



Cadmium and Lead Contamination in Highland Honey from Peru: A Potential Health Risk

Contaminación por cadmio y plomo en miel altoandina del Perú: un riesgo potencial para la salud

Clauss E. Llico-Saénz¹, Juan J. Villanueva¹, Luis Vargas-Rocha^{1*}

Highlights

- A high proportion of honey samples (91.67%) exceeded the Maximum Permissible Limits (MPLs) for cadmium, with increases of up to 2,775% according to MERCOSUR standards.
- Honey from the district of La Encañada showed the highest lead concentrations ($p < 0.05$), with 58.33% of samples exceeding MPLs and increases reaching up to 726.
- These results underscore the need for environmental monitoring and stricter regulatory measures to ensure honey safety and protect consumer health.

Innovaciencia
ISSN: 2346-075X

E- ISSN: 2346-075X

Innovaciencia 2025; 13(1); e4801

<http://dx.doi.org/10.15649/2346075X.4801>

SHORT COMMUNICATION

How to cite this article:

Llico-Saénz CE, Villanueva JJ, Vargas-Rocha L. Cadmium and Lead Contamination in Highland Honey from Peru: A Potential Health Risk. 2025;13(1); e4801

<http://dx.doi.org/10.15649/2346075X.4801>

Received: 18 December 2024

Accepted: 23 May 2024

Published: 16 July 2025

Keywords:

Apis mellifera; food contamination, food safety; heavy metals; toxicity.

Palabras clave:

Apis mellifera; contaminación alimentaria; inocuidad alimentaria; metales pesados; toxicidad.

ABSTRACT

Introduction. Honey has been part of the human diet and medicine for millennia. Although its nutritional composition can vary across regions, the concentration of certain metals must not exceed the maximum permissible limits (MPLs) set by national and international bodies, as these metals are toxic to consumers. **Objectives.** To determine the concentration of cadmium and lead in honey from two districts (Cajamarca and La Encañada) in a northern province of Peru. **Materials and Methods.** Twelve samples were collected from four localities in these two districts of the Cajamarca province. Cd and Pb concentrations were measured using graphite furnace atomic absorption spectrophotometry. **Results and Discussion.** Cd levels ranged from 0.070 to 2.875 mg/kg, while Pb levels varied from <0.001 to 2.478 mg/kg. The highest Cd concentrations were found in honey from the Cajamarca district and its two localities; however, these differences were not statistically significant ($p > 0.05$). Honey from La Encañada and its localities showed the highest Pb levels ($p < 0.05$). Compared to MPLs established by Mercosur (Cd: 0.10 mg/kg; Pb: 0.30 mg/kg), 91.67% (95% CI: 61.52 - 99.79) of the samples exceeded these limits for Cd, with increases of up to 2,775%. Similarly, 58.33% (95% CI: 27.67 - 84.83) of the samples exceeded MPLs for Pb, with increases of up to 726%. **Conclusions.** Honey samples from two northern Peruvian districts exhibited Cd and Pb levels above Mercosur MPLs, posing potential health risks for consumers and rendering the honey unsuitable for trade.

RESUMEN

Introducción. La miel de abeja ha formado parte de la dieta y medicina milenaria del hombre. Aunque su composición nutricional puede variar de un lugar a otro, la concentración de algunos metales no debe sobrepasar los límites máximos permisibles (LMP) establecidos por organismos nacionales e internacionales por ser tóxicos para los consumidores. **Objetivo.** Determinar la concentración de cadmio y plomo en miel de abeja de dos distritos (Cajamarca y La Encañada) de una provincia del norte de Perú. **Materiales y Métodos.** Se tomaron doce muestras de cuatro centros poblados ubicados en dos distritos de la provincia de Cajamarca, Perú. La concentración de Cd y Pb se determinó mediante espectrofotometría de absorción atómica en horno de grafito. **Resultados y Discusión.** Los niveles de Cd oscilaron entre 0,070 y 2,875 mg/kg y de Pb desde $<0,001$ hasta 2,478 mg/kg. La mayor concentración de Cd se observó en miel colectada del distrito de Cajamarca y sus dos centros poblados, sin embargo, no mostraron diferencias estadísticas ($p > 0,05$). La miel proveniente de La Encañada y sus centros poblados tuvo los mayores niveles de Pb ($p < 0,05$). Comparado con los LMP establecidos por Mercosur (Cd: 0,10 mg/kg; Pb: 0,30 mg/kg), el 91,67% (IC95% 61,52 - 99,79) de las muestras sobrepasaron los valores para el Cd, con incrementos de hasta 2,775%. Por su parte, el 58,33% (IC95% 27,67 - 84,83) de las muestras sobrepasaron los LMP de Pb, con incrementos hasta 726%. **Conclusiones.** Las muestras analizadas presentaron concentraciones de Cd y Pb por encima de los límites de seguridad establecidos, lo que podría representar un potencial riesgo para la salud del consumidor y limitar su idoneidad para el comercio nacional e internacional.



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INTRODUCTION

Honey produced by the Western honeybee (*Apis mellifera* L.) is highly nutritious, with bactericidal activity, immunostimulatory properties, and other health benefits ⁽¹⁾. Its quality depends on its mineral composition, concentrations of heavy metals, and physicochemical attributes. When these concentrations exceed internationally recommended limits, they can pose significant health risks, including mutagenic and carcinogenic effects ⁽²⁾.

The composition and characteristics of honey are directly influenced by its botanical and geographical origin, including the specific type of flora, the timing of harvest, and the techniques used for processing and storage ^(3,4). Elevated levels of metals have been reported in honey samples collected near anthropogenic sources such as mining areas and sedimentation ponds ⁽⁵⁾. Bees can come into contact with heavy metals during foraging, acquiring contaminants from polluted vegetation, water sources, and airborne particles that adhere to their bodies ⁽⁶⁾. Within the hive, these metals can accumulate in bee-derived products such as pollen, wax, propolis, and honey itself ⁽⁷⁾.

Honey is considered a potential bioindicator of heavy metal pollution, although its usefulness can vary depending on floral origin, atmospheric particle retention by flowers, and other environmental variables ⁽⁸⁾. For example, studies in Turkey have reported Cd concentrations ranging from 0.00 to 0.29 mg/kg and Pb concentrations from 0.00 to 3.03 mg/kg ⁽⁹⁾; in an industrial region of Romania, levels ranged from 0.05 to 3.81 mg/kg for Cd and 0.76 to 3.41 mg/kg for Pb ⁽¹⁰⁾. In Peru, Pb levels in honey from the Arequipa region ranged from 0.68 to 2.74 mg/kg ⁽¹¹⁾, whereas in Junín they ranged from 0.003 to 0.09 mg/kg ⁽¹²⁾.

Food safety has become a growing global concern, driving consumer preference for high-quality products ⁽¹³⁾. Contaminants in honey have garnered research interest due to honey's value as a bioindicator of environmental pollution, which is strongly influenced by geographical and ecological conditions ⁽¹⁴⁾. Comprehensive evaluation of physicochemical properties, mineral content, and the presence of heavy metals is therefore essential to ensure the authenticity of honey and improve its production capacity to meet market demands ⁽¹⁵⁾.

Cajamarca is one of the leading beekeeping regions in Peru, with approximately 15,491 beehives—ranking just below Cusco, La Libertad, Junín, Lima, and Apurímac ⁽¹⁶⁾. However, there is limited information on the nutritional composition of its honey, particularly regarding the presence and concentrations of toxic metals. This study was thus conducted to determine the levels of Cd and Pb in honey produced by *Apis mellifera* in two districts of the Cajamarca province, Peru.

MATERIALS AND METHODS

Sampling was conducted from August to September 2023 in apiaries located in rural localities within two districts of the Cajamarca province, in northern Peru. The study area is characterized by a dry temperate climate, with an average annual temperature of 14.9 °C, relative humidity of 64.5%, and annual precipitation of 537 mm ⁽¹⁷⁾. The local economy is primarily based on agriculture and livestock (including cattle, sheep, and guinea pigs), with crops such as cereals, tubers, and vegetables, as well as mining activities.

The selected apiaries were situated in four localities at different altitudes: Combayo (3,268 m) and Romeral (3,149 m) in the district of La Encañada, and Huambocancha (2,986 m) and La Paccha (2,649 m) in the district of Cajamarca (Figure 1). Altitude data were obtained using the GPS Waypoints application (v. 3.13). One apiary was selected per locality, and three unique honey samples of 350 g each were collected from each apiary.

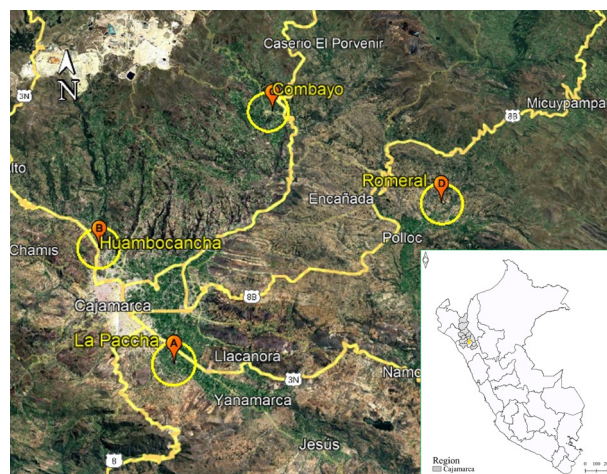


Figure 1. Geographic location of the honey sampling sites in the Cajamarca province, Peru.

Sample collection was carried out at 11:00 a.m. following standard honey extraction procedures. The hive cover was removed, three frames from the production chamber were extracted, and the wax cappings were removed using an appropriate tool. The frames were then placed in a centrifugal extractor operated continuously and vigorously. The extracted honey was collected in a clean plastic container (Figure 2), and the required volume was subsequently transferred into hermetically sealed glass jars, properly labeled. The jars were wrapped in absorbent paper to prevent breakage, placed in cardboard boxes, and transported to the laboratory.



Figure 2. Steps in the honey collection and packaging process: (a) Placement of frames into the manual centrifuge for extraction; (b) Collection of honey after centrifugation and transfer to a plastic container; (c) Packaging of samples into glass jars for shipment to the laboratory.

The concentrations of Cd and Pb were determined using graphite furnace atomic absorption spectrophotometry (GFAAS)⁽¹⁸⁾, with a Thermo Scientific iCE 3000 spectrometer. Prior to analysis, the honey samples were heated in a water bath to reduce viscosity, weighed, and incinerated in a muffle furnace at 450 °C for 16 hours to eliminate organic matter. The remaining residue was treated with purified nitric and perchloric acids and heated to near dryness. The digested material was then filtered and diluted to a specific volume for analysis.

Cadmium was measured at a wavelength of 228.8 nm using argon as the carrier gas and Zeeman background correction. A calibration curve was prepared using standard Cd solutions at concentrations ranging from 5 to 50 ppb to ensure analytical accuracy. Lead was quantified using a similar method, with detection at 217 nm using a Pb-specific hollow cathode lamp and deuterium background correction. Atomization conditions included a temperature of 1,800 °C and ultra-high purity argon as the carrier gas. A calibration curve for Pb was prepared with standard solutions ranging from 50 to 300 ppb.

All analyses were performed at the Center for Toxicological Information, Control, and Environmental Management Support, Faculty of Pharmacy and Biochemistry, National University of San Marcos, Lima – Peru.

The Cd and Pb concentrations were compared against the Maximum Permissible Limits (MPLs) set by the MERCOSUR Technical Regulation on Inorganic Contaminants in Food (MERCOSUR/GMC/RES. No. 12/2011), which establishes an MPL of 0.10 mg/kg for Cd and 0.30 mg/kg for Pb in honey.

Data were analyzed using descriptive statistics. Normality was assessed with the Shapiro–Wilk test. Based on the results, differences in Cd concentrations between the two districts were evaluated using the Mann–Whitney U test, while comparisons among localities were conducted using the Kruskal–

Wallis test. For Pb, comparisons between districts were performed using the Student's t-test, and among localities using one-way ANOVA followed by Tukey's post hoc test. A significance level of $p < 0.05$ was considered.

Additionally, the percentages of samples exceeding the MPLs for each metal were calculated, along with their corresponding 95% confidence intervals (CIs), using the Clopper–Pearson method, which is suitable for small sample sizes. These analyses were conducted using SPSS software v.27.0.1. The percentages and CIs of samples deemed suitable or unsuitable for human consumption were also calculated.

RESULTS

In the twelve honey samples collected from two districts in the province of Cajamarca (Peru), cadmium (Cd) concentrations ranged from 0.070 to 2.875 mg/kg, while lead (Pb) levels varied from <0.001 to 2.478 mg/kg. At the district level, the highest Cd concentrations were detected in samples from the district of Cajamarca, whereas the highest Pb concentrations were found in samples from the district of La Encañada (**Figure 3**).

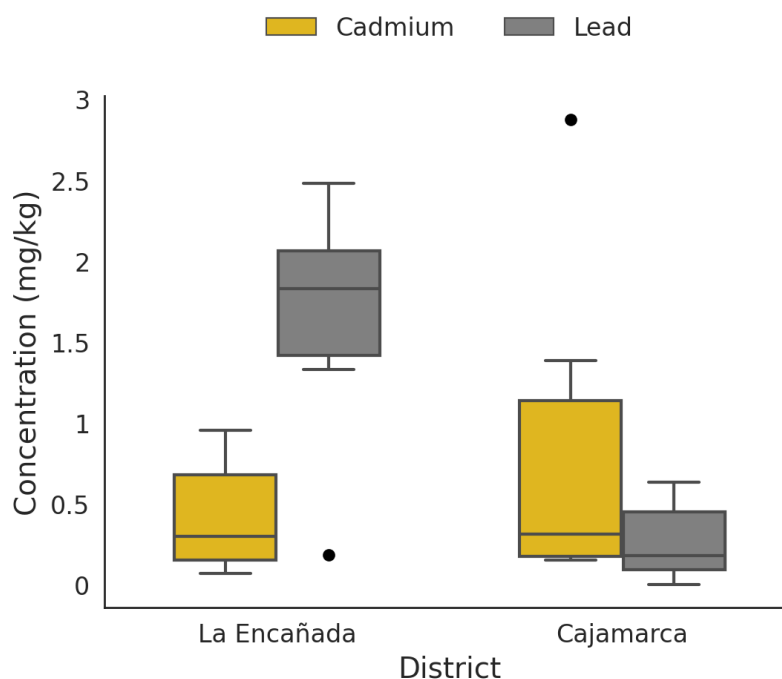


Figure 3. Concentration of cadmium and lead (mg/kg) in honey samples collected from two districts in Cajamarca, Peru.

No statistically significant differences were observed in Cd levels among the different localities ($p > 0.05$). In contrast, Pb concentrations were significantly higher in honey samples from La Encañada and its respective localities compared to those from the district of Cajamarca ($p < 0.05$) (**Table 1**).

Table 1. Comparisons of cadmium and lead concentrations (mg/kg) in honey collected from two districts in Cajamarca, Peru.

	District		Locality		
	Cd	Pb	Cd	Pb	
	Median	Mean \pm SD	Median	Mean \pm SD	
La Encañada	0.300 ^a	1.623 \pm 0.805 ^a	Combayo	<0.154 ^a	1.281 \pm 0.964 ^a
			Romeral	0.466 ^a	1.965 \pm 0.582 ^a
Cajamarca	0.315 ^a	0.267 \pm 0.257 ^b	Huambocancha	0.391 ^a	0.121 \pm 0.106 ^{ab}
			La Paccha	<0.154 ^a	0.412 \pm 0.300 ^{ab}

Different letters within the same column indicate statistically significant differences ($p < 0.05$). Cd was compared using the Mann–Whitney U test and Kruskal–Wallis test; Pb was compared using Student's t-test and one-way ANOVA with Tukey's post hoc test. **SD**: Standard deviation

In relation to the Maximum Permissible Limits (MPLs) established by MERCOSUR, the highest proportion of honey samples with non-permissible Cd concentrations was recorded in the district of Cajamarca, whereas the greatest number of samples exceeding the Pb limit was observed in the district of La Encañada (Table 2).

Table 2. Percentage (%) of honey samples collected in two districts of northern Peru with cadmium and lead concentrations (mg/kg) exceeding the Maximum Permissible Limits (MPLs) established by MERCOSUR*.

Heavy metals		District (% [95% CI])		Locality (% [95%CI])	
Cd	Pb	Cd	Pb	Cd	Pb
<0.154 ^{NP}	0.183 ^P				
0.953 ^{NP}	1.674 ^{NP}			Combayo (<i>n</i> = 3)	25.00 [5.49 – 57.19]
<0.154 ^{NP}	1.986 ^{NP}	La Encañada (<i>n</i> = 6)	41.67 [15.17 – 72.33]	41.67 [15.17 – 72.33]	
0.070 ^P	2.478 ^{NP}				
0.757 ^{NP}	1.332 ^{NP}			Romeral (<i>n</i> = 3)	16.67 [2.09 – 48.41]
0.446 ^{NP}	2.086 ^{NP}				25.00 [5.49 – 57.19]
1.385 ^{NP}	<0.001 ^P				
0.238 ^{NP}	0.201 ^P			Huambocancha (<i>n</i> = 3)	25.00 [5.49 – 57.19]
0.391 ^{NP}	0.16 ^P	Cajamarca (<i>n</i> = 6)	50.00 [21.09 – 78.91]	16.67 [2.09 – 48.41]	
<0.154 ^{NP}	0.632 ^{NP}				
<0.154 ^{NP}	0.070 ^P			La Paccha (<i>n</i> = 3)	25.00 [5.49 – 57.19]
2.875 ^{NP}	0.535 ^{NP}				16.67 [2.09 – 48.41]
Total	<i>n</i> = 12	91.67 [61.52 - 99.79]	58.33 [27.67 - 84.83]	Total	91.67 [61.52 - 99.79]
					58.33 [27.67 - 84.83]

CI: Confidence interval

NP: Non-permissible; **P**: Permissible

*MERCOSUR establishes a maximum permissible limit of 0.10 mg/kg for Cd and 0.30 mg/kg for Pb

The percentage increases in Cd and Pb concentrations relative to the Maximum Permissible Limits (MPLs) established by MERCOSUR were considerably high in most of the honey samples analyzed. Notably, one sample exceeded the MPL for Cd by more than 1,000%, while another surpassed 2,000% (Table 3).

Table 3. Percentage (%) increase in cadmium and lead concentrations (mg/kg) relative to MPLs in honey collected from two districts in Cajamarca, Peru.

Cd			Pb		
MERCOSUR	This study	Increase (%)	MERCOSUR	This study	Increase (%)
	<0.154	<54		0.183	-39
	0.953	853		1.674	458
	<0.154	<54		1.986	562
	0.070	-30		2.478	726
	0.757	657		1.332	344
	0.446	346		2.086	595.33
0.10	1.385	1,285	0.30	<0.001	-<99.67
	0.238	138		0.201	-33
	0.391	291		0.160	-46.67
	<0.154	<54		0.632	110.67
	<0.154	<54		0.070	-76.67
	2.875	2,775		0.535	78.33

DISCUSSION

Cadmium (Cd) and lead (Pb) concentrations in the analyzed honey samples ranged from 0.070 to 2.875 mg/kg and <0.001 to 2.478 mg/kg, respectively. The percentage increases relative to the Maximum Permissible Limits (MPLs) established by MERCOSUR (Cd: 0.10 mg/kg; Pb: 0.30 mg/kg) were notably high, classifying the majority of samples as unsuitable for regional trade. This situation is even more critical in the international context, as the Codex Alimentarius (GSCTFF CXS 193-1995) sets a Pb limit of 0.10 mg/kg. Although it does not specify a Cd limit for honey, it does for vegetables and leafy greens, set at 0.20 mg/kg.

The concentrations observed are partially consistent with international studies. For instance, in Turkey, Cd levels between 0.00 and 0.29 mg/kg and Pb levels between 0.00 and 3.03 mg/kg have been reported⁽⁹⁾. In an industrial region of Romania, ranges of 0.05–3.81 mg/kg for Cd and 0.76–3.41 mg/kg for Pb were found⁽¹⁰⁾. However, the values in this study exceed those from less impacted regions such as the United Kingdom, where Cd has been reported between <0.0003 and 0.3 mg/kg, and Pb between <0.002 and 0.2 mg/kg⁽⁸⁾. Nationally, Pb levels in Cajamarca were higher than those reported in Junín (0.003–0.09 mg/kg)⁽¹²⁾, and similar to those in Arequipa (0.68–2.74 mg/kg), a region with significant

mining activity⁽¹¹⁾. Variations could be attributed to differences in methodologies, environmental conditions, flora types, harvest seasons, or processing techniques.

Several environmental factors such as altitude, soil type, anthropogenic activity, and hydrological conditions can significantly influence heavy metal concentrations in honey^(3,4). In this study, Pb concentrations were higher in La Encañada than in Cajamarca, possibly due to more intense agricultural activity combined with formal and informal mining operations^(19,20). In this region, gold mining is prevalent, involving the use of cyanide, mercury, and lead in leaching processes. These elements can be released into the environment and transported via air, water, or soil, eventually contaminating the nectar and pollen collected by bees.

Although no significant differences in Cd levels were observed between districts, concentrations tended to be higher in the lower-altitude locality. This may be explained by runoff and deposition of contaminated sediments during the rainy season, which can carry pollutants from higher to lower elevations⁽²¹⁾. Additionally, this locality is traversed by a river that receives untreated domestic wastewater from the city of Cajamarca, posing another potential source of Cd contamination, as the metal may accumulate in soil and be absorbed by local vegetation.

Another likely source of contamination is the use of agrochemicals in dominant local crops such as potato, oca, and ulluco. These practices often involve phosphate fertilizers (a known source of Cd), organophosphate pesticides, glyphosate-based herbicides, and fungicides containing metallic compounds. Excessive or inappropriate use of such products, especially in the absence of technical oversight or environmental impact assessments, can lead to metal accumulation in soils and their subsequent uptake by bee forage plants.

It is also important to consider that honeybees forage over areas exceeding 7 km²⁽²²⁾, and in some cases up to 100 km²⁽²³⁾, significantly increasing their exposure to multiple contamination sources. Within this foraging range, the coexistence of agricultural, livestock, and mining activities may result in a complex mixture of environmental risks, which can amplify the presence of heavy metals in nectar, pollen, and, ultimately, honey.

Moreover, the honey extraction method may influence contamination levels depending on the materials used⁽¹⁴⁾. However, in this study, such risk was minimal, as contact with stainless steel from the centrifuge was limited, and honey was stored in plastic and glass containers, avoiding materials like lead that may leach contaminants.

Although Cajamarca is among the main beekeeping regions in Peru⁽¹⁶⁾, the findings of this study suggest that specific areas may be exposed to heavy metal contamination, posing risks to both apiculture and public health. This risk is particularly relevant in rural zones, where sanitary control is limited and honey consumption is frequent.

Dietary exposure to heavy metals such as Cd and Pb poses a substantial risk to human health due to their bioaccumulative nature and chronic toxicity. Long-term Cd intake has been linked to renal damage, bone disorders (e.g., Itai-Itai disease), and cardiovascular, respiratory, and muscular impairments⁽²⁴⁾. The established

Minimum Risk Level (MRL) for intermediate exposure (15–364 days) is 0.5 µg/kg/day, and for chronic exposure (≥1 year), it is 0.1 µg/kg/day ⁽²⁴⁾. Regarding Pb, its neurotoxic effects are particularly concerning in children and women of reproductive age, as it accumulates in the brain, liver, kidneys, and bones. The WHO states that no safe level of Pb exposure exists, and blood levels as low as 3.5 µg/dL can cause cognitive impairment, while levels ≥5 µg/dL in children are already considered harmful ⁽²⁵⁾. These findings underscore the importance of monitoring honey for heavy metal contamination to mitigate health risks.

A key limitation of this study was the relatively small sample size and the restriction to only two districts, which limits the generalizability of the findings. Moreover, no analysis was conducted on soil characteristics or chemical residues in locally used agrochemicals, making it difficult to establish direct causal links. Further studies are recommended, with broader spatial and temporal coverage, including variables such as dominant flowering types, residue analyses in soil and water, and interviews with local farmers and livestock producers regarding their use of agricultural inputs.

Finally, considering that some honey samples exhibited alarmingly high levels of heavy metals, controlled bioassays using model organisms are suggested to assess sublethal and cumulative toxicity. Such experimental approaches would provide a more objective evaluation of the potential health and environmental risks, supporting the need to implement environmental surveillance systems and quality control programs for apicultural products in vulnerable areas.

CONCLUSIONS

Honey samples collected from two districts in the province of Cajamarca exhibited Cd and Pb concentrations exceeding the limits recommended by international health authorities. Compared to the Maximum Permissible Limits (Cd: 0.10 mg/kg; Pb: 0.30 mg/kg) established by MERCOSUR, 91.67% of the samples exceeded the Cd limit, with increases of up to 2,775%. Similarly, 58.33% of the samples surpassed the Pb threshold, with increases reaching 726%.

This situation undermines food safety and poses a significant health risk to consumers, in addition to being incompatible with national and international trade standards. The findings may also reflect environmental contamination in the region, underscoring the need for competent authorities to implement integrated policies and measures to address this issue. Further studies and permanent monitoring programs are recommended for both honey and its consumers.

ACKNOWLEDGMENTS

The authors extend their sincere gratitude to the beekeepers who generously allowed the collection of honey samples from their hives.

FUNDING

Universidad Nacional de Cajamarca, Perú.

ETHICAL CONSIDERATIONS

The study was conducted in accordance with national ethical standards and was approved by the Faculty of Veterinary Sciences of the National University of Cajamarca, under Resolution N° 12-2024-FCV-UNC.

DECLARATION OF COMPETING INTEREST

The authors have declared no conflict of interest.

REFERENCES

1. Samarghandian S, Farkhondeh T, Samini F. Honey and health: a review of recent clinical research. *Pharmacogn Res.* 2017;9(2):121–7. doi: <https://doi.org/10.4103/0974-8490.204647>
2. Ćirić J, Đorđević V, Trbović D, Baltić T, Branković Lazić I, Matović K, et al. Risk assessment of toxic elements in Acacia honey. *Meat Technol.* 2020;61(1):70–4. <https://doi.org/10.18485/meattech.2020.61.1.6>
3. Fakhri Y, Abtahi M, Atamaleki A, Raoofi A, Atabati H, Asadi A, et al. The concentration of potentially toxic elements (PTEs) in honey: a global systematic review and meta-analysis and risk assessment. *Trends Food Sci Technol.* 2019;91:498–506. <https://doi.org/10.1016/j.tifs.2019.07.011>
4. Squadrone S, Brizio P, Stella C, Pederiva S, Brusa F, Mogliotti P, et al. Trace and rare earth elements in monofloral and multifloral honeys from Northwestern Italy: a first attempt of characterization by a multielemental profile. *J Trace Elem Med Biol.* 2020;61:126556. <https://doi.org/10.1016/j.jtemb.2020.126556>
5. Bora FD, Babeş AC, Călugăr A, Jitea MI, Hoble A, Filimon RV, et al. Unravelling heavy metal dynamics in soil and honey: a case study from Maramureş region, Romania. *Foods.* 2023;12(19):3577. <https://doi.org/10.3390/foods12193577>
6. Zarić NM, Ilijević K, Stanisavljević L, Gržetić I. Use of honeybees (*Apis mellifera* L.) as bioindicators for assessment and source appointment of metal pollution. *Environ Sci Pollut Res.* 2017;24(33):25828–38. <https://doi.org/10.1007/s11356-017-0196-7>
7. Cunningham MM, Tran L, McKee CG, Ortega Polo R, Newman T, Lansing L, et al. Honey bees as biomonitors of environmental contaminants, pathogens, and climate change. *Ecol Indic.* 2022;134:108457. <https://doi.org/10.1016/j.ecolind.2021.108457>
8. Jones KC. Honey as an indicator of heavy metal contamination. *Water Air Soil Pollut.* 1987;33(1–2):179–89. <https://doi.org/10.1007/BF00191386>
9. Altunatmaz SS, Tarhan D, Aksu F, Ozsobaci NP, Or ME, Barutçu UB. Levels of chromium, copper, iron, magnesium, manganese, selenium, zinc, cadmium, lead and aluminium of honey varieties produced in Turkey. *Food Sci Technol.* 2019;39(2):392–7. <https://doi.org/10.1590/fst.19718>
10. Bartha S, Taut I, Goji G, Vlad IA, Dinulică F. Heavy metal content in polyfloral honey and potential health risk: a case study of Copşa Mică, Romania. *Int J Environ Res Public Health.* 2020;17(5):1507. <https://doi.org/10.3390/ijerph17051507>
11. Cáceres IS. Determinación de los niveles de plomo en miel de abeja por voltamperometría y su aplicación como bioindicador de contaminación ambiental, Arequipa-2012 [thesis]. Arequipa: Universidad Católica de Santa María; 2014.

12. **Centeno MR.** Evaluación de metales pesados como diagnóstico de contaminación ambiental de la miel de *Apis mellifera* en el distrito de Hualhuas, departamento de Junín [thesis]. Huancayo: Universidad Alas Peruanas; 2019.
13. **Wu MYC, Hsu MY, Chen SJ, Hwang DK, Yen TH, Cheng CM.** Point-of-care detection devices for food safety monitoring: proactive disease prevention. *Trends Biotechnol.* 2017;35(4):288–300. <https://doi.org/10.1016/j.tibtech.2016.12.005>
14. **Šerevičienė V, Zigmontienė A, Paliulis D.** Heavy metals in honey collected from contaminated locations: a case of Lithuania. *Sustainability.* 2022;14(15):9196. <https://doi.org/10.3390/su14159196>
15. **Bergamo G, Seraglio SKT, Gonzaga LV, Fett R, Costa ACO.** Physicochemical characteristics of bracing honeydew honey and blossom honey produced in the state of Santa Catarina: an approach to honey differentiation. *Food Res Int.* 2019;116:745–54. <https://doi.org/10.1016/j.foodres.2018.09.007>
16. **Ministerio de Desarrollo Agrario y Riego (Midagri).** Más de 40 mil pequeños productores se dedican a la producción de miel [Internet]. Lima: Midagri; 2020 [cited 2024 Dec 8]. Available from: <https://www.gob.pe/institucion/midagri/noticias/295627-mas-de-40-mil-pequenos-productores-se-dedican-a-la-produccion-de-miel>
17. **SENAMHI.** Cajamarca [Internet]. Servicio Nacional de Meteorología e Hidrología del Perú; [cited 2025 Mar 26]. Available from: <https://www.senamhi.gob.pe/main.php?dp=cajamarca&p=estaciones>
18. **Colabucci A, Turco AC, Ciprotti M, Di Gregorio M, Sorbo A, Ciaralli L.** Analysis of cadmium and lead in honey: direct-determination by graphite furnace atomic absorption spectrometry. *Acta IMEKO.* 2016;5(1):10. https://doi.org/10.21014/acta_imeko.v5i1.288
19. **RCR.** Hay un avance de la actividad minera ilegal en Cajamarca [Internet]. Red de Comunicación Regional; 2024 [cited 2024 Dec 8]. Available from: <https://www.rcrperu.com/hay-un-avance-de-la-actividad-minera-ilegal-en-cajamarca/>
20. **Baca E.** Estudio sobre marco normativo minero en Perú [Internet]. 2014 [cited 2024 Dec 8]. Available from: <https://propuestaciudadana.org.pe/sites/default/files/publicaciones/archivos/Estudio%20EBaca.pdf>
21. **Zhu H, Wu C, Wang J, Zhang X.** The effect of simulated acid rain on the stabilization of cadmium in contaminated agricultural soils treated with stabilizing agents. *Environ Sci Pollut Res.* 2018;25(18):17499–508. <https://doi.org/10.1007/s11356-018-1929-y>
22. **Solayman Md, Islam MdA, Paul S, Ali Y, Khalil MdI, Alam N, et al.** Physicochemical properties, minerals, trace elements, and heavy metals in honey of different origins: a comprehensive review. *Compr Rev Food Sci Food Saf.* 2016;15(1):219–33. <https://doi.org/10.1111/1541-4337.12182>
23. **Zarić NM, Brodschneider R, Goessler W.** Honey bees as biomonitors – variability in the elemental composition of individual bees. *Environ Res.* 2022;204:112237. <https://doi.org/10.1016/j.envres.2021.112237>
24. **Faroon O, Ashizawa A, Wright S, Tucker P, Jenkins K, Ingerman L, et al.** Toxicological profile for cadmium. Atlanta: Agency for Toxic Substances and Disease Registry (US); 2012.
25. **WHO.** Recommendation on the blood lead concentration that should initiate clinical interventions. In: WHO guideline for clinical management of exposure to lead. Geneva: World Health Organization; 2021. p. 42.