis with post-hoc comparisons assessed group differences, Pearson correlation evaluated inter-element relationships, and η^2 estimated effect size.

Results. Frozen fish showed higher Pb (93.70 ± 25.38 µg/kg) and Cd (4.29 ± 1.25 µg/kg) than canned tuna and sardines. Kruskal–Wallis tests were significant for all metals ($p < 0.001$), with η^2 ranging from 0.57 for Zn to 0.89 for Pb. The highest Pb level was detected in Iranian trout (131.20 µg/kg), while the highest Zn level occurred in Chinese sardines (197.10 µg/kg). No sample exceeded Codex MRLs.

Conclusion. Although all products complied with MRLs, imported frozen fish showed substantially higher Pb and Cd levels, supporting targeted import surveillance.

Keywords: *heavy metals; atomic absorption spectroscopy; canned fish; frozen fish; food safety; lead; cadmium; Iraq; Codex Alimentarius*

Introduction

Fish contains one of the best animal proteins of good quality, long-chain polyunsaturated fatty acids of omega-3 and bioavailable micronutrients in the human diet [1, 2]. The Food and Agriculture Organization estimates that the global consumption of aquatic-animal food is 20.7 kg per-capita in 2022, nearly two times higher than the consumption level in 1970 [3]. In Iraq, where freshwater fisheries has declined due to the pressures of upstream water-resource constraints, and reduced discharge of the Tigris Euphrates, canned and frozen imports now contribute a large percentage of national fish consumption [4, 5]. This has ramifications to food-safety governance in that the profile of contaminants of imported product is indicative of environmental conditions in distant source basins, rather than parameters locally controlled.

Industrial effluents, atmospheric deposition, agricultural effluents, and leaching of antifouling coating are the main sources of heavy metals in aquatic ecosystems and the heavy metals are effectively bioaccumulated along the troic gradients [6, 7]. The essential and non-degradable components of the most significant factors are lead and cadmium: chronic exposures are related to nephrotoxicity, neurodevelopmental impairment, cardiovascular disease, and renal-cortex carcinogenesis [8, 9]. Cadmium and inorganic lead compounds are Group 1 and Group 2A carcinogen in the International Agency of Research on cancer respectively [10]. Zinc and nickel are worse off: zinc is a cofactor in over 300 enzymes, although at chronic high levels it disrupts copper homeostasis and induces an oxidative imbalance [11, 12]; nickel is a potent contact allergen, and an almost certainly human carcinogen at high chronic doses [13].

The Codex Alimentarius Commission set a maximum level of Pb in fish at 0.30mg/kg and Cd at 0.05-0.10mg/kg by species and higher values are applied in tuna [14, 15]. The European Commission Regulation (EC) 488/2014 and the following amendments on imports into the EU market [16] impose the harmonised limits. Inconsistent compliance with these standards has been observed in some surveys of the MENA-region: Hossain et al. reported high levels of Pb in canned tuna produced in Bangladesh and Thailand (range 0.04-0.91mg/kg) with the upper tail attributed to migration of solder seams in older can constructions [17]; Al-Obaidy and colleagues, which focused on this area, reported

The three gaps in knowledge are the inspiration behind the current study. Firstly, no published multi-elements survey has been conducted on comparing canned and frozen fish products in the Iraqi market which are offered concurrently since they have a compounding impact on the consumer exposure. Second, the statistics of hypothesis testing have rarely been used with statistics of effect-size estimation and assumption checking in these studies, limiting the reproducibility of the results, as was the case with studies of individual products done in the past. Third, the pattern of inter-elements correlation in classes of products, which can be due to similar sources of contamination or competitive bioaccumulation, has been insufficiently characterised in the region literature.

The objectives of the proposed study are therefore three-fold, (i) to establish the concentration of Pb, Cd, Zn and Ni in 39 different fish products that are comprised of canned tuna, canned sardines and imported frozen fish; (ii) to compare the quantity of loading of the metals in these types of product using statistical methods that are suitable to the underlying.

Materials and Methods

2.1 Study Design and Sampling.

A cross-sectional design was presumed to be comparative and where appropriate followed the STROBE checklist of reporting observational studies. Thirty-nine fish products that are commercially available in Baghdad, Iraq, were purchased via stratified convenience sampling in October-December 2024. The sample frame consisted of: 25 various canned-tuna products which differed in brand, country of origin and packing medium (vegetable oil, olive oil, sunflower oil, soybean oil, brine or water); 7 various canned-sardine products which differed in brand and country of origin; and 7 imported frozen-fish products which included trout (Oncorhynchus mykiss), each To enable traceability, sample codes beginning with T1-T25 (tuna), S1-S7 (sardine), and X1-X7 (frozen) are kept in this manuscript.

The samples were transported to the lab in insulated coolers (4 o C) within four hours of purchase. Homogenisation of canned products involved scraping out the entire edible content (drained when required) and freezing products were thawed at 4 o C overnight and the muscular fillet scraped out and the skin and viscera removed. Tissues were dried at 105 o C in a forced-air oven (until constant mass (typically 2226 h)) and ground in precleaned ceramic mortar to a fine uniform powder (subsample of about 10 g).

2.2 Acid Digestion Protocol

Aliquots of 1.000 + 0.005 g of dry powder were transferred to acid-washed borosilicate digestion tubes. The digestion mixture consisted of 5.0 mL of concentrated nitric acid (HNO_3, 65% w/w, trace-metal grade), 1.0 mL of perchloric acid ($HClO_4$, 70% w/w) and 1.0 mL of sulfuric acid (H_2SO_4, 98% w/w). Tubes were warmed on a digestion block at 80 o C under a fume hood until clear solutions were formed (3-4 h) after which the temperature was temporarily raised to 120 o C to completely oxidise any remaining organics. Digests were cooled and centrifuged at 2,500 rpm, 30 min and transferred to volumetric flasks and raised to 50 mL using 18.2 MΩ•cm deionised water (Milli-Q, Millipore).

Quality control was a reagent blank (one per ten samples), procedural blank that was run through the complete digestion protocol, and an analytical triplicate of each product. Glassware: Glassware was pre-treat with 10 per cent of HNO_3 in 24 hours, rinsed thrice with deionised water and autoclaved in 121 C and 15 psi in 20 minutes. Detection limits, defined as 3σ of the blank signal, were 0.05 µg/kg (Pb), 0.02 µg/kg (Cd), 0.10 µg/kg (Zn), and 0.10 µg/kg (Ni).

2.3 Spectroscopic Quantification

Flame atomic absorption spectroscopy (FAAS) with element-specific hollow-cathode lamps and air-acetylene flame was used to measure the levels of lead, cadmium, zinc and nickel. Every day, certified standard reference solutions (Merck CertiPUR ®) were used to construct calibration curves at 5 concentration points within the expected sample range; coefficients of determination exceeded 0.998 with all four elements. Two procedural-blank-corrected measurements of each replicate were averaged in terms of their meanings. The concentrations are expressed in micrograms of dry tissue per kilogram (µg/kg, equivalent to ppb on mass per mass basis).

2.4 Statistical Analysis

Python 3.11 data were analysed using NumPy, pandas, SciPy 1.13 and statsmodels. The analysis pipeline was pre-determined. The descriptive statistics (mean, SD, median, interquartile range, minimum, maximum) of every metal in every product group were computed. The distributional assumptions were checked by Shapiro-Wilk test (normality) and Levene test (homogeneity of variances); in the case when either of the aforementioned tests was rejected at the level of 0.05, the non-parametric Krustal-Wallis test was applied in place of ANOVA. The three product categories were compared by using tukey honest significant difference procedure with family-wise error control to make pair-wise post-hoc comparisons. The effect sizes were in eta-squared ($\eta 2$) that was deemed as a small (0.01), medium (0.06) and large (0.14) effect as per the Cohen convention.

Inter-element relationships between the sample level mean values in each product category (n = 25 tuna, n = 7 sardines, n = 7 frozen fish) and two tailed significance (0.05) were measured using Pearson product-moment correlations. Compliance with the international standards was measured by the comparison of the sample means with the Codex Alimentarius MRLs (CXS 193-1995 amended 2024): 300 µg/kg Pb in fish, 50-100 µg/kg Cd in different species, and reference values of Zn and Ni are taken in the FAO/WHO.

2.5 Ethical Considerations

The study used commercially available goods in the retail market and did not involve the use of an institutional review board since there were no human or animal subjects used in the study. The laboratory ledger contains the names of brand identities but anonymised in all published outputs to avoid causing reputational harm to commercial interests; no suggestion of a given quality of brand is intended.

Results

3.1 Descriptive Characteristic of Heavy-Metal Concentrations.

Table 1 gives a summary of the mean and variation of the four target metals in the three product categories. Frozen fish contained on average 10 times more lead than either type of canned product (mean: 93.70 µg/kg vs 16.51 in sardines and 10.86 in tuna). The same pattern was observed with cadmium (4.29 vs 1.44 vs 1.12 µg/kg). This order was reversed by zinc; the most prevalent was sardines (mean 102.70) (with one product in China measuring 197.33) followed by frozen fish (35.06), and tuna (34.40). Nickel concentrations were uniform within frozen fish (24.31 ± 0.90 µg/kg) but variable in tuna (6.28 ± 3.30, range 2.84–19.49 µg/kg).

Table 1. *Mean values of heavy-metal levels (µg/kg dry weight) by product.*

Product category	Metal	N	Mean	SD	Median	IQR	Min	Max
Canned Tuna	Pb	75	10.86	3.12	10.19	5.04	5.42	16.49
Canned Tuna	Cd	75	1.12	0.23	1.10	0.33	0.53	1.83
Canned Tuna	Zn	75	34.40	17.49	31.70	18.81	11.60	79.11

Canned Tuna	Ni	75	6.28	3.30	5.32	2.17	2.84	19.49
Canned Sardine	Pb	21	16.51	3.54	15.03	7.99	12.44	22.03
Canned Sardine	Cd	21	1.44	0.47	1.35	0.65	0.66	2.22
Canned Sardine	Zn	21	102.70	42.06	93.90	29.38	62.19	197.33
Canned Sardine	Ni	21	3.37	0.40	3.39	0.33	2.39	3.87
Frozen Fish	Pb	21	93.70	25.38	93.70	24.41	43.48	131.65
Frozen Fish	Cd	21	4.29	1.25	4.02	1.12	2.29	6.83
Frozen Fish	Zn	21	35.06	10.83	39.10	23.16	18.43	47.01
Frozen Fish	Ni	21	24.31	0.90	24.42	0.68	22.28	25.60

Note. Values are triplicate measurements that are combined under each category of products. S = standard deviation; IQR = interquartile range.

3.3 Checks of Assumptions and Inference at Group Level.

Shapiro-Wilk tests rejected the Pb, Zn and Ni distribution normality (p 0.004), and Levene tests rejected the homogeneity of the variances of all four metals (p 0.008). Between-group comparison was thus taken to be done using the Kruskal-Wallis non-parametric procedure (Table 2). The differences across product categories were highly significant in all four metals ($p < 10$ -1 in all cases) with the effect sizes being equally large by the criterion of Cohen (ranged 0.57 to 0.89). Post-hoc comparisons using Tukey HSD (Table 3) found that frozen fish was significantly different compared to both canned products in terms of Pb, Cd and Ni, whereas sardines were significantly different compared to the other two groups in terms of Zn.

Table 2. *Comparison of heavy-metal concentrations (Kruskal-Wallis test) between groups.*

Metal	H statistic	p-value	ANOVA F	η2	Effect size
Pb	69.118	< 0.001	474.16	0.893	Large
Cd	56.818	< 0.001	238.00	0.807	Large
Zn	49.640	< 0.001	75.59	0.570	Large
Ni	76.702	< 0.001	425.54	0.882	Large

Note. Cohen's benchmarks: $\eta^2 \geq 0.14$ indicates a large effect

Table 3. *Pairwise Tukey HSD post-hoc comparisons across product categories.*

Metal	Group 1	Group 2	Mean diff.	p-adj.	Significant
Pb	Sardine	Tuna	−5.65	0.099	No
Pb	Sardine	Frozen	+77.19	< 0.001	Yes
Pb	Tuna	Frozen	+82.84	< 0.001	Yes
Cd	Sardine	Tuna	−0.32	0.078	No
Cd	Sardine	Frozen	+2.84	< 0.001	Yes
Cd	Tuna	Frozen	+3.16	< 0.001	Yes
Zn	Sardine	Tuna	−68.30	< 0.001	Yes
Zn	Sardine	Frozen	−67.64	< 0.001	Yes
Zn	Tuna	Frozen	+0.66	0.993	No
Ni	Sardine	Tuna	+2.90	< 0.001	Yes
Ni	Sardine	Frozen	+20.94	< 0.001	Yes
Ni	Tuna	Frozen	+18.04	< 0.001	Yes

Note. The mean difference is given in µg/kg (Group 2-Group 1 indicates the direction of comparison in the table). p-adj indicates family-wise adjusted p-values.

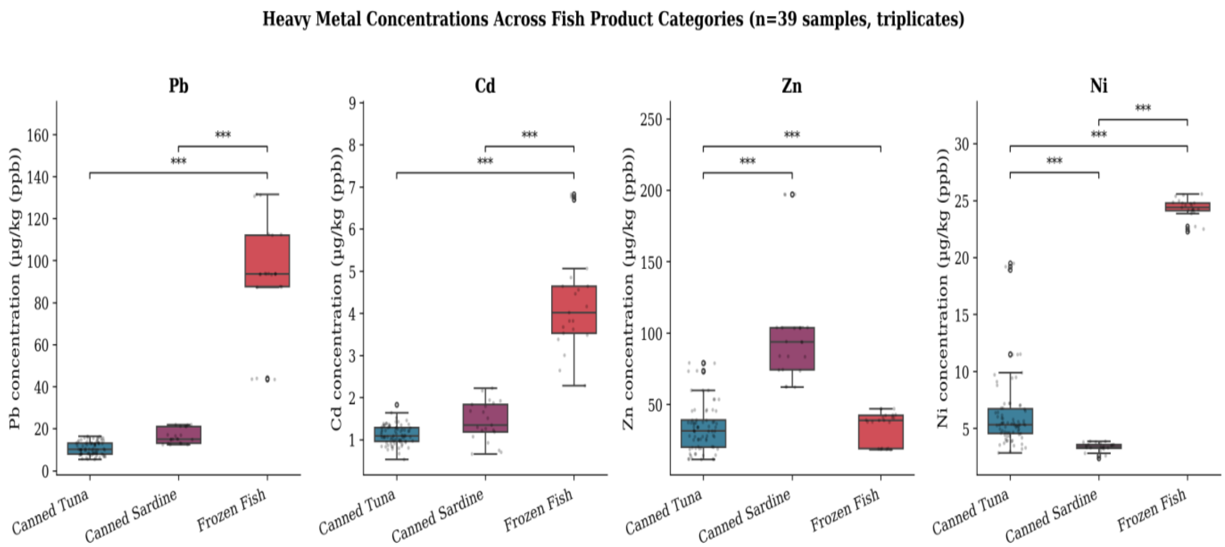

Figure 1. *Pb, Cd, Zn and Ni concentrations in the three product categories. Interquartile range with median is shown in boxes, the whiskers are extended to 1.5 times IQR and individual replicate values are shown as points. The significance brackets are an indication of Tukey HSD results (0.001 < p).*

3.3 Sample Level Variation across Product categories.

There was a great heterogeneity in each category of products, especially the frozen-fish group. The highest single-sample concentration of Pb was observed in Iranian trout (X1), which was 131.20 µg/kg, and then in Chinese pomfret (X3, 112.40), and three samples of Vietnam, Jordan, and Myanmar that were concentrated around 93.70 µg/kg (Figure 5). In canned tuna, the Pb levels were between 5.60 (T12, Indonesia) and 16.20 µg/kg (T4, Thailand), 2.9-fold apart. The highest Cd value in the whole range of data (6.83 µg/kg) was observed in Chinese frozen pomfret (X3), and the highest Zn value (197.33 µg/kg) was observed in Chinese canned sardine (S3). The z-scored profile of each sample can be visually identified in Figure 6, the matrix of all sample-level concentrations summarised.

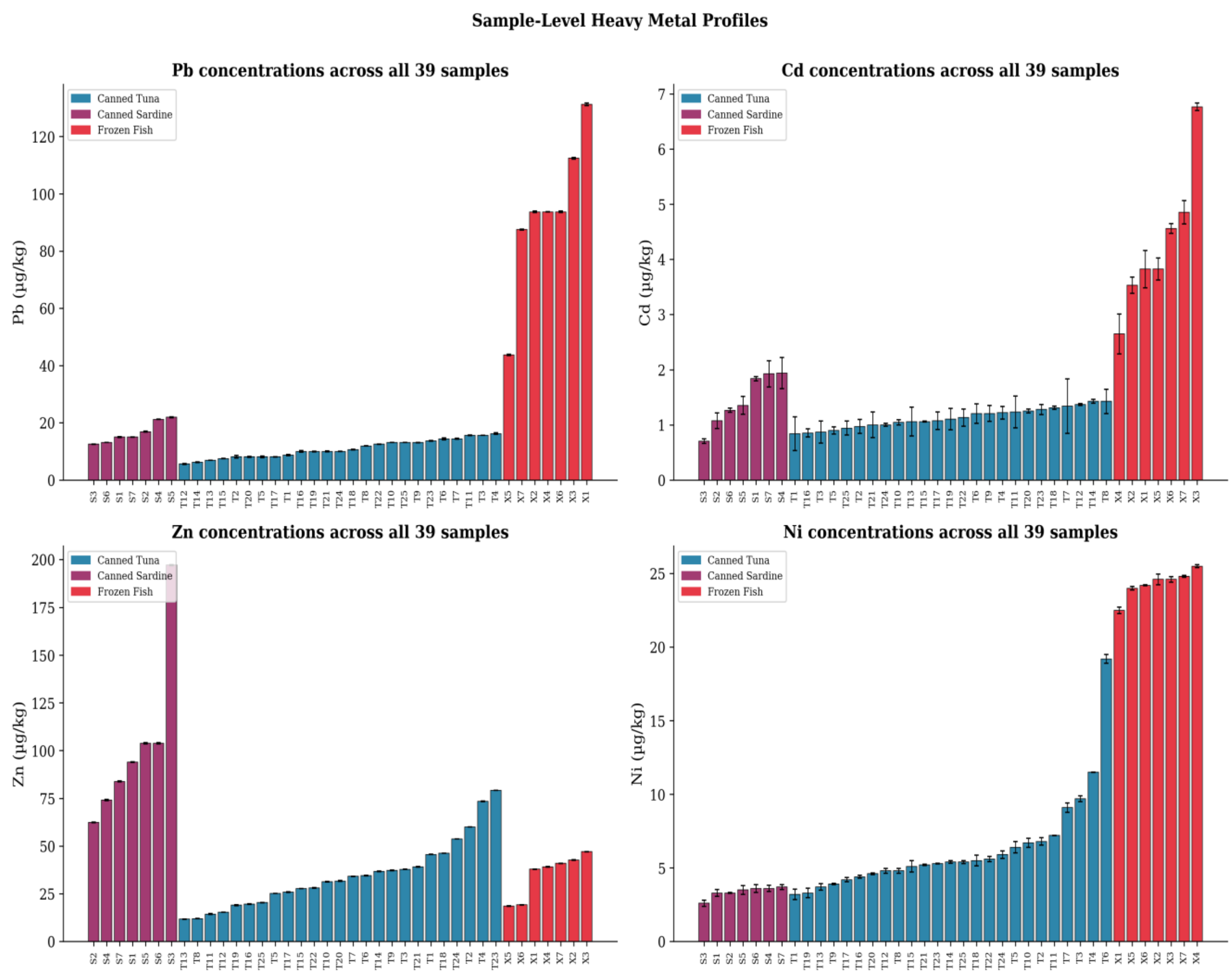

Figure 2. *Sample-level mean concentrations (± SD across triplicates) of Pb, Cd, Zn, and Ni for all 39 products, ordered by group and ascending mean. Bars are colour-coded by product category.*

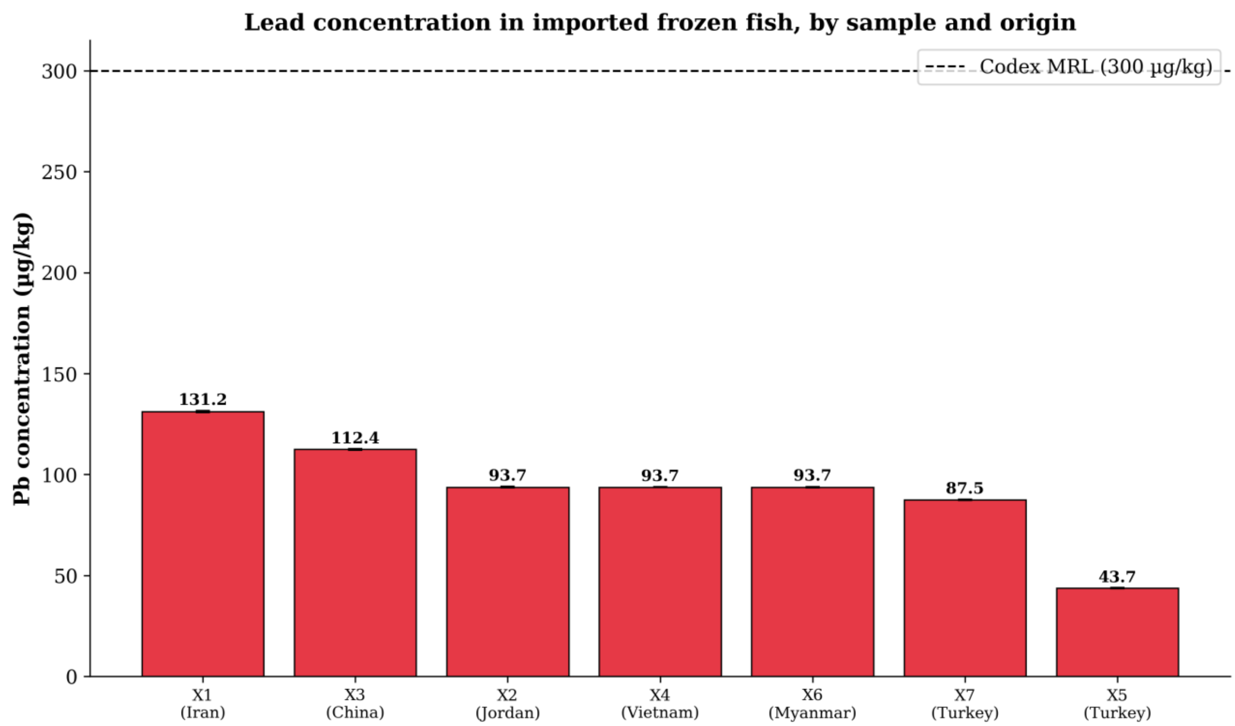

Figure 3*. Lead concentrations in the seven imported frozen-fish products, stratified by country of origin and ranked by Pb load. The dashed line marks the Codex Alimentarius MRL of 300 µg/kg. All sample means remain below this threshold.*

3.4 Inter-Element Correlations

The Pearson correlations of the means of the samples indicated specific correlations in each category of products (Table 4; Figure 4). Both lead and nickel co-occurred in tuna cans ($r = 0.55$, $p = 0.004$), suggesting that the two elements have a common source in the environment or in processing- perhaps as both elements migrate out of the solder joints or metal plating in older can designs. Zinc and nickel were found to have a strong negative relationship with sardines ($r = -0.82$, $p = 0.023$) as would be expected between the competitions of these divalent cations at the sites of biological transport. There are no statistically significant pairwise correlations at 0.05 in frozen-fish group but a moderate positive correlation between Pb and Zn ($r = 0.61$, $p = 0.146$), which is moderately strong because of the small sample size ($n = 7$).

Table 4. *Pearson correlation matrix for heavy-metal pairs within each product category.*

Group	N	Pair	r	p-value	Significance
Canned Tuna	25	Pb–Cd	0.066	0.754	ns
Canned Tuna	25	Pb–Zn	0.264	0.202	ns
Canned Tuna	25	Pb–Ni	0.550	0.004	**
Canned Tuna	25	Cd–Zn	0.005	0.981	ns
Canned Tuna	25	Cd–Ni	0.112	0.593	ns
Canned Tuna	25	Zn–Ni	0.239	0.250	ns

Canned Sardine	7	Pb–Cd	0.371	0.413	ns
Canned Sardine	7	Pb–Zn	−0.488	0.266	ns
Canned Sardine	7	Pb–Ni	0.439	0.324	ns
Canned Sardine	7	Cd–Zn	−0.647	0.116	ns
Canned Sardine	7	Cd–Ni	0.740	0.057	ns
Canned Sardine	7	Zn–Ni	−0.823	0.023	*
Frozen Fish	7	Pb–Cd	0.232	0.617	ns
Frozen Fish	7	Pb–Zn	0.609	0.146	ns
Frozen Fish	7	Pb–Ni	−0.334	0.464	ns
Frozen Fish	7	Cd–Zn	0.251	0.587	ns
Frozen Fish	7	Cd–Ni	−0.031	0.948	ns
Frozen Fish	7	Zn–Ni	0.236	0.611	ns

***Note*.** ** $p < 0.01$; * $p < 0.05$; ns = not significant. Correlations computed on sample-level mean values.

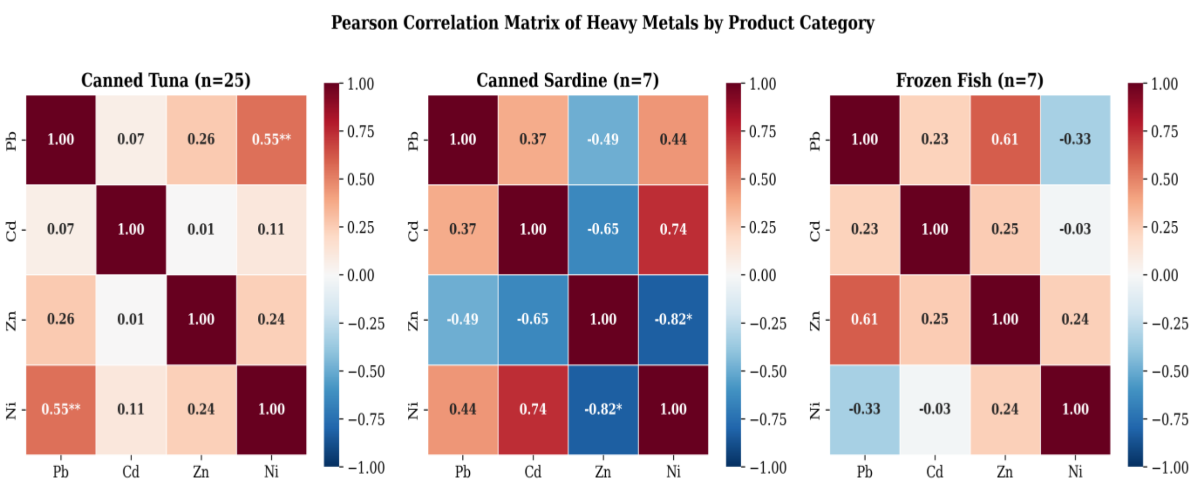

Figure 4. *Pearson correlation heatmaps of heavy-metal pairs within each product category. Asterisks denote significance (* p < 0.05; ** p < 0.01).*

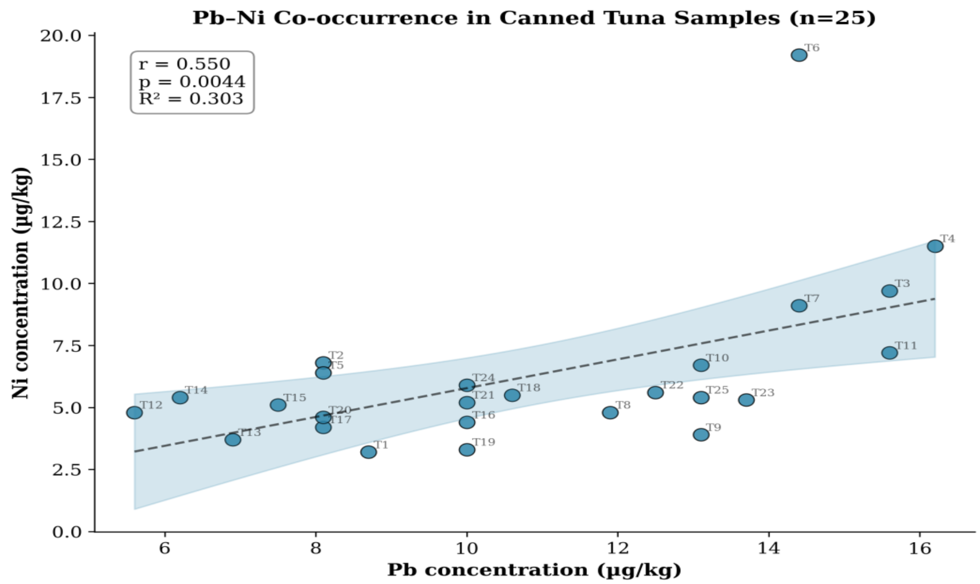

Figure 5. *Scatter plot of Pb against Ni in canned tuna samples (n = 25) with linear regression line and 95% confidence band. The strong positive association supports a shared contamination pathway for these two elements.*

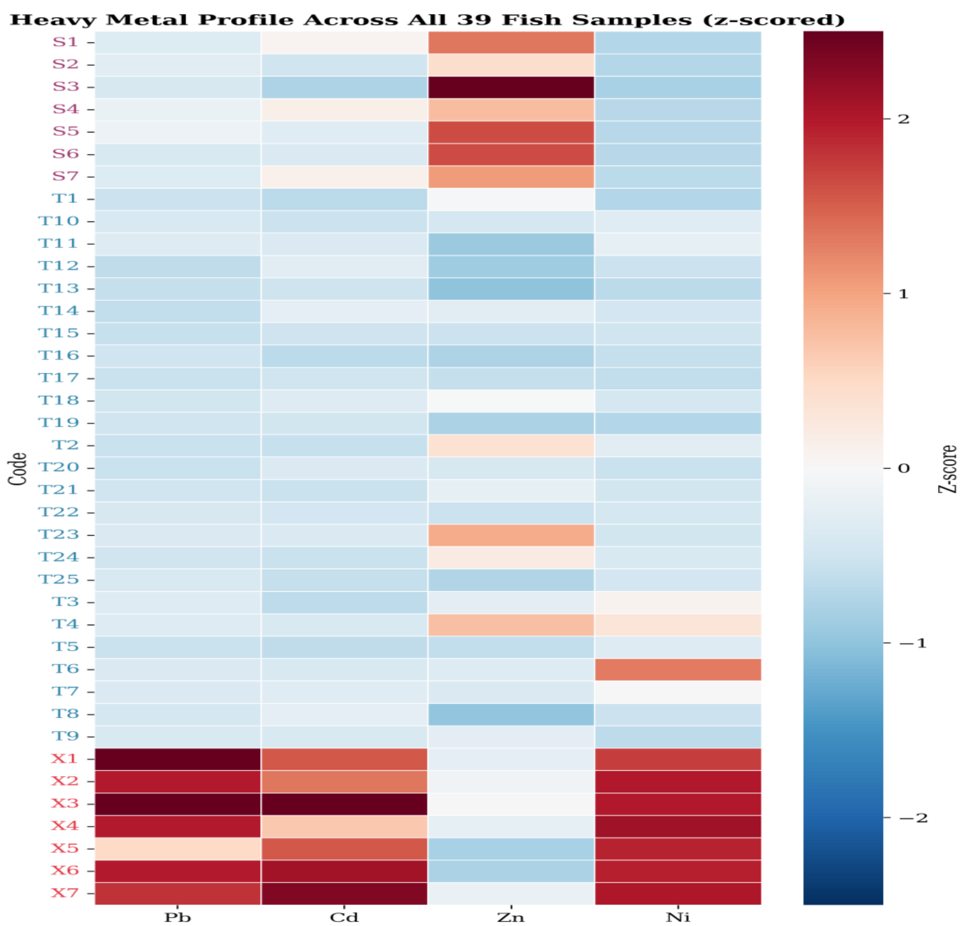

Figure 6*. Z-scored heatmap of all 39 fish products across the four target metals. Row labels are coloured by product category. Pronounced red rows in the frozen-fish block (X1, X3) flag samples with unusually high metal loading.*

3.5 Compliance with International Standards

The 39 sample-level concentrations were all compared with the current Codex Alimentarius MRLs and the amendments to the EU Commission Regulation 488/2014. All the products were below the Pb limit of 300 µg/kg, the Cd limit of 100 µg/kg of tuna, the Cd limit of 50 µg/kg of the broader fish group or the FAO/WHO tentative limit of Zn (50,000 µg/kg). The closest to the regulatory level was the X1 sample (Iranian trout) of 43.7 percent of the Pb MRL and then the X3 (Chinese pomfret) of 37.5 percent. Although the overexceedance was not detected, cumulative dietary exposure as shown by the frequency of consumption of products in the tail of the frozen-fish distribution will be quantitatively determined in a follow-up study.

4. Discussion

In this research, 39 imported canned and frozen fish products sold in Iraq were sampled in four heavy metals and frozen fish was chosen to be priority surveillance category. Three findings are satisfactorily described: order-of-magnitude greater level of Pb in frozen than in canned goods; the signature of sardines of the matrix Zn; the disparity in patterns of co-occurrence of metals among the categories of products. The implications of the two findings on their mechanistic and regulatory aspects are different.

4.1 Lead Burden in Frozen Fish

The concentration of Pb in the Iranian trout (131.20 µg/kg) is a lot lower than the Codex MRL (300 µg/kg), but much higher than the median of tuna in cans of this sample (10.19 µg/kg). This disruption is associated with two processes that are not mutually-exclusive. One, freshwater aquaculture in locations relying on industrial wastewater in filling pond is alleged to increase Pb in species grown [19]. Other similar loadings of Pb reported are 0.082011 mg/kg of Pb in muscular tissue of Iranian inland fishery trout [20] and our X1 value is within the upper bracket of the region base. Second, canning may be a partial sink, rather than a source of Pb, in contemporary two-piece welded cans, with lipid-soluble Pb species separating to the brine or oil packing medium, and may be lost during the draining edible fraction during sample processing [21, 22]. The second process would imply that old three piece soldered cans which still are in use by some manufacturers would add to more canned Pb, but modern construction would not; our data would verify the latter.

The present values are believed to be moderately close to Al-Obaidy [4] who had 0.094mg/kg of Pb in frozen carp in Iraqi markets and Hossain et al. [17] who had 0.043mg/kg in tuna cans in Bangladesh. The price of these canned tuna (median of 0.010mg/kg) is lowest among these comparators and it is understandable since there were more efficient international supply-chain controls between the date of the studies and the date of current sampling. Such discrepancies with larger loading experiments in the local literature e.g. Ahmed et al. [18] finding a median of 0.32 mg/kg of Pb in Persian Gulf species might be due to different target species (predatory versus forage) and harvest location versus industrial sources and not a change in method.

4.2 Zinc Profile of Sardines.

The mean content Zn in sardines (Sardina pilchardus Sardinella spp.) was approximately three times greater than the other kinds of products with the Chinese product S3 having a mean content of 197.33 µg/kg. This observation is biologically justified by the fact that sardines is a low trophic organism which feeds on phytoplankton and zooplankton since they are both Zn-accumulating organisms in coastal ecosystems [23, 24]. The nutritional value of canned sardines (100g 10 µg) of 100g 10 µg of Zn is still much lower than the recommended dietary intake of 11 mg/day of Zn in adults and consequently the amounts of Zn are not a public-health concern. They do not however object to the application of sardines as a sentinel species in trace-element environmental monitoring which has been popularly employed in Mediterranean baseline studies [25].

In sardines, the relationship between Zn and Ni is negative and very strong ($r = -0.82$, $p = 0.023$) and this is probably because the two divalent-cations are competing to be absorbed by the gill ionocytes where both Ni and Zn are probably attracted to the same membrane transporters [26]. This has been found to occur in laboratory exposure experiments, but is rare in observational fish-market surveys, in part because the metal panel that is needed to measure this in most past surveys is not available. Reproduction of bigger samples of sardines would warrant the conclusion, and may be generalized to exposure-source attribution.

4.3 Pb–Ni Co-occurrence in Tuna

Canned-product category has a policy-relevant outcome of a positive relationship between big PbNi in canned tuna ($r = 0.55$, $p = 0.004$). The two metals frequently occur together in industrial effluents, in atmospheric particulates through burning of fossil fuels, and of interest in canned products, in the lead-tin solder of the past to connect side seams of a can and the electroplating layers of nickel implanted on the inside of a can [27, 28]. Even though the level of Pb in this area is within the acceptable regulatory level, the co-elevation pattern indicates that one of the common courses of action is the contamination along the stream of fish capture. Such ambiguity would be removed by quantitative analyses of speciation, e.g. Pb-isotope ratio analysis to distinguish between sources in the marine-environment and sources in packaging would be used [29].

4.4 Limitations

The current results have several limitations that limit its generalisability. To begin with, the size of the frozen-fish sample ($n = 7$) and the sardine sample ($n = 7$) is low in terms of statistical power due to their small size to detect smaller correlations and explain within-group heterogeneity. Power calculations indicate that doubling these sample sizes would enable magnitude of correlation to be detected to increase to approximately $r = 0.71$ with 80 percent power at 80 percent power at 0.05. Second, the dynamic range limits are also undermined and simultaneous multi-element determination with an equivalent degree of accuracy cannot be achieved with FAAS as it can be done with current inductively coupled plasma systems, but an isotope-dilution calibration can be performed in some cases [30]. Third, cross-sectional design can only look through a window at a single market, and can not tell heterogeneity in seasonal or batch level; imports that the market makes in a season of supply disruption may vary in their profiles. Fourth, the overall concentrations of the metals are not speciated in the study, but are merely reported; the toxicity of Pb and Cd is also at least partly a question of chemical form, and the bioavailability of the metals in the human gastrointestinal tract is a product-matrix effect, with oil-packed products, in particular, not releasing metals as effectively as brine-packed analogs do during digestion

4.5 Future Directions

Three studies can be conducted to follow up the current work. A 4-quarter-long longitudinal repeat-purchase test would assist in deciding whether the high Pb signal in frozen fish is a supply-chain effect that is long-term or a batch heterogeneity. The portion of the inorganic and organic species of Pb and Cd that would be utilized to refine the estimates of the exposure which would be utilized in risk assessment would be determined by a high-performance liquid chromatography with ICP-MS. The input of an input-output consumer-survey-linked dietary-exposure model would be the existing concentration data and the other input would be the most likely estimates of the daily intake and the values of the margin-of-exposure of Pb would be compared to the EFSA-derived BMDL 1 references of Pb (1.50 µg/kg b) and Cd (0.36 µg/kg bw/day) [32].

5. Conclusion

A spectroscopic examination of 39 imported fish product in the Iraqi retail market had determined that the imported frozen fish product contains an order-of-magnitude higher Pb load than canned tuna or canned sardines but the sample means were all within the current Codex Alimentarius regulatory limits. Sardines proved to be the most concentrated food of Zn and canned tuna had a reproducible co-occurrence of Pb and Ni as did packaging contamination. These data justify the importance of focusing frozen-fish imports as a spectroscopic surveillance object at the entry point, the application of sardines as a sentinel matrix in environmental Zn monitoring, and a renewed interest in the quality of can-construction in the whole canned-tuna industry. The most educative fact concerning health of the populace is the order-of-magnitude difference between canned and frozen foods; any regulatory measure exercised in regard to the latter will have the greatest marginal protection in surveillance per dollar.

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