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Potentially Toxic Elements (PTEs) in the Fillet of Narrow-Barred Spanish Mackerel (*Scomberomorus commerson*): a Global Systematic Review, Meta-analysis and Risk Assessment

Van Nam Thai[1] · Reza Dehbandi[2] · Yadolah Fakhri[3] · Mansour Sarafraz[4] · Amene Nematolahi[5] · Seyedeh Samaneh Dehghani[6] · Abdolmajid Gholizadeh[7] · Amin Mousavi Khaneghah[8]

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Abstract

The contamination of seafood like narrow-barred Spanish mackerel *(Scomberomorus commerson)* fillets by potentially toxic elements (PTEs) has converted to worldwide health concerns. In this regard, the related citations regarding the concentration of PTEs in fillets of narrow-barred Spanish mackerel were collected through some of the international databases such as Scopus, Cochrane, PubMed, and Scientific Information Database (SID) up to 10 March 2020. The concentration of PTEs in fillets of narrow-barred Spanish mackerel fish was meta-analyzed and the health risk (non-carcinogenic risk) was estimated by the total target hazard quotient (TTHQ). The meta-analysis of data indicated that the rank order of PTEs in fillet of narrow-barred Spanish mackerel was Fe (10,853.29 μg/kg-ww) > Zn (4007.00 μg/kg-ww) > Cu (1005.66 μg/kg-ww) > total Cr (544.14 μg/kg-ww) > Mn (515.93 μg/kg-ww) > Ni (409.90 μg/kg-ww) > Pb (180.99 μg/kg-ww) > As (93.11 μg/kg-ww) > methyl Hg (66.60 μg/kg-ww) > Cd (66.03 μg/kg-ww). The rank order of health risk assessment based on the country by the aid of TTHQ for adult consumers was Malaysia (0.22251) > Philippines (0.21912) > Egypt (0.08684) > Taiwan (0.07430) > Bahrain (0.04893) > Iran (0.03528) > China (0.00620) > Pakistan (0.00316) > Yemen (0.00157) > India (0.00073). In addition, the rank order of health risk assessment based on the country by the aid of TTHQ for child consumers was Malaysia (1.03838) > Philippines (1.02257) > Egypt (0.40523) > Taiwan (0.34674) > Bahrain (0.22832) > Iran (0.16466) > China (0.02892) > Pakistan (0.01474) > Yemen (0.00731) > India (0.00340). Therefore, the children in Malaysia and the Philippines were at considerable non-carcinogenic risk. Hence, approaching the recommended control plans in order to decrease the non-carcinogenic risk associated with the ingestion of PTEs via the consumption of narrow-barred Spanish mackerel fish fillets is crucial.

Keywords Potentially toxic elements (PTEs) · Fish · Narrow-barred Spanish mackerel · Health risk assessment · Food contamination

✉ Yadolah Fakhri
Ya.Fakhri@Gmail.Com

[1] Ho Chi Minh City University of Technology (HUTECH) 475A, Dien Bien Phu, Ward 25, Binh Thanh District, Ho Chi Minh City, Vietnam

[2] Department of Environmental Health Engineering, Health Sciences Research Center, Faculty of Health, Mazandaran University of Medical Sciences, Sari, Iran

[3] Food Health Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran

[4] Environmental Health Research Center, Department of Environmental Health Engineering, Faculty of Health, Golestan University of Medical Sciences, Gorgan, Iran

[5] Department of Food Safety and Hygiene, School of Health, Fasa University of Medical Sciences, Fasa, Iran

[6] Department of Environmental Health Engineering, Student Research Committee, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran

[7] Department of Environmental Health Engineering, School of Public Health, North Khorasan University of Medical Sciences, Bojnurd, Iran

[8] Department of Food Science, Faculty of Food Engineering, University of Campinas (UNICAMP), Campinas, São Paulo, Brazil

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Introduction

The health of humans is associated with feeding habits [1]. A healthy diet should not only contain vitamins and essential trace elements but also should be free of chemical contaminants (heavy metals and persistent organic pollutants) and pathogenic microorganisms (bacteria and virus) [2–4]. While some of the food products, such as fish, attracted considerable attention due to their rich content of protein, their contamination by pollutants is a matter of concern. Fish is in the marine feeding chain's highest loops and is one of the most important food sources for humans [5]. Fish fillet has high protein with low-calorie content, constitutes 6% and 17% of protein requirement and animal protein, respectively, as compared to other food sources [5]. At the same time, the fish fillet consumption (twice a week) is recommended due to its high omega-3 fatty acids content like eicosapentaenoic acid [6], which can significantly reduce the risk of cardiovascular disease [7, 8] besides the proposed role in preventing thrombosis and arrhythmia and following decreasing triglyceride levels [9]. Despite the several benefits, fish fillet consumption plays a considerable role in transmitting environmental contaminants to humans [10, 11]. Natural sources like crust corrosion can contaminate aquatic environments, or mainly anthropogenic sources consist of agricultural, industrial, and municipal wastewater and solid waste disposal, industrial processes, smelting procedures, mining, and application of herbicides [12–14].

Potentially harmful elements (PTEs) are elements are categorized into two groups of essential elements like zinc(Zn), iron (Fe), copper (Cu), calcium (Ca), and selenium (Se) and heavy metals like as mercury (Hg), cadmium (Cd), arsenic (As), lead(Pb), nickel(Ni), and copper (Cu) [15, 16]. However, the essential elements in low concentrations are posing some benefits for humans' health; in high concentrations, they can be harmful to health; however, non-essential elements (heavy metals) can endanger health, while in low concentrations [15]. The non-essential elements are non-biodegradable, demonstrating the stable properties among the food chain [17]. The exposure to PTEs leads to adverse health effects on humans' nervous system, kidney, liver, cardiovascular, and bone [18–20]. Besides, they pose teratogenesis, mutagenesis, and carcinogenesis properties [21–23].

Narrow-barred Spanish mackerel (*Scomberomorus commerson*) is a large predatory fish that live on the coast of southeast Asia, the east coast of Africa, the Persian Gulf, northern coastal Indian ocean, and southwest Pacific ocean [24]. Narrow-barred Spanish mackerel is a popular and high-consumption marine food resource in the world due to its delicious meat [25–27]. Moreover, other similar seafood consumptions, such as narrow-barred Spanish mackerel fish, have increased in recent years [24–27].

However, many investigations have been conducted to measure the PTEs in narrow-barred Spanish mackerel worldwide [28–44]; no systematic review study was performed. Hence, the current study's aim was a meta-analysis of the concentration of PTEs, including inorganic As, Methyl Hg, Total Cr, Cd, Pb, Cu, Zn, Fe, Mn, and Ni in narrow-barred Spanish mackerel fillet on a global scale. Moreover, the related health risk assessment for exposed population-based countries was estimated.

Material and Method

Search Strategy

Cochrane protocol was used to conduct systematic review [45], and the following selection process of studies was done according to PRISMA (Fig. 1) [46]. Scopus, Cochrane, and PubMed, scientific information database (SID) databases, were used to search articles on the concentration of PTEs in the fillet of narrow-barred Spanish mackerel up to 10 March 2020. Keywords consist of "heavy metals" OR "trace metals" OR "toxic metal" OR metals OR metal (oid) s OR element AND "marine food" OR fish OR seafood's OR "Narrow-barred Spanish mackerel" OR "*Scomberomorus commerson* were used. The reference articles were screened to retrieve more citations.

Selection Criteria and Data Extraction

The inclusion criteria consisted of analysis concentration of PTEs in the fillet of narrow-barred Spanish mackerel; descriptive study; present of average or range concentration of PTEs; present of sample size; and access English language full text. Books, review articles, letters, and conferences were excluded based on protocol. Moreover, experimental studies, like studies on the bioaccumulation of PTEs indifferent fish tissues of narrow-barred Spanish mackerel, were excluded. Country, year of study, location of sampling, sample size, the average concentration PTEs, standard deviation (SD) of PTEs, and range of concentration of PTEs and method of detection were extracted.

Meta-analysis of Data

The concentration of PTEs in fillets narrow-barred Spanish mackerel was meta-analyzed using the standard error (SE) equation (Table 1). The I^2 index and chi-square were used to analysis of heterogeneity. If $I^2 > 50\%$, heterogeneity is considerable [53–55]; hence, a random effect model (REM) was used for meta-analysis. A meta-analysis of data was conducted using Stata, version 14 (Stata Corporation, College Station, TX).

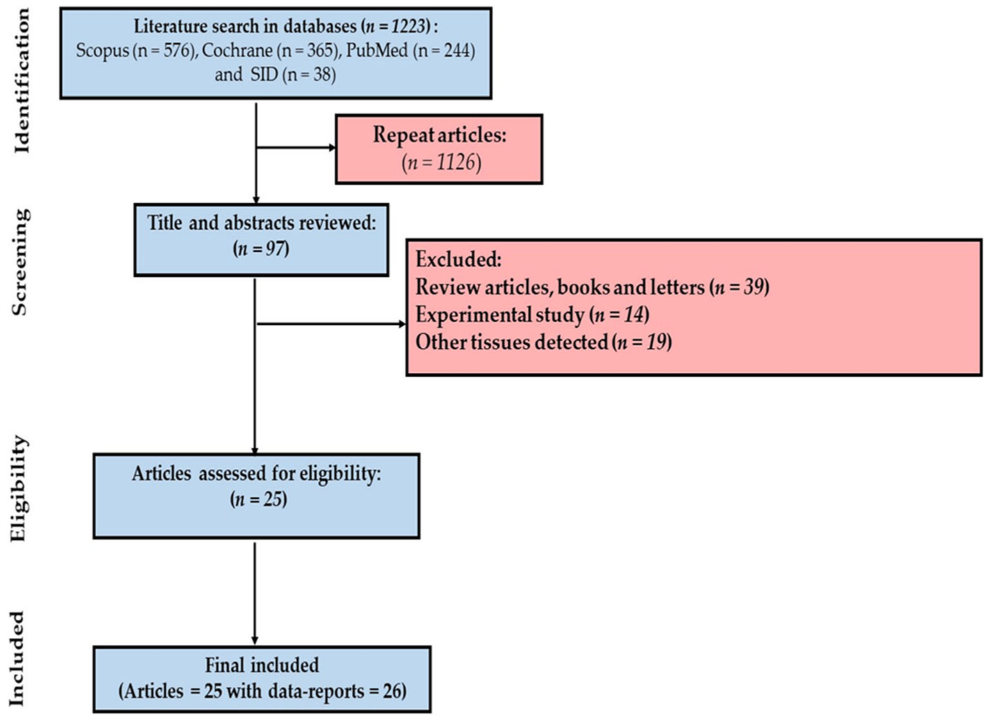

Fig. 1 Process to select articles for inclusion in this review based on PRISMA diagram

Health Risk Assessment

Health risk assessment can provide more interpretive results regarding human exposure to contaminated food products [56–58]. All equations used in health risk assessment are presented in Table 1 and per capita consumption of fish in Table 2, followed by the included studies' main characteristics presented in Table 1S.

Table 1 The statistical and risk assessment equations applied in this study

Number	Equation	Description	References
1	$SE = \frac{SD}{\sqrt{n}}$	SE: standard error. SD: standard deviation. *n*: sample size.	[47]
2	$EDI = \frac{C_m \times IR \times EF \times ED}{BW \times ATn}$	EDI: estimated daily intake. C_m: concentration of metal (mg/kg-wet weight). IR: ingestion rate (presented in Table 2). EF: exposure frequency (350 day/year). ED: exposure duration (children = 6 years and adults = 30 years). BW: Body weight (children: 15 kg and adults: 70 kg). ATn (EF × ED): average time exposure for non-carcinogenic risk (children: 2190 days and adults: 10950 days).	[49]
3	$ww = \frac{dw \times (100 - \%M)}{100}$	ww: wet weight. dw: concentration based on dry weight. %M: moisture content of 79%.	
4	$THQ = \frac{EDI}{RfD \text{ or } TDI}$	THQ: target hazard quotient. R*f*D: oral reference dose. R*f*D for As (inorganic), Hg, Cr (Total), Cd, Cu, Zn, Fe, Mn and Ni is 0.0003, 0.0001, 1.5, 0.001, 0.04, 0.3, 0.7, 0.14, and 0.011 mg/(kg·day), respectively. TDI: tolerable daily intake. Pb: 0.0036 mg/(kg·day). Due to most As form in fish is organic that is nontoxic hence non-carcinogenic risk not estimated.	[50, 51]
5	$TTHQ = THQ_1 + THQ_2 + \ldots THQn$	TTHQ: total target hazard quotient is equal to sum THQ of individual PTEs.	[52]

Table 2 Ingestion rate of fish and following fillet silver pomfret in countries [48]

Country	kg/capital year*	g/capital day**
Iran	11.20	3.07
China	32.90	9.01
Egypt	22.10	6.05
Bahrain	11.60	3.18
Pakistan	2.00	0.55
Yemen	3.00	0.82
Philippines	35.90	9.84
India	5.50	1.51
Malaysia	54.90	15.04
Taiwan	33.00	9.04

* Average consumption of fish

** Average consumption of fillet silver pomfret based on assume 10% of total mean fish consumption

Results and Discussion

The Concentration of PTEs in the Fillet of Narrow-Barred Spanish Mackerel in Different Countries

The rank order of PTEs in fillet of narrow-barred Spanish mackerel was Fe (10,853.29 μg/kg-ww) > Zn (4007.00 μg/kg-ww) > Cu (1005.66 μg/kg-ww) > Cr (544.14 μg/kg-ww) > Mn (515.93 μg/kg-ww) > Ni (409.90 μg/kg-ww) > Pb (180.99 μg/kg-ww) > As (93.11 μg/kg-ww) > Hg (66.60 μg/kg-ww) > Cd (66.03 μg/kg-ww). The concentration of toxic metals (As, Hg, and Cd) is much lower than the essential elements (Fe, Zn, and Cu), which justifies the latter's higher affinity to enter the fish body [59, 60]. In the present study, Fe showed the highest concentration among investigated PTEs because this element is the most abundant metal present on the earth's crust, which is essential for most biological functions in the fish and other animals' bodies [61]. In this regard, Biswas et al. (2012) stated that terrestrial erosion is the main mechanism enhancing Fe concentration in the seawater [43]. It was also reported that high amounts of Zn in the fillet of narrow-barred Spanish mackerel were derived from food supplies compared to the water [29].

PTEs can be stored in the fish through the water, food, and sediments. Therefore, fish is considered as an indicator of PTEs contamination in the coastal environment [43]. PTEs observed in the fish body are resulted from two main sources: (1) the natural presence of PTEs in the earth's crust and are introduced to the water medium through weathering mechanism, and (2) the introduced PTEs to the aquatic medium through anthropogenic activities (i.e., through urban run-off, agricultural wastes, industrial effluents, and emissions or unintentional spill of oil from boats and ships) mainly in the coastal areas [34, 35, 38, 40, 62].

The essential elements need to be taken up from the water, food, or sediment for fish's normal metabolism. However, non-essential elements are also taken up by fish simultaneously and accumulate in their tissues [29, 35, 38]. It is worth mentioning that the affinity of different PTEs is not similar, influencing their bioaccumulation degree within the fish body. In this regard, Heshmati et al. (2019) noted that toxic metals' affinity was significantly lower than that of essential metals [63]. For instance, essential elements (like Fe and Zn) had the highest affinity rate since they are essential elements, and fish take up them as much as needed from the surrounded milieu [61]. Therefore, the level of toxic metals in the fillet of narrow-barred Spanish mackerel is much lower than that of the essential metals [15].

It should bear in mind that different PTEs considerably depend on their concentrations and their bioavailability in the water media and exposure time [64]. Furthermore, factors like ingestion quantity, storage level, and excretion percentages of PTEs in the fish body effectively affect their bioaccumulation after absorption [65, 66].

Numerous factors are influencing PTE concentrations in fish tissues, including biological factors related to fish (like species, growth-dependent factors like age, length, sex and body weight, tissue, habitat, trophic level, feeding behavior, and migration) and ecological factors (water chemistry like salinity, hardness, pH as well as geographical conditions and season) [35–37, 40, 41, 43, 67].

Narrow-barred Spanish mackerel (*Scomberomorus commerson)*is grouped as pelagic and carnivores on macrofauna [32, 41]. They exist and feed by small fishes like anchovies, clupeids, carangids, and squids and shrimps in the sea [36]. Sary & Velayatzadeh (2014) studied Pb and Zn levels in some fish species, including the *Scomberomorus commerson* from the Persian Gulf in Iran. Their results showed that both metals' concentration is higher in the gills and liver of *Scomberomorus commerson* than in the muscle. Furthemore, Bibak et al. (2020) also showed that PTE concentrations in the liver of 2 fish species were much more than muscle [68]. The PTE levels also in 2001 were higher than those in 2011 [67]. It should bear in mind that a higher concentration of most PTEs in the liver results from the fact that this organ has the primary physiological role in fish metabolism and shows higher metabolic activity in detoxification of these contaminants [29, 37, 69].

Generally, PTE levels increase with the size and length of fish [36]. The fish size impacts the value of intake, distribution, translocation, and elimination of PTEs in the fish body. Older fish show higher PTE concentrations than younger because of extensive exposure time [36]. For example, Abdallah (2008) observed that the PTE concentrations reduced considerably with fish's body weight. However, a positive association with body weight was detected for Zn, Cu, and Pb concentrations. For example, significant negative correlations with body weight were found for Cd and Pb; however, a positive correlation was found for Cr in *Scomberomorus commerson* [41]. Furthermore, Anual (2018) reported that Hg concentrations in fish with body length below 20 cm were 1.5 times lower than fish with more than 20 cm [36]. The accumulation of PTEs in different parts of the fish body is also related to the type of metal. In this regard, Khaled (2004) noted that Fe, Zn, and Cu had the highest concentrations in the liver while Cd, Cr, and Pb had their highest levels in the kidneys, gills, and bones [37].

It is worthy to note that the type of PTEs in each area is different. In this regard, Abdallah (2008) observed that the concentrations of Cu and Cr were lower in fishes from El-Mex Bay than Eastern Harbor, while the reverse trend was reported for Cd, Pb, and Zn, representing the close sources of toxic elements present in El-Mex shoreline region (Egypt) which is exposed to significant inputs of anthropogenic and agricultural pollution during the past years. There are different industrial plants in this area including chloralkali, iron, steel factories, tanneries, and petroleum refining [41]. Furthermore, Bibak et al. (2020) investigated the concentration of PTEs in fishes caught from 4 different Persian Gulf areas. Their results showed that fish samples of Emam Hassan Port were more contaminated than other ports due to pollutant discharge from oil refinery [68]. It was stated that season is an important factor affecting PTE concentration in the fish tissues due to alterations in water temperature and salinity as well as growing and reproductive phases [29]. For instance, Saei-Dehkordi et al. (2010 and 2011) reported that most of all fish samples had more PTEs (Hg and As) concentration in winter than in summer. In winter, the higher PTE level could be due to high rainfall, which rinsed the wastes [32, 40]. In contrast, Khaled (2009) observed opposite results [29].

Nevertheless, muscle tissues cannot store high amounts of most PTEs, but in contaminated zones, such toxic metals in muscles may increase [69]. Thus, the PTE concentrations in the fish living in the water medium close to industrialized areas are much higher than in other areas [38]. Shwafi (2002) reported that the differences in the concentration of PTEs in the fish muscle were mostly attributed to rocks' mechanical and chemical eroding rather than anthropogenic activities [70]. Pilehvarian et al. (2015) also revealed that industries close to the Persian Gulf could introduce many PTEs to the water environment [35]. Furthermore, Ahmed et al. (2015) observed that the PTE concentrations in 2010–2011 were considerably higher than those in 2006–2007 [38]. Prudente (1997) also reported that Manila Bay in China accepts major discharges of urban and industrial disposals [71]. Yasmeen et al. (2016) also indicated that in the Port located near the Karachi, disposal of industrial and municipal waste is the main reason for the high concentration of PTEs in the fish tissues [44].

Concentration of Pb

Pb does not have positive or nutritional influences on organisms as it is toxic [41]. After its entrance to the body through gills, and is accumulated in gills, liver, and muscles [67]. Pb can negatively affect cognitive growth and intellectual functioning in children [72]. It could also increase blood pressure and heart-related diseases in adults [70], anemia, renal failure, and liver injury in humans [34].

The results of the current study showed that the ranking of countries based on Pb concentration in fillet of narrow-barred Spanish mackerel fish was Egypt (851.81 μg/kg-ww) > Iran (458.97 μg/kg-ww) > Pakistan (167.25 μg/kg-ww) > Yemen (52.03 μg/kg-ww) > Philippines (27.30 μg/kg-ww) > Bahrain (10.00 μg/kg-ww) > China (5.91 μg/kg-ww) > India (0.63 μg/kg-ww) (Table 3).

Pb′s mean concentration in all investigated countries was lower than the permissible limit (FAO: 500 μg/kg-ww) [81], except in Egypt. In Egypt, fish are caught and collected either from wild sources or aquacultures distributed in different localities worldwide, and many industries discharge their polluted effluent into water sources such as the Nile River [84–88]. Lead is used in different industrial activities and is a major residue from gasoline-burning, which diffuses the atmosphere in a large amount [41]. Pb enters into water throughout industrial waste (like painting, battery manufacturing, dyeing, and oil refineries) [72]. Furthermore, Pb could enter the sea from natural supplies and the atmosphere [67]. Thus, Pb concentration increases due to industrial activities as well as using pesticides and fertilizers [72]. For example, using gasoline additives and lubricants high in the lead in the mining and industrial parts could increase Pb concentration in the food chain [35, 44].

Ni Concentration

Ni poisoning complications include headache, insomnia, nausea, dizziness, skin inflammation, and lung cancer [89]. The maximum limit of Ni in fish tissue recommended by USFDA is 80,000 μg/kg ww [83]. The rank of Ni concentration in narrow-barred Spanish mackerel fish in different countries was as Iran (1358.34 μg/kg) > Egypt (587.85 μg/kg) > Pakistan (630.00 μg/kg) > China (32.27 μg/kg) > Bahrain (32.27 μg/kg). Therefore, according to Table 3, Ni concentration in all investigated countries was considerably lower than the permissible level.

Ni is widely distributed in the environment through fossil fuels, mining and refineries, waste incineration, and land erosion by rainfall into water resources [90].

Fe Concentration

Fish is a significant iron source, an important essential element for the body's metabolism, and has a leading role in transporting oxygen and cellular respiration [16]. Iron deficiency leads to anemia [34, 43]. Fe has an effective function in forming hemoglobin in combination with protein and Cu [44]. However, too much concentration of Fe is toxic and dangerous to humans health [91].

Table 3 Pooled concentration of PTEs in fillet of narrow-barred Spanish mackerel based on countries (μg/kg ww)

	Inorganic As	Methyl Hg	Total Cr	Cd	Pb	Cu	Zn	Fe	Mn	Ni
Iran [28, 32, 33, 35, 39, 40, 42, 73–77]	93.11	21.90		45.87	458.97	201.01	3421.20	550.20	84.00	1358.34
Egypt [37, 41, 78, 79]		50.40	746.00	181.00	851.81	922.44	5429.09	18,055.87	736.48	587.85
Bahrain [30]		100.00		10.00	10.00	4000.00		5000.00	40.00	32.27
China [34]			820.00	1.57	5.91	370.00	4240.00	5470.00	1720.00	32.27
Pakistan [38, 44]			330.00	199.94	167.25	2807.41	6740.00	15,885.94		630.00
Yemen [70]				121.79	52.03	64.85	454.34			
Philippines [80]		153.30		2.00	27.30	577.00	14,595.00		2793.00	
India [43]			81.90		2.10	525.00	4515.00	3990.00	105.00	
Malaysia [36]		108.00								
Taiwan [31]		60.00								
Guideline FAO [81, 82]		500.00	1000.00	500.00	500 .00	30,000.00		100,000.00	300,000.00	
Standard limit FDA [83]										80,000.00
Guideline WHO [81, 82]		500.00	50,000.00			30,000.00	30,000.00			

FAO, Food and Agriculture Organization; *FDA*, Food and Drug Administration; *WHO*, World Health Organization

The rank of Fe concentration in narrow-barred Spanish mackerel fish in different countries was as Egypt (18,055.87 μg/kg) > Pakistan (15,885.94 μg/kg) > China (5470.00 μg/kg) > Bahrain (5000 μg/kg) > India (3990.00 μg/kg) > Iran (550.20 μg/kg). The observed Fe concentrations in narrow-barred Spanish mackerel fish from all studied countries (Table 3) were much lower than acceptable standards set by WHO (100,000 μg/kg ww) [92]. Fe is the main constituent of the earth's outer and inner core and the fourth most common element in the crust [93].

Cd Concentration

Cd is a prevalent toxic metal that is not essential in the fish body, and it is hard to excrete after ingested [41]. After Cd's ingestion through food consumption, it may trigger kidney disorders, skeletal impairment, and reproductive shortages [34]. It boosts the generation of renal stones and secretion of calcium through urine [44].

The rank of Cd concentration in fillet of narrow-barred Spanish mackerel fish in different countries was Pakistan (199.94 μg/kg) > Egypt (181.00 μg/kg) > Yemen (121.79 μg/kg) > Iran (45.87 μg/kg) > Bahrain (10 μg/kg) > Philippines (2 μg/kg) > China (1.57 μg/kg) (Table 3).

The Food and Agriculture Organization (FAO) allows maximum concentrations of 500 μg/kg Cd [81]. Our results showed that the Cd concentration in all investigated countries was lower than the FAO's acceptable level. This pollutant is naturally present in surface and groundwater [94]. However, most of it enters the aquatic ecosystems through soil and bedrock erosion, polluted sediments derived from industrial plants, wastewater from contaminated areas, and sludge and fertilizer in agriculture [95, 96]. Tepanosyan et al. (2017) attributed high Cd concentrations in the environment to vehicle tires and the burning of fossil fuels [97]. At the same time, Najm et al. (2014) emphasized the widespread use of phosphate fertilizers in agriculture as the main reason for the increase of Cd in water, sediments, and finally, the aquatic life of Babolsar Coastal Waters [98].

Total Cr Concentration

Cr is effective in macronutrient metabolism and considers as an essential element in humans [43]. Cr is the seventh most abundant element in the earth's crust and has various oxidation states, of which forms Cr (III), and Cr (VI) can be frequent and more stable in the environment. Cr (III) is an important component in the balance of human and animal diets, and its deficiency leads to disruption of glucose and fat metabolism [99]. However, Cr (VI) is highly toxic and carcinogenic, causing death in humans, animals, plants, shortness of breath, and inflammation of the mouth, nose, and lungs, and inflammation of the skin, problems with digestion, and damage to the kidneys and liver [98].

The ranking of countries based on total Cr concentration in fillet of narrow-barred Spanish mackerel fish in different countries was China (820.00 µg/kg-ww) > Egypt (746.00 µg/kg-ww) > Pakistan (330.00 µg/kg-ww) > India (81.90 µg/kg-ww) (Table 3).

The FAO and WHO suggested 1000 and 50,000 µg/kg as maximum limits for Cr in fish, respectively [81, 100]. As shown in Table 3, all investigated countries in terms of Cr concentration in the fillet of narrow-barred Spanish fish have reasonable conditions compared with a regulated limit. Type of species, age and developmental stage, temperature, Cr concentration, pH, alkalinity, salinity, and hardness of water can influence Cr concentration in fish tissues [101]. Cr element naturally exists in soil, rocks, animals, and plants [102]. However, anthropologic activities like manufacturing processes of iron and steel industries and cooling towers discharge Cr into the environment [103]. Furthermore, Cr is used in the inks, leather, and steel industries [41].

Zn Concentration

Zn is probably the least toxic of all the PTEs [37]. It is a vital metal in humans and other animals, which acts as an enzyme activator [72]. It can become toxic in excess concentration [43]. It is contributed to several metabolic routes in the human body, and its deficiency can lead to appetite decrement, growth inhibition, skin disorders, and immunological malfunctions [34].

Results showed that the order of different countries based on Zn concentration in fillet of narrow-barred Spanish mackerel fish was Philippines (14,595.00 µg/kg-ww) > Pakistan (6740.00 µg/kg-ww) > Egypt (5429.09 µg/kg-ww) > India (4515.00 µg/kg-ww) > China (4240.00 µg/kg-ww) > Iran (3421.20 µg/kg-ww) > Yemen (454.34 µg/kg-ww). The Zn concentration in all the investigated countries is lower than the standard value (30,000 µg/kg-ww) regulated by FAO/WHO in fish (Table 3) [104]. The high concentration of Zn in the fillet of narrow-barred Spanish mackerel is perhaps due to the incidence of an enormous number of fishing containers that apply galvanized element coatings to avoid rusting, which finally enters into the environment due to leaching [43]. Zn enters into aquatic ecosystems through metal smelting industries, the effect of acid rain on building materials containing zinc, drilling activity, metal condensation, sewage sludge, compost, chemical fertilizers, and insecticides [105]. Leung et al. (2014) carried out a study in India and they reported that the main source of Zn (140 mg/kg) detected in the Estuary and the surrounding coastal area sediments was the Pearl River delta, where is an important area for agricultural, commercial, and industrial development [90]. Additionally, Agah et al. (2008) noted that the high amounts of heavy metal, including Zn, in fishes captured from the Persian Gulf (Iran) could be attributed to growing industrial pressures on the Persian Gulf environment [106].

Mn Concentration

Mn, an essential element in biological systems, plays a coenzyme role in the human body bound to some enzymes such as pyruvate carboxylase and superoxide dismutase to act as an activator in accelerating reactions [107]. Mn is a low toxicity metal. Its increased levels cause severe brain damage with physiological and neurological disorders such as poor reproductive performance, Parkinson (muscle stiffness), and abnormal bone and cartilage [108, 109]. In this study, the rank of Mn concentration in fillet of narrow-barred Spanish mackerel fish in different countries was Philippines (2793.00 µg/kg-ww) > China (1720 µg/kg-ww) > Egypt (736.48.00 µg/kg-ww) > India (105.00 µg/kg-ww) > Iran (84.00 µg/kg-ww) > Bahrain (40.00 µg/kg-ww). The observed Mn concentrations in narrow-barred Spanish mackerel fish from all studied countries (Table 3) were much lower than the legal standards set by FAO (300,000 µg/kg ww) [81]. Therefore, there is no concern in the case of Mn in the fillet of narrow-barred Spanish mackerel fish. Mn could find its way to enter into the environment from industries of iron, alloys, and steel products [37]. Furthermore, fertilizers, fungicides, and dry-cell batteries are considered other Mn sources [43].

Cu Concentration

Copper is an essential metal for animals because it contributes to enzyme function and takes part in respiratory routes [41]. It plays a vital role in the activation of numerous enzymes [43]. It is necessary for the growth and development of bones and human health [44]. However, its high intake can cause adverse health problems such as liver and kidney damage [34].

The rank of Cu concentration in fillet of narrow-barred Spanish mackerel fish in different countries was Bahrain (4000 µg/kg-ww) > Pakistan (2807.41 µg/kg-ww) > Egypt (922.44 µg/kg-ww) > Philippines (577.00 µg/kg-ww) > India (525 µg/kg-ww) > China (370.00 µg/kg-ww) > Iran (201.01 µg/kg-ww) > Yemen (64.85 µg/kg-ww) (Table 3).

The FAO/WHO suggested 30,000 µg/kg-ww as maximum limits for Cu in fish [81]. In the case of Cu, its concentration in fish tissue was significantly lower than the standard limit, so there is no concern. Generally, Cu concentration observed in studied countries originates from natural components (e.g., forest fire, volcanoes, and plant decomposition), as well as human activities (e.g., fertilizers, pesticides, mining, municipal and industrial wastewater industries) [110]. Yi et al. (2011) revealed that the sources of Hg, Cd, Pb, Cr, Cu, and Zn are anthropogenic components and may originate from similar pollution sources, mainly from metal processing, electroplating industries, industrial wastewater, and domestic sewage [111]. Bervoets et al. (2001) concluded that Cu concentration in fish mussels was positively correlated with sediment and water levels [112].

Inorganic As Concentration

Arsenic is a ubiquitous toxic metal that causes adverse biological effects like several types of cancer (liver, skin, and bladder) [40]. Researches on the concentration of As level in the body of narrow-barred Spanish mackerel fish are very limited. Among the countries, the concentration of As in narrow-barred Spanish mackerel fish has been studied only in three studies in Iran **(**Table 3**)**, in which the average amount of inorganic As mentioned was 93.11 μg/kg ww. There is no information about maximum As levels in fish samples in US standards, while the acceptable limit of As in fish tissue in Singapore and Malaysia is 1 ppm [113]. The maximum arsenic level permitted for fishes is 1000 μg/kg, according to Australia standard [113, 114]. According to these, the inorganic As the level in the investigated country (Table 3) is lower than the allowable limit, and there is no considerable concern. Shah et al. (2009) reported the concentration range of 1.01–15.2 μg/g in freshwater fish species [115], while Tuzen (2009) expressed As in the range of 0.0–1.72 mg/kgN ww in canned fishes [113]. As contamination may derive from natural environmental sources percolating into the water, mining activities, and other manufacturing processes [35].

Industrial wastewater from tanneries, ore mining, and dyeing are also significant sources of surface water resource contamination by As [116, 117].

Methylmercury

Over 90% of metallic mercury can be transformed into MeHg by some microorganisms. MeHg, a lipophilic organic substance, is a recognized neurotoxicant related to children's developmental interruptions [118]. Methyl mercury, an extremely poisonous and absorbable kind of mercury, mostly affects the nervous system [31, 35, 40].

According to the Joint FAO/WHO Expert Committee on Food Additives/JECFA, the maximum allowable limit has been reported 500 μg/kg for Hg in fish [82]. The rank of methyl mercury concentration in fillet of narrow-barred Spanish mackerel fish in different countries was Philippines (153.30 μg/kg) > Malaysia (108 μg/kg) > Bahrain (100.00 μg/kg-ww) > Taiwan (60.00 μg/kg-ww) > Egypt (50.40 μg/kg-ww) > Iran (21.90 μg/kg-ww) (Table 3). Considering to Hg concentration in the fillet of narrow-barred Spanish mackerel fish of different countries, it was found that all investigated countries meet the regulated standards.

Natural sources of methylmercury entering the aquatic environment include weathering rocks, erosion of the earth's

Table 4 The non-carcinogenic risk due to ingestion narrow-barred Spanish mackerel content of PTEs

		Malaysia	Philippines	Egypt	Taiwan	Bahrain	Iran	China	Pakistan	Yemen	India
Adults	As (inorganic)						0.01305				
	Methyl Hg	0.22251	0.20664	0.04177	0.07430	0.04356	0.00921				
	Cr (Total)			0.00004				0.00007	0.00000		0.00001
	Cd		0.00027	0.01500		0.00044	0.00193	0.00020	0.00151	0.00137	
	Pb		0.00102	0.01961		0.00012	0.00536	0.00020	0.00035	0.00016	0.00001
	Cu		0.00194	0.00191		0.00436		0.00114	0.00053	0.00002	0.00027
	Zn		0.00656	0.00150			0.00048	0.00174	0.00017	0.00002	0.00031
	Fe			0.00214		0.00031	0.00003	0.00096	0.00017		0.00012
	Mn		0.00269	0.00044		0.00001	0.00003	0.00152			0.00002
	Ni			0.00443		0.00013	0.00519	0.00036	0.00043		
	TTHQ	0.22251	0.21912	0.08684	0.07430	0.04893	0.03528	0.00620	0.00316	0.00157	0.00073
Children	As (inorganic)						0.06090				
	Methyl Hg	1.03838	0.96432	0.19493	0.34674	0.20329	0.04298				
	Cr (Total)			0.00019				0.00031	0.00001		0.00001
	Cd		0.00126	0.07000		0.00203	0.00901	0.00092	0.00703	0.00638	
	Pb		0.00477	0.09151		0.00056	0.02502	0.00094	0.00163	0.00076	0.00006
	Cu		0.00907	0.00892		0.02033		0.00533	0.00247	0.00009	0.00127
	Zn		0.03060	0.00700			0.00224	0.00814	0.00079	0.00008	0.00145
	Fe			0.00998		0.00145	0.00015	0.00450	0.00080		0.00055
	Mn		0.01255	0.00203		0.00006	0.00012	0.00708			0.00007
	Ni			0.02067		0.00060	0.02423	0.00169	0.00201		
	TTHQ	1.03838	1.02257	0.40523	0.34674	0.22832	0.16466	0.02892	0.01474	0.00731	0.00340

crust, and volcanoes [119]. Critical anthropologic sources of methylmercury result from rapid urbanization and industrialization, including coal combustion, paper and cellulose industries, the mining industry and by-products, agricultural fertilizers, and fungicides, and solid waste incineration [120]. Driscoll et al. (2013) noted that mercury's most important anthropogenic sources in the environment are coal combustion [121].

Health Risk Assessment

A total target hazard quotient (TTHQ) equal or less than 1, the non-carcinogenic risk is a safe range, while for TTHQ higher than 1, adverse health effects are considerable [122]. The rank of countries based on the TTHQ in adults was the rank order of health risk assessment by country based on the TTHQ for adult consumers was Malesia(0.22251) > Philippines (0.21912) > Egypt (0.08684) > Taiwan(0.07430) > Bahrain(0.04893) > Iran (0.03528) > China(0.00620) > Pakistan (0.00316) > Yemen(0.00157) > India(0.00073), while the corresponding values for child consumers was Malaysia (1.03838) > Philippines (1.02257) > Egypt (0.40523) > Taiwan (0.34674) > Bahrain (0.22832) > Iran (0.16466) > China (0.02892) > Pakistan (0.01474) > Yemen (0.00731) > India (0.00340) (Table 4). Children in Malaysia and the Philippines were at considerable non-carcinogenic risk [122–125] due to the ingestion of PTEs via the consumption of narrow-barred Spanish mackerel fish (Table 2). The high TTHQ in Malaysia and the Philippines can be correlated with the high concentration of PTEs in the targeted food products (Table 3) and high ingestion rate (Table 2).

Similarly, some studies were conducted regarding PTEs in foods such as seafood, meat products, cereal-based foods, and vegetables and associated health risks in adults and children in Iran [123, 126–130]; TTHQ in the child consumers was ~ 4.68 times higher than adults. The higher TTHQ in children is related to their lower BW, and hence, children are at a higher health risk than adults [125, 131–134].

Differences in concentrations of PTEs in narrow-barred Spanish mackerel fish, ingestion rate, exposure time, exposure frequency, exposures duration, average life-time, body weight, and toxicity of PTEs play significant roles in the health risk of consumers. Hence, we observed various TTHQ values for PTEs in the countries investigated [125, 131, 133–135].

Conclusions

This study was designed to retrieve all the studies on the concentration of PTEs, including inorganic As, methyl Hg, Total Cr, Cd, Pb, Cu, Zn, Fe, Mn, and Ni in fillets of narrow-barred Spanish mackerel fish. Concentrations of PTEs were meta-analyzed according to the country; finally, the exposed population's health risk was estimated. The lowest and highest concentrations in fillets of narrow-barred Spanish mackerel fish were related to Cd and Fe, respectively. Children in Malaysia and the Philippines were at considerable non-carcinogenic risk; hence, control plans for reducing the concentration of PTEs in fillets of narrow-barred Spanish mackerel fish are necessary.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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