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Research Article

Research for the Common Good: Unreliable Lead-Free Marketing for Tableware

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Abstract

Tableware often contains glazes that may contain lead and other toxins. Inadequate firing processes can result in lead seepage into food, posing health risks upon ingestion. 1. Besides glaze, the ceramic material itself may contain heavy metals, such as lead. Even exposure to very low levels of lead can significantly impact childhood IQ, which has been a public issue since the 1960s. Near-zero levels of exposure to toxins are essential to protect public health. 2. Health organizations have published recommended "safe" levels of lead and other toxins. For example, California Proposition 65: <0.1 ppm; Massachusetts 105 CMR 460.200 Lead Poisoning and Control: <2 ppm; Food and Drug Administration (FDA): <0.5 ppm for mugs. In this study, ceramic cups specifically advertised as lead- and cadmium-free were tested. While the primary goal was to verify the legitimacy of lead- and cadmium-free advertisements as an educational service to consumers, levels of chromium and zinc were also tested. Specifically, the level of toxins within the ceramic, the amount of toxins leaching into the consumable liquids, and changes in leached levels over time were investigated. Samples were examined by using Inductively Coupled Plasma (ICP) analysis. Our findings show a wide range of toxin exposure, indicating that the marketing is false.

Keywords

Lead, Zinc, Cup, ICP

1. Introduction

Historically, lead was frequently used in paint and glazes that seal earthen tableware. Lead in tableware glazes has long been associated with poisoning cases spanning millennia dating back at least 2,500 years. [7] Since the 1960s, childhood lead poisoning has become a recognized public health concern. [11] Identifying lead poisoning can be challenging because the symptoms frequently seem very benign and manifest in different ways, such as gastrointestinal problems, delays in physical development, and impaired neurological development. [14] An analysis that pooled data from seven countries concludes that there is no threshold before a loss in IQ takes place and advises that the protection of children against lead poisoning must start during pregnancy. [9] Even exposure to very low levels of lead is associated with a significant loss of IQ during childhood; hence, to protect public health, near-zero levels of exposure to toxins are essential. [8]

Cadmium, akin to lead, adversely affects the nervous system and other bodily functions. [5] Cadmium is used as a pigment and produces vibrant yellow, orange, and red colors and glazes. [17] This toxin has a long half-life, and kidneys retain cadmium for 10-30 years. [4]

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While chromium as a pure metal is not toxic to the human body, chromium compounds can cause toxic effects such as severe skin reactions, ulcers, asthma reactions, gastrointestinal and liver issues, and cancers. [1] Zinc is considered relatively nontoxic but can cause impaired immune function and adverse cholesterol effects in excess amounts. [6]

Although public health agencies, such as the Food and Drug Administration (FDA), the World Health Organization (WHO), and California Proposition 65 (Prop 65) publish their perspectives on "safe" levels of toxins, people, especially parents of young children, might decide to avoid any such toxins altogether. [18-20] Can they select lead-free and cadmium-free tableware for the desired health level of their family? One convenient option is to visit the e-commerce platform of Amazon.com, where sellers can offer their products to interested buyers. There, people interested in lead-free and cadmium-free coffee cups will find a variety of offerings that meet their specifications. [23-25] Although the FDA has regulations in place whereby sellers should adhere to their lead-free claims, [16] many buyers have no guarantee that the stated claims are true. Does lead-free really mean there is no lead in the purchased coffee cup?

Many studies conducted in the U.S., [13] Turkey, [2] Belgium, [10] and other countries examined pottery and reported the levels of toxins found during the analyses. There were few peer-reviewed studies that tested claims of lead-free and cadmium-free tableware. Thus, lead-free and cadmium-free labeled drinkware sold in the U.S were examined in this study as a service to consumers.

2. Experimental

Two acid digestion analyses were performed. The first acid digestion measured the leaching of metals from the glaze (cup exterior), and the second acid digestion determined metals in the ceramic (cup interior). All chemicals were purchased from Fisher Scientific (Chicago, IL). Solutions were prepared with DI (deionized) water, unless otherwise specified. Deionized water was purified with Milli Q Direct Q-UV (Merck KGaA, Darmstadt, Germany). A series of standard solutions containing lead, zinc, cadmium, and chromium were prepared by diluting multi-element solution standards from Fisher Scientific (Chicago, IL). Calibration curves were based on the analysis of ten standard solutions ranging from 5.00 ppb to 500 ppm. The peak area of the signal was employed to generate the calibration plot for calculating concentrations of heavy metals in sample solutions. Each element's calibration curve was generated using Microsoft Excel with a R^2 value above 0.99. Standard solutions and sample solutions were prepared with the same acidity and were run on the instrument on the same day. All standard and sample solutions were repeated ten times, respectively.

2.1. Acid Digestion of Glaze

This analysis followed the standard procedure used by the European Commission (EC) in Council Directive 84/500/EEC, [21] the California Proposition 65 Compliance requirements, [19] and the Food and Drug Administration (FDA). [18, 20] All cups used in the experiment were intact, properly cleaned, and filled with freshly prepared 4% (v/v) acetic acid of analytical quality to approximately 1 mm from the upper rim. The cups with the acid solutions rested at 22 ℃ for 24 hours. This process was carried out three times for each cup to determine the change in leaching over time. Appropriate amounts of each solution were transferred into labeled 20 mL vials, which were stored until used for ICP (inductively coupled plasma mass spectrometry) analysis.

2.2. Acid Digestion of Ceramic

The cups to be analyzed for their levels of lead and cadmium were purchased from Amazon in May 2022. All cups claimed online to be either lead-free or both lead- and cadmium-free. To ensure that the cups are a good representation of what U.S. consumers use (i.e., cups that are widely used and purchased), cups must have a minimum of 100 ratings on Amazon. Lastly, to allow for a variety of different sellers, each seller was included only once, even if the company sells multiple lead- and cadmium-free cups. A summary of the eight cups used in this study is provided in Table 1. All eight cups in the sample were advertised as lead-free, and six cups were also advertised as cadmium-free. Colors of the cups ranged across the spectrum, from red to dark blue, and the number of ratings on Amazon ranged from 104 to 2,050, as shown in Table 1.

2.3. Instrumentation

The liquids from the two types of acid digestion were analyzed using a Series 710-ES Inductively Coupled Plasma-Optical Emission Spectrometer (ICP) by Varian Inc. The machine is certified to detect ranges of lead (13.1-14.5 mg/kg), cadmium (21.0-22.4 mg/kg), and chromium (17.1-18.3 mg/kg). [22] Since ICP can only analyze liquids and gasses, acid digestion methods had to be used to extract the solid metals from the ceramic and the glaze so they could be examined. An ICP machine uses optical emission spectrometry to analyze samples. First, an electromagnetic field is used to ionize argon gas, thereby creating plasma. The sample to be analyzed is then irradiated with this plasma, exciting the component atoms of the sample. When the excited atoms return to their low energy positions, they release emission rays that correspond to their respective atoms' photon wavelengths. The machine then measures the position and intensity of the photon rays, determining both the element types and the amounts of each element in the sample. [3]

For more information, Hou et al. and Charles and Fredeen provide excellent and comprehensive backgrounds of ICP methodology. The results of the analysis are presented in Table 2.

2.4. Tables

Table 1. *Cups used in the analysis.*

Sample #	Company	Color	Lead-free claim	Cadmium-free claim	# Amazon Ratings (May 2022)
1	TEANAGOO	white/blue fade	yes	yes	473
2	Serami	dark blue	yes	yes	683
3	Dowan	black	yes	--	155
4	Lifecapido	black outside, red inside	yes	yes	2050
5	Xiteliy	red outside, white inside	yes	yes	104
6	MIWARE	blue	yes	yes	142
7	Bruntmor	yellow	yes	--	294
8	Koja	pattern (tall blue ovals) on white background	yes	yes	190

Table 2. *Levels of lead, cadmium, chromium, and zinc in the ceramic.*

	Concentration Mean +/- Standard Deviation in ppm			
Cup	Lead (Pb)	Cadmium (Cd)	Chromium (Cr)	Zinc (Zn)
1	N/D	5.33 +/- 0.49	3.98 +/- 0.19	39.8 +/- 1.06
2	55.5 +/- 1.9	4.62 +/- 0.39	36.2 +/- 0.95	1715 +/- 57
3	6.2 +/- 2.3	11.7 +/- 0.30	68.8 +/- 0.71	139 +/- 2.1
4	69.1 +/- 8.8	18.6 +/- 0.38	63.3 +/- 5.37	1045 +/- 84
5	4.7 +/- 2.3	7.80 +/- 0.49	12.4 +/- 0.70	923 +/- 39
6	44.7 +/- 9.0	7.80 +/- 0.49	32.3 +/- 1.57	1354 +/- 78
7	46.3 +/- 9.2	28.6 +/- 3.19	22.5 +/- 2.59	1080 +/- 140
8	67.8 +/- 6.3	13.0 +/- 0.38	53.2 +/- 6.26	408 +/- 43

Table 3. *Levels of lead, cadmium, chromium, and zinc leaching from the glaze into the liquid. Each cup was tested three times to measure leaching differences over time. The recorded results are the averages of the three rounds.*

	Concentration Mean +/- Standard Deviation in ppm: Average of 3 Rounds			
Cup	Lead (Pb)	Cadmium (Cd)	Chromium (Cr)	Zinc (Zn)
1	0.056 +/- 0.042	0.030 +/- 0.009	0.024 +/- 0.010	0.110 +/- 0.008
2	0.064 +/- 0.080	0.026 +/- 0.008	0.014 +/- 0.004	0.081 +/- 0.007
3	0.112 +/- 0.060	0.025 +/- 0.011	0.021 +/- 0.009	0.086 +/- 0.004
4	0.185 +/- 0.078	0.022 +/- 0.010	0.015 +/- 0.009	0.087 +/- 0.009

	Concentration Mean +/- Standard Deviation in ppm: Average of 3 Rounds			
Cup	Lead (Pb)	Cadmium (Cd)	Chromium (Cr)	Zinc (Zn)
5	0.303 +/- 0.075	0.020 +/- 0.008	0.009 +/- 0.004	0.084 +/- 0.008
6	0.276 +/- 0.074	0.021 +/- 0.012	0.014 +/- 0.004	0.146 +/- 0.011
7	0.252 +/- 0.130	0.027 +/- 0.015	0.016 +/- 0.003	0.117 +/- 0.011
8	0.308 +/- 0.088	0.023 +/- 0.012	0.009 +/- 0.006	0.929 +/- 0.058

Table 4. *Cups with greatest and lowest toxin concentrations for both ceramic and glaze.*

	Ceramic: Best Cup	Ceramic: Worst Cup	Glaze: Best Cup	Glaze: Worst Cup
Lead (Pb)	Cup 1 (N/D)	Cup 4	Cup 1	Cup 8
Cadmium (Cd)	Cup 2	Cup 7	Cup 5	Cup 1
Chromium (Cr)	Cup 1	Cup 3	Cup 5	Cup 1
Zinc (Zn)	Cup 1	Cup 2	Cup 2	Cup 6

3. Materials and Methods

The Materials and Methods section should provide comprehensive details to enable other researchers to replicate the study and further expand upon the published results. If you have multiple methods, consider using subsections with appropriate headings to enhance clarity and organization.

4. Results and Discussion

Although all eight cups were marketed as lead-free, and all but cups #3 and #7 also as cadmium-free, the analysis of the ceramic shows unequivocally that those claims are false. The mean of five measurements shows that lead concentration in the sample ranges from 4.65 ppm (cup #5) to 69.09 ppm (cup #4) and that cadmium concentration from 4.62 ppm (cup #2) to 28.61 (cup #7). There is no apparent correlation between lead and cadmium concentration. Further, the chromium concentration ranges from 3.98 ppm (cup #1) to 68.83 (cup #3), and the zinc concentration from 39.83 (cup #1) to 1715.04 ppm (cup # 2).

One might argue that if there is no crack, fracture, or damage to the glaze seal, the metals from the ceramic will not travel into the consumed liquid. In such optimal conditions, the only exposure to the consumable liquid is generated from the glaze used in the firing process. The subsequent test, therefore, examines how much, if any, metals would leach from the glaze into the liquid. Again, if the lead-free and cadmium-free claims were true, no such metals should be detected in the analysis. The results of the leaching experiment are summarized in Table 3.

The glaze analysis echoes the results of the ceramic analysis. All eight cups leach both lead and cadmium, as well as chromium and zinc, from their glaze. Compliance limits for lead leaching in ceramic coffee mugs range from a maximum of 0.1 ppm to 0.5 ppm in the U.S. [20] and 4.0 ppm in Europe. [21] Compliance limits for cadmium range from 0.189 ppm to 0.5 ppm in the U.S. [20] and 0.3 ppm in Europe. [21]

With respect to the U.S. compliance limits for lead, all cups fall below the FDA maximum, but cups #3 - #8 are above the Prop 65 maximum. For cadmium, all cups are below the maximums set by the FDA and Prop 65. [18, 19] Nevertheless, they are clearly violating their claim of being lead-free and cadmium-free. Further, the FDA states on its official website that "If ceramicware bearing the term 'Lead Free' in its labeling contains extractable lead, FDA may consider the use of the term 'Lead Free' in the labeling to be false and misleading, and therefore the ceramicware misbranded under section 403(a)(1) of the Act (21 U.S.C. 343(a)(1))." [16]

Table 4 shows which cups were the "best" and "worst;" i.e., which cups had the greatest and lowest concentrations of each toxin for both the ceramic and glaze.

5. Conclusions

The study revealed that despite being marketed as lead- and cadmium-free, all eight cups, except cups #3 and #7, contained detectable levels of lead and cadmium. By employing FDA acid digestion methods, lead and cadmium presence in the glaze. [20] Using the EPA acid digestion method, it was also found that, except for cup #1, which did not have any detectable lead, all other cups have detectable lead and cadmium in the ceramic. [15] Although all cups met the FDA's lead compliance limits, cups #3 through #8 surpassed Prop 65's maximum limit for lead. However, all cups stayed within the FDA and Prop 65 limits for cadmium.

All cups are clearly violating their claim of being lead-free and cadmium-free; therefore, according to the FDA, the claims of the cups tested in this study are false and misleading [16] and thereby are harming consumers. To reiterate, the consumption of lead and cadmium has proven to have negative health effects. [5, 7, 8, 12] Mercola further states that "Nearly 1 in 5 (18%) of all deaths and more than 1 in 4 (28.7%) of all cardiovascular deaths are related to lead toxicity."

In conclusion, this study finds that health-conscious consumers who are aware that any amount of lead is harmful [8] and who therefore wish to use lead-free and cadmium-free tableware cannot always trust marketing labels. The study invalidates claims of lead- and cadmium-free tableware, exposing potential health risks. The discrepancy between claims and actual toxin levels highlights a pressing need for more stringent monitoring and accurate labeling of consumer goods.

While this study tested only a limited sample of products, the possibility exists that genuinely lead- and cadmium-free cups may be available. However, to ensure safety, consumers may need to resort to laboratory testing or rely on reliable consumer advocate groups for product recommendations.

Future research could include exploring toxin levels in conventional, non-labeled cups to ascertain potential toxin ingestion by the average consumer. This comparison could shed light on whether non-labeled cups exhibit significantly higher toxin levels than those studied here.

Additionally, investigating alternative materials such as stainless steel or clear glass warrants attention. As these materials usually do not contain colors or glazes, cups made from stainless steel or clear glass may have lower levels of lead and cadmium. Ball mason jars, for example, might be an excellent alternative. Although the jars were not tested in a scientific environment, Tamara Rubin used XRF (X-ray fluorescence spectroscopy) to determine that various Ball products, including the 6- and 16-oz clear glass Ball mason jars, had consistently undetectable levels of lead and cadmium, as well as arsenic and mercury. [12]

Abbreviations

FDA	Food and Drug Administration
WHO	World Health Organization
Prop 65	California Proposition 65
DI	Deionized [Water]
EC	European Commission
ICP	Inductively Coupled Plasma Mass Spectrometry
XRF	X-ray Fluorescence Spectroscopy

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Author Contributions

Sofia Steigner: Conceptualization, Resources, Research Performance, Writing – original draft, review & editing

Qiyang Zhang: Data curation, Methodology, Resources, Writing – review & editing

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Data Availability Statement

Not applicable.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Qiyang Zhang is an Associate Professor at Emporia State University, Forensic Sciences Program. He completed his PhD in Chemistry from Wichita State University in 2016. He served as the Chair of ACS Wichita Section in 2021. Sofia Steigner is an undergraduate student at Emporia State University. After graduating, she plans to attend medical school and later become a pediatric neurosurgeon.

Research Field

Sofia Steigner: Biochemistry, Analytical Chemistry
Qiyang Zhang: Analytical Chemistry, Forensic Chemistry