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MINI REVIEW

Heavy metal levels in fish products in Indonesia: a survey

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Abstract

Indonesia is the biggest archipelago in the world with large water areas. Indonesia produces and consumes a high amount of fishery products. However, there is a heightened risk of heavy metal contaminants in those products as heavy metals are accumulated along the aquatic food chain. In this review, the concentration of heavy metals, mainly arsenic, cadmium, mercury, and lead, in fish and fish products acquired in Indonesia were discussed. Those heavy metals are toxic at low levels and their concentrations in fish and fish products are regulated by the National Agency of Drug and Food. In some polluted areas, such as Ciliwung River (Jakarta and West Java), Donan River (Central Java), and Jakarta Bay, the content of heavy metals in fish were above the permitted threshold. Surveillance of the heavy metal concentrations in fish and fish products by the National Agency of Drug and Food has been implemented but a more frequent and thorough inspection is needed. Moreover, fishing should be discouraged in highly polluted areas by the local government to avoid the consumption of contaminated aquatic animal products.

1. Introduction

Fish is one of the popular sources of protein that is widely consumed in the world. Fish contains essential nutrients that are needed by the human body. Based on the data from the Ministry of Marine Affairs and Fisheries (MMAF), Republic of Indonesia, Indonesia consumed approximately 56.39 kg of fish per person per year in 2020. The total fisheries captured nationally were almost 8 million tons in 2020. By that figure, Indonesia is one of the biggest aquacultures producing countries and ranks fourth in the world. The fisheries are dominated by small-scale freshwater farms, accounting for more than 2 million farmers (Takarina *et al*., 2021). Recent studies indicated that the marine biota was contaminated with heavy metals along the food chain (Khairuddin and Yamin, 2021). Some heavy metals, present in small amounts, are essential for homeostasis in organisms. The presence of increased amounts of heavy metals, albeit their essentiality, is toxic for organisms. Other heavy metals are not essential for the human body and are inherently toxic. Presence of heavy metal pollutants can be accumulated in marine biota with various amounts of absorption and accumulation in different biological systems and body organs. The concentration of heavy metals is higher in the body of fish which sits further in the food chain (Riani *et al*., 2018).

In recent years, heavy metal contamination in the environment increases globally and it gives a threat to human health. The industrialization acceleration has increased the heavy metal emissions from anthropogenic activities, and as a consequence, a series of incidents related to heavy metal pollution occurred such as mercury pollution inducing Minamata disease, cadmium pollution which caused Itai-Itai disease, and poisoning induced by lead and arsenic. In Indonesia, heavy metal pollution due to gold mine operation and closure in

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Buyat Bay, North Sulawesi, severely impacted the health and environment of the local area that more than 50% of the nearby waterfront community left the village (Bentley and Soebandrio, 2017). Empirical research revealed that some heavy metals are carcinogens. Additionally, heavy metals could be associated with numerous diseases including cardiovascular, kidney, nervous system, and bone diseases. The levels of heavy metals of copper (Cu), chromium (Cr), cadmium (Cd), mercury (Hg), lead (Pb) and arsenic (As) had been widely studied in marine biotas such as fishes, crabs, and shrimps (Han *et al*., 2020).

The maximum permitted level of heavy metals in fish and fish products in Indonesia is regulated by the National Agency of Drug and Food Control [Badan Pengawas Obat dan Makanan (BPOM)] and the National Standardization Agency of Indonesia [Badan Standardisasi Nasional (BSN)]. The regulation by BSN is issued as the Indonesian National Standard [Standard Nasional Indonesia (SNI)]. BPOM and SNI regulation set a limit on heavy metal concentrations of As, Cd, Hg and Pb in different fish and fish products, while FAO-WHO only determines the maximum permitted level of Cd, Hg, and Pb (Table 1). Some of the maximum limits of the heavy metals differ between the two regulations, with regulation from BPOM being stricter. In this review, publications about heavy metal levels in fish and fish products from Indonesia, written in English or Indonesian, were reviewed. The analytical techniques

Table 1. Maximum permissible level of heavy metals in fish and fish products.

Element	Products	Maximum level	Regulation
As	Fish and fish products (including molluscs, crustaceans, Echinodermata, amphibia, and reptiles)	0.25 mg/kg	BPOM (Number 5 Year 2018)
	Fish and fish products (including molluscs, crustaceans, Echinodermata, amphibia, and reptiles)	1.0 mg/kg	SNI 7387:2009
Cd	Fish and fish products (including molluscs, crustaceans, Echinodermata, amphibia, and reptiles), except for predatory fish	0.10 mg/kg	BPOM (Number 5 Year 2018)
	Fish and fish products	0.1 mg/kg	SNI 7387:2009
	Predatory fish (such as tuna, milk shark, marlin, etc.)	0.5 mg/kg	SNI 7387:2009
	Predatory fish (such as tuna, milk shark, marlin, etc.)	0.3 mg/kg	BPOM (Number 5 Year 2018)
	Bivalve molluscs and sea cucumber	1.0 mg/kg	SNI 7387:2009
	Marine bivalve molluscs	2.0 mg/kg	Codex Standard 193-1995
	Shrimp and other crustaceans	1.0 mg/kg	SNI 7387:2009
Hg	Fish and fish products including molluscs, crustaceans, Echinodermata, amphibia, and reptiles), except for predatory fish	0.50 mg/kg	BPOM (Number 5 Year 2018)
	Fish and fish products	0.5 mg/kg	SNI 7387:2009
	Fish	0.5 mg/kg (as methyl-Hg)	Codex Standard 193-1995
	Predatory fish (such as tuna, milk shark, marlin, etc.)	1.0 mg/kg	SNI 7387:2009; BPOM (Number 5 Year 2018)
	Predatory fish	2.0 mg/kg (as methyl-Hg)	Codex Standard 193-1995
	Bivalve molluscs and sea cucumber	1.0 mg/kg	SNI 7387:2009
	Shrimp and other crustaceans	1.0 mg/kg	SNI 7387:2009
Pb	Fish and fish products (including molluscs, crustaceans, Echinodermata, amphibia, and reptiles), except for predatory fish	0.2 mg/kg	BPOM (Number 5 Year 2018)
	Fish and fish products	0.3 mg/kg	SNI 7387:2009
	Fish	0.3 mg/kg	Codex Standard 193-1995
	Predatory fish (such as tuna, milk shark, marlin)	0.4 mg/kg	SNI 7387:2009; BPOM (Number 5 Year 2018)
	Bivalve molluscs and sea cucumber	1.5 mg/kg	SNI 7387:2009
	Shrimp and other crustaceans)	0.5 mg/kg	SNI 7387:2009
	Shrimp paste	1.0 mg/kg	SNI 7387:2009

SNI: Standar Nasional Indonesia (Indonesian National Standard), BPOM: Badan Pengawas Obat dan Makanan (the National Agency of Drug and Food Control Inodonesia).
Source: BSN (2009), BPOM (2018), FAO, WHO (1995).

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Table 2. Concentration of heavy metals in fish and fish products in Indonesia. The ranges presented here were compiled from several types of samples or products, or from several sampling sites whenever available.

Food products	Locations	Level of heavy metals in mg/kg (methods)										References
		Cd	Cu	Zn	Pb	Hg	Fe	Cr	As	Sn	Ni	
Fishes	Blanakan River estuary, West Java	0.845-2.230[a]	nd-18.640[a]	21.54–105.52[a]								Takarina *et al.* (2021)*
Tuna, marlin, green mussels	Jakarta fishing port, aquaculture site in Jakarta Bay					0.56-1.51[c]			2.71 - 6.77[c]			Koesmawati and Arifin (2015)*
Fishes	Ponds and estuaries in coastal areas of northern Central Java	nd[a]	0.25-1.88[a]	3.70-40.11[a]	nd-0.14[a]	nd-0.12[a]			nd[a]			Suyanto *et al.* (2010)
Fishes	Gresik coastal waters, East Java	nd-0.0013[d]	0.039-1.166[d]	0.435-2.437[d]	0.021-0.047[d]			0.002-0.056[d]	0.003-0.084[d]	nd-0.026[d]	0.004-0.012[d]	Soegianto *et al.* (2012)*
Amazon sailfin catfish (*Pterygoplichthys pardalis*)	Ciliwung river, West Java and Jakarta	0.075-0.828[a]			1.609-5.467[a]	2.826-4.333[a]						Aksari *et al.* (2015)
Milk fish (*Channos channos*)	Ponds in Ujung Pangkah, Gresik, East Java		0.891 - 3.088 (muscle) 56.64-322.94 (liver)[a]									Sari *et al.* (2016)
Reef fishes	Krakatau islands, West Java	0.07-0.21[d]		4.31-10.53[d]	0.12-1.94[d]		1.743-23.27[d]	0.007-0.472[d]			0.20-1.06[d]	Muwarni (2019)
Carp, Nile tilapia, and striped catfish	Cirata Dam, West Java	nd[a]	7.40-14.78[a]		2.03-3.97[a]	nd[a]						Junianto *et al.* (2017)
Seluang (*Rasbora* sp.) and belanak (*Mugil chepalus*)	Musi River estuary, South Sumatra		0.27-8.42[a]		0.16-1.00[a]							Eka Putri *et al.* (2016)*
Freshwater fishes	Payau River, Kutai Kartanegara, East Kalimantan	<0.002[a]	2.63-2.93[a]	60.23-65.55[a]	<0.003[a]							Hidayat *et al.* (2020)
Freshwater and saltwater fishes	Bantul market, Yogyakarta					0.315-0.323[b]						Suratno *et al.* (2017)
Whiting fish (*Sillago sihama*)	Donan River estuary, Cilacap, Central Java	0.11-0.56[a]	0.36-1.39[a]		<0.005-9.19[a]	0.31-4.54[f]						Cahyani *et al.* (2017)

nd = not detected, *method validation / verification was stated, [a]AAS = (Flame) Atomic Absorption Spectrometer, [b]CV-AAS = Cold Vapor – Atomic Absorption Spectrometer, [c]ICP-MS = Inductively Coupled Plasma – Mass Spectrometer, [d]ICP-OES = Inductively Coupled Plasma – Optical Emission Spectrometer, [e]MP-AES = Microwave Plasma-Atomic Emission

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Food products	Locations	Level of heavy metals in mg/kg (methods)										References
		Cd	Cu	Zn	Pb	Hg	Fe	Cr	As	Sn	Ni	
Nila fish (*Oreochromis* sp.)	Garang watershed, Semarang, Central Java		1.35[a]		0.63-0.68[a]							Ujianti *et al*. (2018)
Angel fish (*Chelmon rostractus*)	Coast of Batam, Riau Islands	0.03-0.16[a]	0.07-0.88[a]		0.71-2.57[a]							Ismarti *et al*. (2017)*
Selar (*Alepes vari*) and gulamo (*Johnius belangerii*)	Musi river estuary, South Sumatra		0.03-0.85[a]		6.76-8.25[a]							Agustriani, Purwiyanto, Putri and Fauziyah (2019)
Fishes	Musi river estuary, South Sumatra				1.6-8.3[a]							Agustriani *et al*. (2019)
Layang fish (Decapterus ruselli)	Gabion Belawan, Medan, North Sumatra				0.035-0.054[a]							Sinaga and Yusni (2020)
River catfish (*Mystus* sp)	Blanakan river, West Java	0.03-0.10[a]										Anjani and Takarina, 2020)
Fishes	Barito River, South Kalimantan	0.003-0.070[a]	0.003-0.273[a]		nd-0.102[a]	nd-0.162[a]						Dwiyitno *et al.* (2008)
Tank goby (*Glossogobius giuris*)	Segara Anakan, Cilacap, Central Java	0.001-0.032[a]	0.164-0.293[a]		nd-0.005[a]	nd-0.044[b]						Sulistiono *et al.* (2018)
Mullet (Chelon subviridis)	Donan river estuary, Cilacap, Central Java	0.017-0.231[a]	0.50-2.60[a]									Prastyo *et al.* (2017)
Blood cockle (*Anadara granosa*)	Musi river, South Sumatra		0.36-0.73[a]									Filipus *et al*. (2018)
Blood cockle (*Anadara granosa*)	Pasaran Island, Bandar Lampung, Lampung		5.87-95.11[e]		10.58-206.51[e]							Rahmah (2019)
Crab meat (*Scylla serrata*)	Mati River estuary, Bali							nd-9.12[d]				Suteja and Dirgayusa (2018)

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Food products	Locations	Level of heavy metals in mg/kg (methods)										References
		Cd	Cu	Zn	Pb	Hg	Fe	Cr	As	Sn	Ni	
Crab meat (*Scylla serrata*)	Banyuasin estuaries, South Sumatra		0.281-0.371[a]		0.0043-0.0073[a]		0.554-2.054[a]					Sandro *et al.* (2013)
Mantis shrimp (*Harpiosquilla harpax*)	Eastern region of Java Sea	1.5-1.6[a]	11.5-15.5[a]	18.6-27.3[a]	1.4-1.5[a]	0.04-0.06[b]		0.02-0.03[a]				Candra *et al.* (2019)*
Shellfishes	Bima bay, West Nusa Tenggara	0.066-0.802[a]			0.756-1.59[a]							Khairuddin and Yamin (2021)

nd = not detected, *method validation / verification was stated, [a]AAS = (Flame) Atomic Absorption Spectrometer, [b]CV-AAS = Cold Vapor – Atomic Absorption Spectrometer, [c]ICP-MS = Inductively Coupled Plasma – Mass Spectrometer, [d]ICP-OES = Inductively Coupled Plasma – Optical Emission Spectrometer, [e]MP-AES = Microwave Plasma-Atomic Emission Spectrometer, [f]CV-AFS = Cold Vapor – Atomic Fluorescence.

used to determine the level of heavy metals were also discussed.

2. Methods

During performing this narrative review, several databases including Scopus, PubMed, and DOAJ were used for preparing this review. These databases were identified, analyzed and selected to obtain the most appropriate ones. The keywords used during searching of information were (heavy metals + *Fish* + *Indonesia) or* (specific heavy metals such as As, Cu + *Fish* + *Indonesia).*

3. Analytical methods for determination of heavy metals

Determination of metal concentrations in fish and fish products used (flame) atomic absorption spectrometer (AAS), cold vapour – (CV-)AAS, inductively coupled plasma–optical emission spectrometer (ICP-OES), inductively coupled plasma–mass spectrometer (ICP-MS), and microwave plasma-atomic emission spectrometer (MP-AES) (Table 2). Prior to instrumental analysis, the sample was digested to remove the organic matter and ease the metal atomization. AAS with a flame source is by far the most common method for metal determination. CV-AAS is a specialized AAS instrument for volatile metals, such as Hg, which does not use high-temperature flame for ionization to reduce Hg leak resulting in higher sensitivity (Fernández *et al*., 2015). AAS is a desirable instrument as it has low capital and operating cost. The instrument is robust and easy to operate. The limit of quantification of AAS is not as low as the ICP technique, but it is enough to reach the maximum permitted level of heavy metal contaminants in food by BPOM (Planeta *et al*., 2021).

MP-AES and ICP-OES are both atomic emission techniques. In MP-AES, the plasma is generated by a magnetic field using a magnetron. This is in contrast to ICP-OES which uses an electric field to generate plasma. The quantification range for MP-AES is around medium ppb to percentage, which is in between AAS and ICP-OES. MP-AES utilizes nitrogen from compressed air to fuel the plasma. Thus, compared to ICP-OES which uses argon, the operating cost of MP-AES is lower. As for ICP-MS, it permits high throughput analysis with superior detection limits (Agilent Technologies, 2021). However, the purchasing and operating cost is very high, thus, it is not widely available in Indonesia.

Method validation and/or verification is of importance for the determination of heavy metal concentrations in fish and fish products to ensure the analytical results reliable and legitimate. Besides the accuracy, precision, and linearity of the methods, the limit of quantification is critical and should include the maximum permitted level of heavy metal contaminants sets by the authority (ICH, 1995). However, there are a few articles that stated the method of validation or verification that the authors employed (Table 2). The method validation or verification should be carried out and described, and the results should be stated to ensure that the analytical method performed is suitable for the intended purposes and that the readers can judge the validity of the analytical results.

3.1 Arsenic

Arsenic (As) with an atomic number of 33 amu on the periodic table is often referred to as a semi-metal or metalloid as it has intermediate physicochemical properties between metal and nonmetal. According to International Agency for Research on Cancer (IARC), As has been recognized as a carcinogen group 1 or having a high potential for toxicity, while the Hazardous Substances Priorities List published by the Agency for Toxic Substances and Disease Registry (ATSDR) recognized that As is the most toxic element to human health (Upadhyay *et al*., 2019). In nature, As can be found in three forms, which are elemental As (As0), inorganic As, and organic As. Inorganic As include salts of arsenite (As(III)) and arsenate (As(V)) such as arsenide (As^{3-}), arsorite (AsO_3^{3-}), and arsenenate (AsO^{3-}). Organic As that are commonly found are methyl arsine (CH_5As), dimethyl arsine (C_2H_7As), and dimethyl arsenic acid $(CH_3)_2As(O)OH$. The toxicity of As depends on its form, whereby inorganic arsenic compounds are considered to be more toxic than others. Among the four oxidation states of As, the form of arsenite anion is considered to be more toxic and is responsible for carcinogenic activity (Kato *et al*., 2020).

The maximum permitted concentration in fish and fish products is 0.25 mg/kg based on BPOM regulation (Table 1). Not many published data on As level in fish and fish products in Indonesia can be found in the literature although As concentration is regulated by the governing body. A high level of As (2.71-6.77 mg/kg) above the permitted level was found in fish at the Jakarta fishing port and aquaculture site in Jakarta Bay (Koesmawati and Arifin, 2015). A sedimentary layer of Jakarta Bay may receive polluted streams containing high concentrations As from the Citarum river (Wook Ji and Soo Yoo, 2018). Therefore, aquatic organisms will take up and accumulate As. Fishes from the coast of Central and East Java, which has less populated settlements than Jakarta, contained a safe level of As.

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3.2 Cadmium

Cadmium (Cd) is a non-essential metal element that is generally toxic to humans. Ingestion through food and water is the main route of Cd exposure, followed by inhalation and cigarette smoking. Plant-based food has a higher level of Cd compared to an animal-based diet. The consumption of rice, especially those that were grown in Cd-rice soil, is the most common route of Cd exposure. The kidney and liver are the most sensitive organs to Cd toxicity. Metallothionein, a protein that binds to Cd to counter its toxicity, is abundant in both kidneys and the liver when Cd toxicity occurs (Genchi *et al*., 2020). The mechanism of Cd toxicity may include induction of oxidative stress, inflammation, metal dyshomeostasis, and genomic instability. It manifested as cancer, diabetes mellitus, cardiovascular, kidney, liver, skeletal, and other diseases (Tinkov *et al*., 2018). Exposure to low Cd concentration in a prolonged time impaired male and female reproduction systems. It also affected pregnancy and showed bigger adverse effects on female neonates (Kumar and Sharma, 2019). Acute exposure to high concentrations of Cd may cause spine injuries and bone deterioration, as reported in the Itai-Itai outbreak (Genchi *et al*., 2020).

The permitted level of Cd in fish and fish products varies depending on the type of the products (Table 1). Based on BPOM regulation, most fish and fish products should have Cd levels below 0.1 mg/kg, except for Cd in predatory fish which should be below 0.5 mg/kg. The range of Cd in some fish found in the coastal area of Jakarta and West Java and shrimp found in the eastern region of the Java Sea exceeded the safe level. Intriguingly, the level of Cd in fish from the Ciliwung River is only slightly above the safe level, although the concentration of Cd in the water varied from 0.3-6.3 mg/L exceeding the quality standard of 0.01 mg/L. The Cd contained in the water may not be retained during the river flow as the level of Cd in sediment was well below the threshold of 2 mg/L (Elfidasari *et al*., 2020). In coastal areas away from populated places, such as in East Kalimantan, South Kalimantan, and Riau Islands, the level of Cd in fish was very low.

3.3 Mercury

Mercury (Hg) exists as natural Hg, inorganic Hg, and organic Hg. Inorganic Hg may exist as mercurous chloride (Hg_2Cl_2) or mercuric sulfide (HgS), while organic Hg could be found as methylmercury (MeHg). Organic Hg is found to be more toxic than inorganic Hg and the half-life in the body is much longer. Organic Hg can be ingested along the food chain whereby organism at the top of the food chain contains a higher concentration of Hg, especially in the aquatic habitat. Hg is mainly accumulated in the kidney and liver, however, MeHg can enter the central nervous system rapidly and damage the brain (Raihan *et al*., 2020). The biomolecular process deteriorates in the presence of Hg. Signalling processes, enzymatic activities, and genetic expression are known to be disrupted by MeHg as evidenced in *in vivo* and *in vitro* experiments (Yang *et al*., 2020). It interrupts cell proliferation and differentiation which may result in cell death and necrosis of organs, or underdevelopment of the biological system if present during embryonic neurogenesis (Abbott and Nigussie, 2021).

The maximum limit of Hg in fish and fish products is 0.50 mg/kg based on BPOM regulation or 1.0 mg/kg for certain types of aquatic animals based on SNI (Table 1). The Hg content of predatory fish captured in the Ciliwung River (West Java and Jakarta) was much higher than the safe level, reaching 4 mg/kg. Ciliwung River is a river flowing in the metropolitan city of Jakarta that is known to be heavily polluted by agricultural practices, industrial activities, and household waste. The highest Hg content in the water and sediment was found to be 2 mg/L and 1.8 mg/L, respectively, much exceeding the quality standard of 0.002 mg/L and 0.035 mg/L, respectively (Elfidasari *et al*., 2020). Some fish samples found in Donan River (Central Java) and Jakarta Bay also contained higher Hg concentrations than the permitted level. The consumption of fish from these areas should be a concern since fish, especially those that sit further in the food chain, will accumulate a high amount of heavy metal contaminants. Hg concentration in whole blood and breast milk of Indonesian (5.8–10 and 3-4 µg/L, respectively) is relatively high compared to people living in North America and Europe (Abbott and Nigussie, 2021). Fishes acquired in other rivers and coastal areas were relatively low in Hg.

3.4 Lead

Lead (Pb) is a non-essential metal for humans that may induce toxicity during acute and chronic exposure. Drinking water and household apparatus are common sources of Pb pollutants. Leaded gasoline had previously contributed as the main source of environmental Pb pollution, but the usage of leaded gasoline has been banned (Komárek *et al*., 2008). Pb toxicity increases the risk of cardiovascular, renal, skeletal, immune, liver, and respiratory diseases. The multi-organ manifestation of Pb toxicity is due to the rise of oxidative stress levels, which induces inflammation, hormonal disturbance, and disruption of many biological systems. On a molecular level, Pb exposure may cause epigenetic changes, such as DNA methylation, histone modification, and alteration of miRNA expression (Mitra *et al*., 2017).

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BPOM regulation stated that Pb concentration in fish and fish products should be less than 0.2 mg/kg, except for predatory fish that should contain less than 0.4 mg/kg of Pb. SNI regulation has various limits of Pb concentration depending on the products, with bivalve molluscs and sea cucumbers having the highest limit of 1.5 mg/kg (Table 1). Fish captured from various areas in Indonesia contained higher Pb concentrations than the safe level. While some samples were on the borderline of the permitted level, fish from Ciliwung river (West Java and Jakarta), Donan river (Central Java), Musi river (South Sumatra), and Pasaran Island (Lampung) contain more than 5 mg/kg of Pb. Those rivers and coastal areas are located near industrial areas which may pollute the nearby water. Blood cockle (bivalve mollusc) found on Pasaran Island contained a worrying Pb concentration of 10.58-206.51 mg/kg (Rahmah, 2019). Bivalve molluscs incorporate heavy metal through passive adsorption and accumulate it during their growth so that the heavy metal concentrations are affected by the surrounding water and sediment (Zuykov *et al*., 2013). Thus, the high concentration of Pb in the sediment in Pasaran Island, which reached more than 600 mg/kg, influence the Pb level in the bloody cockle. The quality standard by the US Environmental Protection Agency states that the Pb concentration in the sediment should be less than 47.82 mg/kg (Rahmah, 2019).

3.5 Other heavy metals

The maximum permitted concentration of other metals in fish and fish products is not regulated by BPOM. Essential heavy metals such as Cu, Zn, and Fe are required by the human body for normal functioning. While Ni is not considered an essential metal, its presence is beneficial for humans and animals (Maret, 2016). Inadequate intake of these metals is more common than toxic exposure which very rarely happened under normal circumstances. Metal toxicity usually only occurs in patients with genetic defects, such as Wilson's disease whereby Cu cannot be properly eliminated from the body, or during accidental exposure to high-dose metal, such as inhalation of Zn-containing fume or accidental ingestion of Ni in occupational settings (Sunderman *et al*., 1988; Plum *et al*., 2010). The Food and Nutrition Board of the US National Academy of Sciences sets the Tolerable Upper Intake Level (UL) for healthy adults as 10 mg/day for Cu, 45 mg/day for Fe, 40 mg/day for Zn, and 1.0 mg/day for Ni. The UL is the maximum daily intake of metals from all sources that should not cause adverse effects for the targeted population (National Academy of Sciences, 2019). If a person consumes a standard serving size of 100 g fish, the level of Cu, Fe, Zn, and Ni in the fish found in Indonesia (Table 2) is considered safe.

The essentiality of Cr for humans is debatable. Cr (III) is required by our body and it has a Dietary Reference Intake (DRI) of 35 µg/day for healthy adults. On the other hand, Cr(VI) is carcinogenic. There is no UL available for Cr (Maret, 2016; National Academies of Sciences, Engineering, and Medicine, 2019). In Table 2, the Cr concentration in fish and fish products in Indonesia was low, except for crab meat from Mati River (Bali) which reached Cr concentration of 9 mg/kg (Suteja and Dirgayusa, 2018). In 100 g crab meat, the Cr content of the sample would be approximately 25 times the DRI.

4. Future perspectives

The high concentration of heavy metal pollutants in fish and fish products captured in some areas that potentially leak heavy metal contaminants, such as heavily populated areas, and industrial and mining sites, was alarming. Tighter monitoring and inspection should be conducted in order to prevent the distribution of contaminated fish to consumers. However, most of the literature that we cite analyzes fish from farming or fishing sites, which may not reflect the fish that are sold to end customers. Nevertheless, more surveillance should be done to check the heavy metal concentration in fish and fish products, especially those that are sold in traditional markets as the products do not undergo rigorous quality and safety control. For this purpose, cheap and portable instruments for heavy metal analysis, such as X-ray fluorescence (XRF) and laser-induced breakdown spectroscopy (LIBS), will be practical. The methods should be validated prior to routine analysis, especially for the determination of low-level metals.

Efforts to lessen the heavy metal pollution in the environment should be a priority to reduce the source of contamination. Stricter law enforcement for industrial and mining activities which dump waste over permitted levels of heavy metal contaminants should be implemented. New industries and mines should stick to and follow the guidance of the environmental impact analysis. Capturing fish in polluted rivers or coastal areas should be banned to avoid the consumption of polluted aquatic organisms.

5. Conclusion

The concentrations of As, Cd, Hg, and Pb as heavy metal pollutants in fish and fish products captured in Indonesia varied based on the fishing area. Those captured near heavily populated places, industrial areas, or mining sites, such as Ciliwung River, Donan River, and Buyat Bay, were found to contain heavy metals higher than the permitted levels established by Indonesian authorities. More rigorous surveillance

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should be done to prevent the consumption of contaminated fish by consumers.

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