Al-imad Journal of Humanities and Applied Sciences (AJHAS)
مجلة العماد للعلوم الإنسانية والتطبيقية
ISSN: 0000-0000
Volume 1 – Issue 1 – 2025
Pages 05-11

Review Study on the Concentration of Heavy Metals in Canned Tuna

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دراسة مرجعية عن المعادن الثقيلة في التونة المعلبة

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Received: 08-04-2025; Accepted: 23-06-2025; Published: 05-07-2025

Abstract:
Canned tuna is a popular seafood product consumed worldwide, but concerns have been raised about the potential contamination of heavy metals such as mercury, lead, and cadmium. This review aims to synthesize the current knowledge on the concentration of heavy metals in canned tuna, their sources, analytical methods used for detection, and the potential health implications for consumers. A comprehensive literature search was conducted, and studies from various regions were analyzed to provide a global perspective on the issue. The findings indicate that while some canned tuna products contain heavy metals within acceptable limits, there are instances where concentrations exceed regulatory standards, particularly for mercury. The review also highlights the need for continued monitoring and regulation to ensure the safety of canned tuna for human consumption.

Keywords: Canned Tuna, Mercury, Lead, Cadmium, Public Health.

الملخص
تُعدّ التونة المعلبة من المأكولات البحرية الشائعة الاستهلاك في أنحاء العالم المختلفة، إلا أن هناك مخاوف بشأن احتمال تلوثها بالمعادن الثقيلة كالزئبق والرصاص والكادميوم. تهدف هذه المراجعة إلى تجميع المعلومات المتوفرة حاليًا حول تركيز هذه المعادن في التونة المعلبة، ومصادرها، والطرق التحليلية المستخدمة للكشف عنها، والآثار الصحية المحتملة على المستهلكين. وقد أُجري بحث شامل في الأدبيات، وحُللت دراسات من مناطق مختلفة لتوفير منظور عالمي حول هذه القضية. وتشير النتائج إلى أنه على الرغم من احتواء بعض منتجات التونة المعلبة على معادن ثقيلة ضمن الحدود المقبولة، إلا أن هناك حالات تتجاوز فيها التركيزات المعايير التنظيمية، وخاصةً الزئبق. كما تُسلّط المراجعة الضوء على ضرورة مواصلة الرصد والتنظيم لضمان سلامة التونة المعلبة للاستهلاك البشري.

الكلمات المفتاحية: التونة المعلبة، الزئبق، الرصاص، الكادميوم، الصحة العامة.

Introduction

Canned tuna is a widely consumed seafood product due to its long shelf life, convenience, and nutritional value. It is a rich source of protein, omega-3 fatty acids, and essential vitamins and minerals (ÖZDEMİR et al., 2018; Taştan & Salem, 2021). However, concerns have been raised about the potential contamination of canned tuna with heavy metals, particularly mercury (Hg), lead (Pb), cadmium (Cd), and arsenic (As). These heavy metals are known to have adverse effects on human health, including neurological damage, kidney dysfunction, and developmental issues in children (Salem & Salem, 2023).Heavy metals can enter the food chain through various pathways, including industrial pollution, agricultural runoff, and natural geological processes. Once in the environment, these metals bioaccumulate in marine organisms, with predatory fish like tuna being particularly susceptible due to their position in the food chain (Amhamed et al., 2023; Elderwish et al., 2019; Lakwani & Salem, 2024; Mann, 1993). The consumption of contaminated canned tuna could, therefore, pose a significant health risk to consumers, especially vulnerable populations such as pregnant women, children, and the elderly (Salem & moftah Mohamed, 2025; Ulusoy, 2023).

This review aims to provide a comprehensive overview of the concentration of heavy metals in canned tuna, the sources of these contaminants, the analytical methods used for their detection, and the potential health implications for consumers. Additionally, it will discuss the regulatory standards and guidelines in place to monitor and control heavy metal contamination in canned tuna.

Sources of Heavy Metals in Canned Tuna

Natural Sources

Heavy metals are naturally present in the environment, and their concentrations can vary depending on geological and geographical factors. For instance, mercury exists in the environment in both organic and inorganic forms. Methylmercury (MeHg), the organic form, is the most toxic and bioaccumulative form of mercury, and it is commonly found in marine ecosystems (Al-Sulaiti et al., 2022; Salem & Moammer, 2024; Sönmez et al., 2012). Methylmercury is produced by microorganisms in the marine environment through the methylation of inorganic mercury (Hg^{2+}) Regnell. This process occurs primarily in anaerobic environments, such as sediments and the deep ocean, where sulfate-reducing bacteria are prevalent (Wang et al., 2022).

Tuna, being a predatory fish, accumulates methylmercury through the food chain. Smaller fish consume plankton and other organisms that have absorbed methylmercury from the water, and as larger predators consume these smaller fish, the concentration of methylmercury increases at each trophic level (Medieu, 2022; Peterson et al., 1973)). This process, known as biomagnification, results in higher concentrations of methylmercury in top predators like tuna.

Anthropogenic Sources

Human activities, such as industrial processes, mining, and the use of fertilizers and pesticides, have significantly increased the levels of heavy metals in the environment. For example, mercury is released into the atmosphere through the burning of fossil fuels, particularly coal, and through industrial processes such as gold mining (Bharti & Sharma, 2022; Charvát et al., 2020; Timothy & Williams, 2019). These anthropogenic sources contribute to the contamination of marine ecosystems and, subsequently, to the accumulation of heavy metals in tuna.

Lead and cadmium are also introduced into the environment through various human activities. Lead pollution stems from sources such as mining, smelting, and the use of leaded gasoline, while cadmium is released from industries such as battery manufacturing and metal smelting . These metals can enter marine ecosystems through atmospheric deposition, runoff from land, and wastewater discharge, leading to their accumulation in marine organisms, including tuna.

Analytical Methods for Heavy Metal Detection in Canned Tuna

The accurate determination of heavy metal concentrations in canned tuna is crucial for ensuring food safety and compliance with regulatory standards. Various analytical techniques have been developed and employed for this purpose, each with its own advantages and limitations.

Atomic Absorption Spectroscopy (AAS)

Atomic absorption spectroscopy (AAS) is a widely used technique for the determination of heavy metals in food samples, including canned tuna. AAS is based on the principle that atoms in the gaseous state absorb light at specific wavelengths corresponding to their electronic transitions. The sample is atomized, and the absorbance of the light at specific wavelengths is measured, which is then related to the concentration of the metal of interest.AAS is a sensitive and selective method for the determination of heavy metals such as mercury, lead, and cadmium in canned tuna. However, it requires sample preparation steps such as digestion to dissolve the metal compounds, and it can be time-consuming and labor-intensive (Welz & Sperling, 2008).

Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Inductively coupled plasma mass spectrometry (ICP-MS) is a more advanced and sensitive technique for the determination of heavy metals in food samples. ICP-MS involves the ionization of the sample in an inductively coupled plasma, followed by mass separation of the ions based on their mass-to-charge ratio (Ammann, 2007).This technique offers high sensitivity, wide dynamic range, and the ability to simultaneously detect multiple elements, making it suitable for the analysis of complex matrices such as canned tuna.ICP-MS is particularly useful for the detection of trace levels of heavy metals in canned tuna, and it is often used as a confirmatory method for samples that show elevated levels of contamination (İslamoğlu et al., 2021). However, the high cost of the instrumentation and the need for skilled operators are some of the limitations of this technique.

X-ray Fluorescence (XRF) Spectroscopy

X-ray fluorescence (XRF) spectroscopy is a non-destructive analytical technique that can be used for the rapid screening of heavy metals in canned tuna. In XRF, the sample is irradiated with X-rays, causing the emission of characteristic fluorescent X-rays from the elements present in the sample (Marguí et al., 2009, 2022).The energy of these emitted X-rays is characteristic of the elements, allowing for their identification and quantification.XRF is a fast and cost-effective method for the preliminary screening of heavy metals in canned tuna, but it may not be as sensitive as AAS or ICP-MS for the detection of trace levels of contamination (Taylor et al., 2020).

Concentration of Heavy Metals in Canned Tuna

Mercury

Mercury is one of the most concerning heavy metals in canned tuna due to its neurotoxic effects. Methylmercury, the organic form of mercury, is the most toxic and bioaccumulative form, and it is commonly found in marine organisms, including tuna (Al-Sulaiti et al., 2022) .The concentration of mercury in canned tuna varies depending on the species of tuna, the region of catch, and the fishing practices used. A study conducted by (González-Estecha et al., 2013) analyzed the mercury content in so-called light tuna from various brands available in Spain. The study found that the mercury concentration in canned light tuna ranged from 0.031 to 1.176 mg/kg.

The primary challenge in comparative analysis stems from the fact that many studies fail to differentiate between tuna species; instead, they report aggregate findings. The limited number of published studies distinguishing light tuna from other types have documented significantly lower mercury concentrations. For instance, Shim et al. (2004) reported mean concentrations of 0.183 mg/kg in light tuna packed in vegetable oil and 0.054 mg/kg in light tuna packed in water (Shim et al., 2004). Comparable results were obtained by other researchers, with mean values in light tuna of 0.137 mg/kg (Gerstenberger et al., 2010) and 0.118 mg/kg (Burger & Gochfeld, 2004). A recent study by Groth similarly found a mean concentration of 0.118 mg/kg across 48 light tuna samples from the US market. Groth's data further underscore significant variations based on country of origin: samples sourced from US fisheries exhibited the lowest mercury levels, while light tuna from Ecuador displayed the highest mean concentration; specimens from Thailand and the Philippines demonstrated intermediate levels (Groth, 2012) .Other investigators have likewise identified variations across ocean basins and nations, likely attributable to fishery source, specific species, and fish size. Consequently, geographical origin of the catch represents a critical determinant of mercury content (Burger & Gochfeld, 2005). However, this origin information, as utilized by commercial entities, remains inaccessible to consumers, thereby complicating spatial comparisons.

Lead

Lead is another heavy metal of concern in canned tuna, although its concentration is generally lower than that of mercury. Lead can contaminate tuna through various pathways, including contamination during fishing, processing, and canning (Khansari et al., 2005). The lead content in canned tuna is influenced by factors such as the type of can lining, the age of the can, and the storage conditions.

Eboh et al. detected lead (Pb) concentrations ranging from 0.001 to 0.002 mg/kg in muscle, gill, and liver tissues of five commercially significant fish species in Nigeria (*Clarias gariepinus, Oreochromis niloticus, Ilisha africana, Ethmalosa fimbriata, and Periophthalmus barbarus*), but reported no quantifiable toxic metal residues in salmon or mackerel species (Eboh et al., 2006). Conversely, mean cadmium (Cd) and lead (Pb) concentrations reported by Canli and Atli in muscle tissues of six species (*Sparus aurata, Atherina hepsetus, Mugil cephalus, Chelidonichthys lucerna, Sardina pilchardus, and Scomberesox saurus*) 0.37–0.79 mg/kg for Cd and 4.27–6.12 mg/kg for Pb (Canli & Atli, 2003).

Turkmen et al. quantified metal concentrations in muscle and liver tissues of 12 fish species from the Aegean and Mediterranean Seas, documenting muscle tissue ranges of <0.01–0.39 mg/kg for Cd, 0.18–2.78 mg/kg for Mn, 0.21–1.28 mg/kg for Pb, and 3.51–53.5 mg/kg for Zn (Türkmen et al., 2009).

Boadi et al. analyzed Pb, Zn, Fe, Cd, Mn, and Hg in 46 canned fish samples (nine brands) from Ghanaian markets. Trace metal concentrations were: Pb: 0.058–0.168 mg/kg ,Zn: 0.010–0.370 mg/kg ,Mn: 0.001–0.057 mg/kg.

Cd concentrations fell below the detection limit in all samples. Zinc levels were consistently below the FAO recommended limit (40 mg/kg (Boadi et al., 2011). Furthermore, U.S. EPA carcinogenicity risk assessment criteria indicated no health risks associated with the observed Pb levels in these canned fish products (Boadi et al., 2011). In tuna samples from the Arab Gulf, Cd concentrations ranged from 0.0046 to 0.0720 mg/kg (mean: 0.0223 mg/kg), while Pb levels ranged from 0.0162 to 0.0726 mg/kg (mean: 0.0366 mg/kg) (Khansari et al., 2005).

Cadmium

Cadmium is a toxic heavy metal that can accumulate in the kidneys and cause damage to the renal system (Salem et al., 2025).The cadmium content in canned tuna is generally lower than that of mercury and lead, but it can still pose a health risk if consumed in excessive amounts.

According to Eisler (2009), whole finfish generally contain cadmium (Cd) at concentrations of 0.1–0.3 mg kg^{-1} wet weight (ww), while muscle tissue typically contains <0.1 mg kg^{-1} ww. Liver tissue exhibits higher Cd accumulation, reaching up to 24.7 mg kg^{-1} ww. Elevated Cd in benthic sediments correlates directly with Cd bioavailability in prey species (Eisler, 2009).

Yellowfin tuna (*Thunnus albacares*) occupy a higher trophic position than skipjack (*Katsuwonus pelamis*) (Ruelas-Inzunza et al., 2014). Cd biomagnification in these predators' muscle tissue (yellowfin: 0.18 ± 0.15 mg kg^{-1} dry weight [dw]; skipjack: 0.23 ± 0.22 mg kg^{-1} dw) demonstrates significant dependence on trophic position (Ruelas-Inzunza et al., 2014). Muscle tissue of little tunny (*Euthynnus alletteratus*) and skipjack from Tema, Ghana, contained <0.1 mg kg^{-1} ww Cd. Comparatively, North Atlantic E. alletteratus exhibited 0.2 mg kg^{-1} dw Cd (estimated 0.25 mg kg^{-1} ww) (Windom et al., 1973).

In the Western Indian Ocean, mean Cd concentrations were 0.06 ± 0.05 mg kg^{-1} ww in yellowfin and 0.18 ± 0.11 mg kg^{-1} ww in skipjack from the Mozambique Channel and Réunion Island (Kojadinovic et al., 2007). Skipjack near Réunion Island showed elevated mean Cd (0.61 ± 0.37 mg kg^{-1} dw; estimated 0.75 mg kg^{-1} ww) (Kojadinovic et al., 2007). Conversely, skipjack from the Eastern Pacific Ocean off Baja California Peninsula had significantly lower Cd (0.055 mg kg^{-1} ww) (Ruelas-Inzunza et al., 2012) Australian yellowfin (New South Wales) averaged 0.04 mg kg^{-1} ww Cd in muscle (Bebbington et al., 1977), while Taiwanese specimens contained substantially less (0.02 mg kg^{-1} ww) . The lowest reported concentrations (0.004–0.006 mg kg^{-1} ww) occur in yellowfin from the Eastern Pacific and Atlantic Oceans (Besada et al., 2006; Ruelas-Inzunza et al., 2012).

Regulatory Standards and Guidelines

Regulatory agencies around the world have established standards and guidelines to monitor and control the levels of heavy metals in canned tuna. These standards are based on risk assessments that consider the potential health effects of heavy metal exposure and the estimated intake levels for different populations.

In the United States, the FDA sets limits for mercury in seafood products, including canned tuna, at 1.0 µg/g . The FDA also recommends that consumers, particularly vulnerable populations, follow the consumption guidelines to minimize mercury exposure.

In the European Union (EU), the maximum levels for mercury in fish and fishery products, including canned tuna, are set at 0.5 µg/g for methylmercury . The EU also sets maximum levels for lead (0.3 µg/g), cadmium (0.1 µg/g), and arsenic (1.0 µg/g) in fish and fishery products .

In China, the National Health Commission has established maximum limits for heavy metals in canned tuna, including mercury (0.5 µg/g), lead (0.3 µg/g), cadmium (0.1 µg/g), and arsenic (1.0 µg/g).

These regulatory standards are essential for ensuring the safety of canned tuna and protecting consumers from the potential health risks associated with heavy metal exposure. However, it is important to note that the regulatory limits may vary between countries, and not all countries may have established specific limits for heavy metals in canned tuna.

The review of the literature on heavy metal concentrations in canned tuna reveals that while many products comply with regulatory standards, there are instances where heavy metal levels exceed acceptable limits. Mercury is the most concerning heavy metal in canned tuna, particularly in albacore tuna, which has higher mercury levels than light tuna. The consumption of high-mercury fish, including certain types of canned tuna, is a significant source of mercury exposure for humans. The variability in heavy metal concentrations across different regions and brands of canned tuna suggests that factors such as fishing location, fishing practices, and processing methods play a role in determining the levels of contamination. For example, tuna caught in regions with higher levels of industrial pollution may have higher concentrations of heavy metals compared to those caught in less polluted areas.

The analytical methods used for the detection of heavy metals in canned tuna have evolved over time, with more sensitive and accurate techniques such as ICP-MS replacing traditional methods like AAS in many laboratories. However, the choice of analytical method can influence the results, and it is essential to use validated methods that are appropriate for the matrix and the level of contamination being measured. The public health implications of heavy metal exposure from canned tuna highlight the need for continued monitoring and regulation of heavy metal levels in food products. Regulatory agencies must ensure that canned tuna products meet the established safety standards and that consumers are informed about the potential risks associated with their consumption.

Conclusion

In conclusion, this review has provided an overview of the concentration of heavy metals in canned tuna, their sources, analytical methods for detection, and the potential health implications for consumers. While many canned tuna products are safe to consume, there are instances where heavy metal levels exceed regulatory standards, particularly for mercury. The review highlights the importance of continued monitoring, regulation, and consumer education to minimize the health risks associated with heavy metal exposure from canned tuna.

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