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Heavy metal contamination during processing of canned fish: a review on food health and food safety

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ABSTRACT

Fish in cans is more popular than ever because of its convenience, improved quality, less risk of contamination, and long shelf life. To preserve seafood products, the canning process uses a hermetic closure and thermal techniques. Tuna, salmon, mackerel, and herring are a few marine fish species that are widely used in canned goods. The canning procedure has significant shortcomings. Problems with canning include the transfer of hazardous metals from the cans into the food, incorrect canning, which can cause botulism, and chemical contamination. The biggest and most pervasive issue is the presence of heavy metals like Pb, Hg, Cd, Cu, and Zn in canned fish. These metals are exceedingly poisonous, persistent, and difficult to biodegrade even at low concentrations. Heavy metals significantly affect marine bioaccumulation, toxicity, and water contamination. Heavy metals build up in marine fish along the food chain as a result of growing industrial and agricultural environmental harm, and they are eventually absorbed by humans through canned foods. While Pb and Cd toxicity can result in renal, cardiovascular, and reproductive issues, heavy metal (Hg) toxicity can lead to eye impairment, vertigo, and a weakened immune system. So that consumers may learn more and make wise decisions about consuming canned fish, the main method by which heavy metal contamination in canned fish spreads could be identified in this review paper.

Keywords: Heavy metal, Canning, Fish, Food health, Food safety

1. Introduction

Fish is nutritious for humans because it serves as a dietary protein with low saturated fat. Due to being a major source of several nutritional elements including omega-3 and polyunsaturated fatty acids, vitamins and essential minerals, fish is now widely consumed around the world [1]. Because of its' perishable quality, fish products with maximum durability is given utmost consideration during processing and preservation. One of the modern techniques of processing is 'Canning' which involves a hermetically sealing method with thermal processes that aims to preserve fishery products [2]. Furthermore, the shift in consumer behavior and adoption of healthier dietary habits following the pandemic has led to a rise in the worldwide popularity of canned fish products [3].

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Typically, the cans are crafted from tin or steel and are externally coated with white tin. Within this process, the canned fish undergo heating at sterilization temperatures, usually ranging from approximately 110°C–120°C, with the purpose of eradicating or hindering the proliferation of microorganisms [4]. A variety of marine fish species, including tuna, salmon, mackerel, and herring, are frequently employed in the production of canned fish products. In Italy, approximately 2.5 kg of canned tuna-related items are consumed annually [5].

The consumption of canned fish products is notably prevalent in countries like the USA, Portugal, Libya, Iran, and Turkey [6,7]. The concept underlying fish canning is centered on the notion that treated fish products will exhibit improved quality, reduced contamination, an extended shelf life, and enhanced convenience for the ultimate consumers.

Challenges associated with canning encompass the transfer of harmful metals from the containers into the food, improper canning techniques (Table 1) that may result in botulism, and the potential for chemical contamination arising from the production of Bisphenol A (BPA), posing a threat to human well-being [8]. Canned fish products frequently contain significant amounts of toxic heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), copper (Cu), zinc (Zn), and others. This stands as a major and prevalent issue. These metals possess high levels of toxicity, remain persistent over time, and prove resistant to natural degradation, even when present in minimal concentrations [9].

Heavy metals have a significant impact in water pollution, toxicity, and bioaccumulation in marine organisms [4]. Due to the rapid industrial and agricultural environmental destruction, heavy metals accumulate in marine fish along the food chain and are ultimately ingested as canned goods by humans [6]. Fish organs accumulate heavy metals to varying degrees, with the largest levels seen in the kidney, liver, and gills, while fish muscle poses the greatest risk as a food source. Although the levels of heavy metal contamination vary on a number of variables, such as exposure to toxins in the water and eating patterns, sex, age, fish species, etc., the contamination levels in fish are often high [10]. One of the most serious chemicals risks associated with the fishing industry is the presence of Hg, Cd and Pb in fish products [11]. Cancer, neurological and skeletal illnesses, anemia, bronchitis, and Alzheimer's disease may result from the ingestion of marine foods contaminated with heavy metals [12]. Heavy metals (Hg) toxicity can result in decreased vision, vertigo, and a weakened immune system, whilst Pb and Cd toxicity can result in renal, cardiovascular, and reproductive issues [13]. In addition, methyl mercury damages the neurological system of the fetus when exposed to pregnant women through canned fish products [11]. Cr at high tissue concentrations has also been associated with lung cancer in humans [6]. Owing to the exposure of humans to heavy metals through the consumption of canned fish products, it is crucial to address the public in order to minimize and manage the contamination level in fish products [11]. An attempt was made to assess the exposure to heavy metals during processing of canned foods.

2. Heavy metals

Metals or metalloids that possess an atomic number greater than 20 and an atomic density of above 5 g/cm^3 are called heavy metals or trace metals [14]. These metals maintain a variety of biochemical and physiological processes in living things at very low concentrations, but when their concentrations exceed a certain level, they become toxic [15]. Because of their persistent behavior and propensity to bioaccumulate in the food chain, these elements pose a serious threat to the aquatic environment [16]. Due to not being able to deteriorate or decompose over time because of their persistent nature, heavy metals become toxic at concentrations higher than allowed [17]. Heavy metals are the most harmful toxic pollutants in the aquatic environment. Additionally, these substances are less mobile in water columns. They tend to precipitate on the waterbody's sediment column as a result of their continuous accumulation in natural water systems, where they can interact with the food-chain system [13]. However, these metals adversely affect the surrounding environment and living organisms.

3. Eco-biological risks

An integrated system that provides insightful information on ecological effects of pollution in the environment is known as ecological risk index [18]. In order to evaluate the effects of one or more elements on the ecology of a specific study area, the potential ecological risk (PER) concept is introduced. The approach considers the risk index (RI), which reflects the sensitivity and toxicity response of biological communities [19]. Aside from the ingestion of contaminated water and/or aquatic organisms, the harmful heavy metals can enter the body through dermal contact with contaminated water as well. Toxic heavy metals may cause mild (irritation) or severe health effects (teratogenic, mutagenic and carcinogenic). Physical, muscular, skeletal, and neurological disorders can result from exposure to these toxic metals. However, prolonged exposure can also result in fatal conditions like cancer, Parkinson's and Alzheimer's disease, and multiple sclerosis [20]. Moreover, these redox active metal ions have also been linked to promoting oxidative damage, which can cause chronic inflammatory disease [21].

3.1. Perceptions of canned products

The principle of canning includes packaging of a food in a container with the application of thermal process for the purpose of extending its useful life. An optimal thermal process will destroy any pathogenic or disease-causing bacteria as well as kill or control spoilage organisms present in the food particles, and have minimal effect on the nutritional and physiological qualities of the food [22]. Although we think of canning in terms of steel or possibly aluminum cans, the principles apply equally well to a variety of food containers such as glass jars, plastic and foil-laminated pouches, semi-rigid plastic trays or bowls, as well as metal cans of any one of several shapes, including cylindrical, oval, oblong, or rectangular. The concept of aseptic packaging (sterilizing

Table 1
Heavy metal contamination in canned fish products

Study area	Fish products	Analytical method	Heavy metals	Salient findings	References
Iran	Tuna	AAS	Pb, Cd, Sn, Hg	Value for Sn, Hg, Pb, Cd were 0.0096, 0.185, 0.0099 and 0.0021, respectively	[43]
Tijuana, Mexico	Tuna	GFAAS	Hg, Pb, Cd, Cr	Hg level 0.005–1.17 mg/kg, Pb level 0.07–0.32 mg/kg, Cd level (ND) - 0.007 mg/kg, and for Cr 0.02–0.65 mg/kg	[11]
Iran	Tuna, kilka	ICP-OES and DMA	Cd, Hg, Pb, Se, Sn, Zn	Contents of Cd, Hg, Pb, Se, Sn and Zn (lg/g) in canned samples were 0.10 ± 0.04, 0.13 ± 0.05, 0.75 ± 0.65, 2.04 ± 0.43, 0.18 ± 0.03 and 12.61 ± 11.92, respectively	[6]
India	Tuna	ICP-MS Elan-DRC-e	Pb, Cd, Hg	Among tested metals, Hg had the highest concentrations, followed by Cd and Pb. None of the tested samples surpassed the European Regulatory Limits	[44]
Iran	Tuna	AAS	Pb, Zn, Cd, Mn	Pb, Zn, Mn and Cd value were 0.01, 0.5, 0.01 and 0.01 mg/kg	[45]
Tehran, Iran	Tuna	AAS	Ar, Pb, Cd	Ar-0.25, Pb-0.053 and Cd-0.013 mg/kg	[13]
Iran	Tuna	AAS	Cr	Cr value for brands A, B, C and D were 2.57, 3.24, 3.16 and 1.65 μg/g, respectively	[6]
Italy, Spain	Tuna	AAS	Hg, Pb, Cd	Highest concentration detected was by Pb followed by Hg and Cd	[11]
Canada, India	Tuna	Inductively coupled plasma-optical emission spectrometer (ICP-OES)	Al, Cd, Pb, Hg	Al (1.806 to 3.161 μg/g), Hg (0.60 to 0.62 μg/g), Cd and Pb ranged from 0.020 to 0.025 and 0.011 to 0.089 μg/g, respectively	[46]
Turkey	Canned bonito, sardines, and mackerel	ICP-MS	Iron, Zn, Cu, Hg, Pb, Sn, Fe, Cd	Minimum and maximum concentrations of trace metals were found in canned bonito, sardines and mackerel	[47]
Korea	Mackerel, tuna, pomfret, salmon, cod, walleye pollock, woo luck	ICP-MS	Hg, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn	Cu > Zn > As > Mn > Cr > Cd > Fe > Pb > Hg	[48]
Italy	Tuna	AAS & GFAAS	Hg, Cd, Pb	Hg > Pb > Cd	[48]
Taif Market, KSA	Sardine, tuna and salmon	AAS	Al, Se, Zn	Comparative evaluation of heavy metal concentrations of the examined caned were-Al > Se > Zn	[49]
Persia, Iran	Tuna	AOAC	Pb, Cd, Sn, Hg, Ar	Hg, Ar and Cd value in canned tuna were 0.117, 0.0046 and 0.0223, respectively	[50]

the food and the container prior to filling and sealing) also follows the same principles [23].

3.2. Consequences of canned fish

One of the major sources of animal protein comes from fish. Therefore, efforts are needed to improve the quality and storage of fishery products through processing and preservation, which also aims to diversify processed products so that the use of fish as a source of protein is maximal. Packaging can prevent or reduce damage, protecting the materials in it from contamination well as physical disturbances such as friction, impact, and vibration [24]. Packaging is also one way to inhibit environmental water vapor absorbed by dry food products. It can extend shelf life and maintain the material quality for longer. The use of packaging is one way to minimize the damage to foodstuffs after production [25]. Canning is one of the modern forms of processing that is hermetically packaged through thermal processes which aims to preserving and diversifying fishery processed products [26]. Cans are sheets of steel covered by tin (Sn) or some containers made of steel and coated with a thin white tin with a content of no more than 1.00%–1.25% of the weight of the can. Meanwhile, steel is the main alloy metal or alloy maker. The main advantage of canned packaging is that the sterilization process can be done so that the food it stores becomes sterile, not easily damaged and durable. Other advantages of packaging fish in can include practical for consumers in cooking, can be stored longer and can minimize contamination (Table 1) from the outside such as bacteria, but in its use need to be wary because in canned food there can be heavy metal contamination from the packer [27].

4. Sources of heavy metal in canned fish

5. Aquatic environmental pollution

Pollution in seawater comes from both natural and artificial sources that lead to the direct or indirect release of harmful substances into the aquatic environment which consequently affects the human health. Some heavy metals such as lead (Pb), cadmium (Cd), and particularly mercury (Hg) as well as persistent organic compounds including polychlorinated biphenyls and dioxins, can cause problems for consumers due to their bioaccumulation and biomagnification in marine organisms through the food chain [28]. The maximum levels of bioaccumulation are found in predatory fish species at the highest trophic levels, such as tuna and swordfish [29,30]. In case of such species, the age and size of the animal is related to the accumulation of contaminants, particularly Hg [29,31,32]. Heavy metal pollution has dreadful effects on the environmental equilibrium and a variety of aquatic entities [33,34]. Heavy metals in fish come mainly from their diet, and levels of bioaccumulation of contaminants are higher in fish which comes higher in food chain [35]. Five heavy metals, that is, zinc, nickel, cadmium, lead and chromium has been determined from fishes, sediments and water [36]. Heavy metals concentrate in water and entered into the food chain. The patterns of bioaccumulation of heavy metals are determined by the absorbance and excretion rates of fish. Different factors such as physical and chemical properties of water as well as seasonal changes are the reason of significant augmentation of metals in different fish tissues [37,38]. Metal residual problems in the fish epithelium are stern, because of the presence of higher metal concentrations in water and sediments [39]. On the contrary, heavy metals are of serious concern in this respect because they can be easily elevated in the food chain due to their bioaccumulation processes [40]. Fish may be contaminated by toxic elements during growth, transportation, and storage.

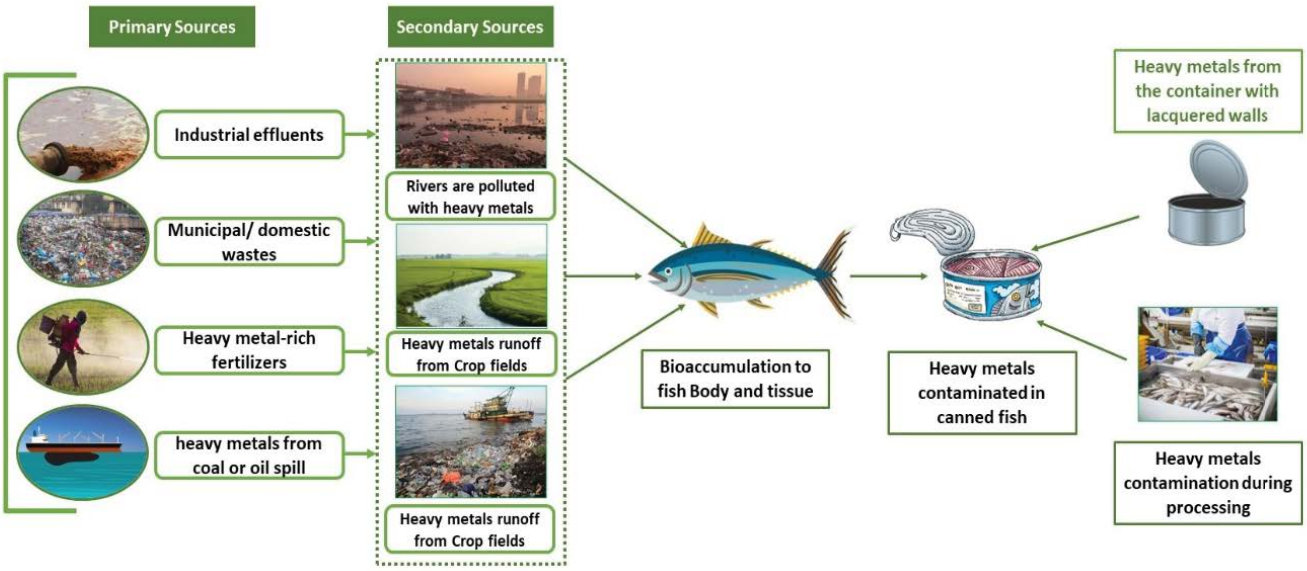

Fig. 1. Transmission route for heavy metal contamination in canned fish (Source: Field survey during this review, 2022).

Contamination may also occur during the production handling and canning process. Lead poisoning is generally ranked as the most common environmental health hazard [41]. Apart from the threat of a polluted environment, canned fish is subjected to lead contamination during the canning process (Fig. 1). The solder used in the manufacture of cans has been recognized as a source of lead contamination during canning (MAFF, 1995). Cadmium may also enter into the atmosphere from zinc, lead or copper smelter [42]. It can enter into the fresh water by disposal of industrial and household waste. Fertilizers often contain some cadmium. Reproduction rate of aquatic organisms may also be affected due to Exposure to heavy metals and can lead to a gradual extinction of their generations in polluted waters [43].

One of the most serious chemical risks to food safety in the fishing industry the presence of Pb, Cd, and Hg in fish products. Issues such as the gradual increase of pollution in the oceans, the globalization of markets in terms of production of raw materials and location of processing plants, and the increasing sensitivity of consumers to food safety make heavy metal pollution a critical factor for development and competitiveness in the fish industry. Even though contamination can be derived from natural geological sources, human activities can also contaminate the environment with metals.

The presence of Pb, Cd, and Hg in fish products is one of the most important chemical threats to food safety in the fishing business [51]. Heavy metal pollution is a crucial issue for the growth and competitiveness of the fish industry due to factors like the gradually rising ocean pollution, the globalization of markets in terms of the production of raw materials and the location of processing plants, and the growing sensitivity of consumers to food safety. Even though pollution might come from natural geological sources, human activities can also introduce metals into the environment [52,53].

The accumulation of heavy metals in fish is influenced by species-specific attributes, developmental stages, psychological factors, and fish age [54]. Fish serve as significant carriers of arsenic and mercury, primarily due to their efficient uptake mechanisms. Human exposure to these elements often stems from consuming fish [55]. Industries like detergent, textile, and cosmetics, located near rivers, release wastewater with elevated heavy metal concentrations. Such contamination can disrupt the natural equilibrium of river ecosystems when present in excessive amounts [56].

The scheme of the accumulation of heavy metals in the liver and gills were found maximum for Cd and Pb, respectively. Similarly, for flesh tissues, the maximum concentration of Pb and Cd was found. Among all heavy metals, the bioaccumulation of lead and cadmium proportions was extensively ugmented in tissues of *Cyprinus carpio* [40].

Heavy metals entre in fish bodies by three possible ways: by gills, by digestive track and body surface. The gills are considered as the significant site for direct uptake of metals from the water [38,40] though the body surface is normally estimated to take a minor part in the uptake of heavy metals in fish [57]. Heavy metal accumulation can also be caused by the food source, possibly leading to bio-magnification, the augmentation of toxins up the food chain [58]. The largest source of cadmium release to the environment is known to be the burning of fossil fuels and municipal waste (such as coal or oil) [59].

The level of contaminants in fish is influenced by the duration of exposure of fish to contaminants in water, feeding habits of fish, concentrations of contaminants in the water column, water chemistry, [59] contamination of fish during handling and processing, quality of canned fish, and shelf life of canned fish. However, excessive levels of tin can pose health risks. Accurate measurement helps ensure that canned fish products do not contain excessive tin that could be harmful to consumers' health [8,60].

A high tin content indicates migration of tin from the container to food, especially due to poor lacquering [61,62]. Because of the observed low Sn values, it might be concluded that there was no migration of Sn from can to the fish. This is the result of new packaging technologies, especially the use of cans with lacquered walls and a mechanical seam [50]. Since various types of fish are found to be contaminated with lead, the monitoring of lead concentration in canned fish is of great importance and solder is a source of contamination of food caused by lead used in the manufacture of cans [48].

6. Contaminated process canned products

Even though modern food technologies tend to minimize this risk, technological processes and/or the materials may increase the metal content in food [13]. The food industry trend is to adopt safer technologies, such as cans with lacquered walls and electric welding rather than Pb soldering of metal containers. However, the use of lead-based solder for cans is currently not prohibited, and in developing countries, this risk to human health should not be disregarded [11]. Lead poisoning is generally ranked as the most common environmental health hazard [41]. Apart from threat from polluted environment, canned fish is subjected to lead contamination during canning process. Solder used in manufacture of cans has been recognized as a source of lead contamination during canning [63]. The pH of the canned product, the quality of the lacquer coatings of canned products, oxygen concentration in the headspace, the quality of coating, and storage place may also control metal levels in canned fishes [64]. For some xenobiotics, such as Pb, fish can become contaminated both from marine pollution and during processing.

7. Raw materials

The raw materials for canning are usually not of good quality and the sterilization processes normally used in the canning industry may be insufficient to eliminate the microbiological contamination present at the time of processing [65]. The level of tuna meat contamination is influenced by the environment, conditions and methods of fishing, time of year, handling, processing and evisceration, but particularly by the handling on board and delayed cooling of fish during storage and transfer at markets and processing plants [66].

8. Fish processing environment

Due to the pollution of the environment in which the fish live (geographic region) as well as the duration of exposure

to toxic agent and their diet, toxic metals are found in fin fish meat [67]. Using contaminated water may be a probable source of contamination. In addition, the material from which the can was made could be another contamination source. Although to prevent metals from penetrating into the contents of the can, a special varnish coat is often used inside the can [64]. The level of Pb in the meat of canned fish compared to fresh ones only differs to a slight degree [57]. On the other hand, 30 types of food that the content of toxic metals in canned food was significantly higher than in the respective fresh food [68]. In recent years, scientists from around the world are giving their attention to the problems of environmental contamination, particularly food contamination by chemical pollutants including potential toxic elements [69–71]. When exposed in the environment, trace elements from various sources, particularly processed canned foods, pose a serious threat due to their toxicity and bioaccumulation in the food chain [19].

9. Cross contamination with processing equipment

It seems that the use of poor-quality fish as raw material for canning and/or defective handling techniques of fish during processing are the main reasons for high percentage of unacceptable canned tuna samples [47]. It has been well established that histamine production is associated with the growth of bacteria that possess the enzyme histidine decarboxylase. In fish, several histamine-producing bacteria has been implicated as primary contributors to histamine formation [1].

10. Conclusion

Heavy metal contamination during the processing of canned fish is a serious issue that can pose health risks to consumers, presence of heavy metals can lead to adverse health effects, including neurological, reproductive, and developmental disorders. To minimize the risk of heavy metal contamination, it is crucial to implement strict regulations and monitoring programs to ensure that canned fish products meet safety standards. Here are some strategies and measures ensuring food safety and environmental sustainability that can be implemented to address these issues: Implement rigorous quality control actions at every stage of the production process, from tracing raw materials to packaging the final product; Regular testing for contaminants such as heavy metals, pesticides, pathogens, and other harmful constituents should be conducted to ensure that the canned fish products meet safety standards; Work closely with right-hand suppliers who adhere to sustainable and responsible fishing practices; Regularly monitor and assess their ecological and quality standards to ensure that the raw materials used for canned fish products are safe and free from pollutants; Support and promote sustainable fishing practices that diminish environmental impact; Encourage traders to use methods that avoid overfishing, bycatch, and habitation destruction for healthy marine ecosystems and reduces pollution; Implement effective waste management systems within the production facilities to minimize pollution; Recycle or properly dispose of materials such as cans, packaging, and other waste products to prevent contamination of the environment; Properly treat and manage wastewater generated during the production process to prevent contamination of water bodies; Optimize energy consumption and reduce the carbon footprint of the production process; Educate consumers about the importance of sustainable seafood consumption and the role they play in supporting responsible fishing practices; Raise awareness about the potential risks of contamination and pollution associated with canned fish products; Stay up-to-date with relevant food safety regulations and environmental laws; Establish traceability systems that track the journey of the fish from catch to can; Collaborate with industry organizations, governmental agencies, and certification bodies to promote sustainable and safe practices; By implementing these strategies, the canned fish industry can mitigate contamination and pollution risks, ensuring the safety of their products and contributing to a healthier environment. Overall, the prevention and control of heavy metal contamination in canned fish are critical to safeguarding public health and maintaining consumer confidence in the safety and quality of canned fish products.

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