Archives of Environmental Contamination and Toxicology
https://doi.org/10.1007/s00244-022-00939-2

Risk and Benefit Analysis of Fish Consumption in NW Mexico: Mercury, Selenium, and Fatty Acids

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Received: 3 January 2022 / Accepted: 18 May 2022

Abstract

To balance the risks and benefits of fish consumption, selenium, fatty acids (DHA + EPA), and mercury in fishery products were determined. Analyzed products were canned tuna, frozen tuna (*Thunnus albacares*), smoked striped marlin (*Tetrapturus audax*), fresh Pacific sierra (*Scomberomorus sierra*), fresh dolphinfish (*Coryphaena hippurus*), fresh tilapia (*Gerres cinereus*), and fresh bullseye puffer (*Sphoeroides annulatus*). Mercury (μg g^{-1} wet weight) ranged from 0.01 (dolphinfish) to 0.23 (bullseye puffer); Se ranged from 0.12 to 0.25. EPA + DHA ranged from 1.16 to 10.72 mg g^{-1}. Intake of EPA + DHA was comparable or above the recommended daily intake; Hg intake was below the reference dose but Se intake was below than recommended values for the different population groups. Considering the HBV_{Se}, fishery products had positive values; i.e., they are healthy food items. According to the interaction of Hg and Se and the rate of fishery product consumption, the risk for consumers is below one percent.

The regular consumption of fish is considered a healthy habit due to the presence of high-quality proteins, minerals and trace elements, fat-soluble vitamins, and polyunsaturated fatty acids omega-3 (Sidhu 2003; Domingo et al. 2007) as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). In particular, DHA is important for normal brain function and development (Yavin et al. 2001) and is known to reduce cardiovascular diseases by lowering triglycerides and lipoproteins in adults (AHANC 2009). The daily recommended intake of omega-3 fatty acids is around 0.4 g d^{-1} EPA + DHA in adults and approximately 1 g d^{-1} (Kris-Etherton et al. 2002) for those with high risk of developing coronary heart disease (CHD). However, these benefits are presumably reduced by the presence of Hg in fish. While some studies suggest the link between neurodevelopment damage and MeHg exposure (Cohen et al. 2005; Axelrad et al. 2007), the association of fish consumption during pregnancy and infant cognition was associated with elevated fish consumption (particularly associated with EPA + DHA intake); contrastingly, the presence of high prenatal levels of Hg was related to lower cognition (Lederman et al. 2008; Oken et al. 2008). A defined balance between the risks and benefits of fish consumption is still unclear (Oken et al. 2016).

From a toxicological perspective, methylmercury (MeHg) is the most important mercury (Hg) species in the environment; it is widely distributed and its presence in the aquatic environment and the human food chain is a topic of concern (Esteban et al. 2015). Methylmercury represents 95% of total Hg content in fish muscle (Downs et al. 1998; Freije and Awadh 2009), being fish consumption the main route of Hg intake in populations with no occupational exposure (McDowell et al. 2004; Cheng and Hu 2012). The main health effect of MeHg exposure is neurotoxicity (Karjalainen et al. 2013), related to its liposolubility, which induces a quick transference between blood and brain

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Published online: 12 June 2022

barriers (Clarkson 2002). In the case of severe exposure, such as in Minamata Japan in 1952, fish consumers suffered a collective neurological disorder, now called Minamata disease (Harada 1968); however, the increasing human risk of chronic exposure to low doses of Hg through fish consumption is estimated in billions of people (FAO/WHO 2011).

In 1967, the protective effect of Se against Hg toxicity was reported for the first time (Parizek and Ostadalova 1967). Selenium (Se) is an essential element for animals, necessary for the normal functioning of enzymes that protect the brain and endocrine tissue from oxidative damage (Raymond and Ralston 2009). Selenium is also essential for the production of selenoproteins such as glutathione peroxidase (WHO 1987) and helps to maintain cellular homeostasis. The requirement of Se for adult men and women is 45 µg d^{-1} (Institute of Medicine, 2000), but in elevated (up to 853 µg d^{-1}) levels (Zhang et al. 2014), Se intoxication (selenosis) can cause nail loss and brittleness, gastrointestinal problems, skin rash, and abnormalities in nervous system (Goldhaber 2003)**.** Nevertheless, health risk assessment associated with Hg exposure through fish consumption also requires the estimation of Se (Kaneko and Ralston 2007). The protective effect of Se against Hg toxicity is attained when Se:Hg ratio is significantly higher than one (Ralston 2008; Ralston and Raymond 2010). Given the antagonism between Hg and Se, the molar ratio of Se:Hg is an essential criterion to assess risk exposure to Hg rather than Hg content alone (Ralston et al. 2006; Ralston and Raymond, 2010). In the context of the co-occurrence of Hg and Se in fish, a Se health benefit value (HBV_{Se}) was developed to follow FDA and EPA guidelines for identifying beneficial and non-beneficial seafood items (Ralston et al. 2016).

Therefore, fishing activity worldwide, in addition to represent an important source of income for many families, it also provides food with many benefits for our health. Besides, an increase of fish consumption is expected worldwide by 2030 (21.5 kg per capita ~ 59 g d^{-1}) being Asian countries the main consumers with the 71% of catch (FAO, 2018). As observed, a variation of fish type consumption exists worldwide. Within a country, the differences are more evident in regions near the coastal or inland waters where fish consumption is usually higher. As a result, evaluating fish Hg without knowing their Se or DHA + EPA content is insufficient to distinguish the actual risk and benefits of fish consumption. Under this perspective, the objectives of the present study are: (1) to determine selenium and fatty acids (DHA + EPA) in the edible portion of frequently consumed fish in NW Mexico, (2) to estimate the daily intake of Hg (MeHg), Se and DHA + EPA using published data of fish consumption in coastal populations from Mexico, (3) to determine the health benefit value of selenium (HBV_{Se}) as an indication of the fish products safety, and (4) to evaluate the risk of co-exposure to Hg and Se through molar ratio of Hg/Se and then contrast the results to the risk considering only Hg.

Materials and Methods

Previous Data

A coastal population located in NW Mexico was used to determinate the risk and benefit of fish consumption (Fig. 1). This area is important because it concentrates the main fishery in the country and most of the products are exported to other countries such as the USA, Hong Kong, Japan, and Spain (CONAPESCA 2018). To determine fish consumption frequency in the Mexican population, the procedure described in García-Hernández et al. (2013) and Ortega et al. (1999) was carried out considering that 80 g of meal is a portion. The results were reported in Zamora-Arellano et al. (2018) in four subgroups: children A (2–10 years old), children B (11–15 years old), women in childbearing age (16–40 years old), and rest of population (men > 16 years old and women > 41 years old). In addition, Hg content in muscle was determined in eight fish products (Table 1), using the procedure of MESL (1997) which consist in an acid digestion using HNO_3 (TMG) on a hot plate (120 °C) for 3 h. Analysis of mercury was made by cold vapor atomic absorption

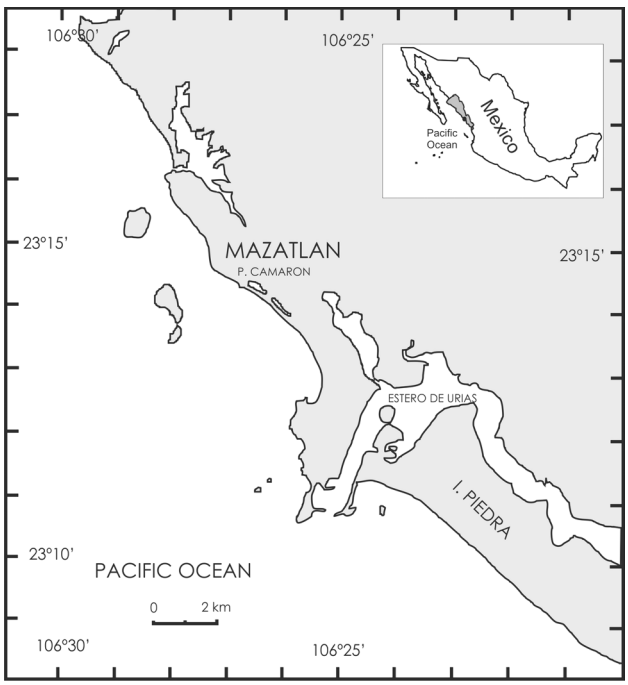

Fig. 1 Location of Mazatlán harbor in NW Mexico, where fish products were purchased

Table 1 Concentrations of Hg and Se (μg g^{-1} ww), range of lipids (%), polyunsaturated fatty acids (PUFA, mg g^{-1}), and eicosapentaenoic acid plus docosahexaenoic acid (EPA + DHA, mg g^{-1}) in eight fish products from NW Mexico. Maximum and minimum values are in parenthesis

Fish product	*N*	Humidity percentage*	Hg*	Se	Lipids	PUFA	EPA + DHA
Canned yellowfin tuna (in oil)	15	72.7 ± 1.6 (78.1–71.2)	0.12 ± 0.17^{a,b,c} (0.39–0.017)	0.12 ± 0.03^{a,b,c,d} (0.17–0.07)	13.1–2.4	80.01 ± 0.35^{a,b,c,d,e,f,g} (80.20–79.61)	5.42 ± 3.16^{a,b,c,d,e,f,g} (8.58–2.27)
Canned yellowfin tuna (in water)	15	75.6 ± 1.8 (77.9–70.9)	0.13 ± 0.08^{d} (0.31–0.04)	0.16 ± 0.03^{e,f} (0.23–0.11)	2.2–0.4	9.20 ± 1.05^{a,h,i,j,k,l} (10.28–8.17)	3.05 ± 0.65^{a,h,i} (3.75–2.46)
Fresh yellowfin tuna (frozen)	15	75.4 ± 0.8 (77.2–74.1)	0.20 ± 0.07^{a,e,f} (0.36–0.09)	0.25 ± 0.06^{a,e,g} (0.35–0.16)	1.1–1.0	3.90 ± 0.92^{b,h,m,n,o} (4.58–2.85)	1.16 ± 0.54^{b,j,k} (1.60.0.06)
Fresh bullseye puffer	15	77.4 ± 0.6 (78.4–76.0)	0.23 ± 0.21^{c,j,k} (0.37–10)	0.18 ± 0.03 (0.23–0.13)	0.7–0.2	3.86 ± 0.29^{c,i,p,q,r} (4.12–3.55)	1.50 ± 0.30^{e,n,p} (1.74–1.16)
Fresh dolphinfish	15	69.7 ± 2.22 (77.0–68.0)	0.01 ± 0.01^{b,d,e,g,i,j} (0.03–0.01)	0.20 ± 0.05^{c,i} (0.25–0.08)	3.9–3.5	18.54 ± 1.52^{d,j,m,p,s,t,u} (19.99–16.95)	8.51 ± 1.70^{d,h,j,l,n,o} 10.21–8.52)
Fresh Pacific sierra	15	73.9 ± 0.9 (74.9–71.6)	0.07 ± 0.01^{f,h,k} (0.17–0.07)	0.14 ± 0.06^{g,h,i,j} (0.35–0.09)	9.4–2.3	32.84 ± 6.31^{f,l,n,q,t,v,x} (40.10–28.71)	10.72 ± 4.44^{f,i,k,m,p,q} (15.83–7.87)
Fresh tilapia	15	73.2 ± 0.8 (75.1–72.0)	0.15 ± 0.19^{i} (0.10–0.057)	0.23 ± 0.04^{d,f,j} (0.35–0.18)	2.8–0.6	8.47 ± 1.97^{g,o,r,u,w,x} (10.63–6.77)	1.91 ± 0.93^{g,o,q} (2.94–1.12)
Striped marlin (smoked)	15	67.8 ± 2.5 (71.1–60.9)	0.15 ± 0.04^{g,h} (0.26–0.09)	0.21 ± 0.03^{b,h} (0.27–0.17)	1.3–0.7	4.83 ± 1.15^{e,k,s,v,w} (5.82–3.56)	1.45 ± 0.73^{c,l,m} (2.17–0.71)

*From Zamora-Arellano et al. (2018); for a given column, same superscript letters indicate significant differences ($p < 0.05$)

spectrophotometry (CV-AAS) Buck Scientific (model 401-A), and the results were expressed in μg g^{-1} wet weight basis.

Se and Fatty Acids Analyses

The quantification of Se and DHA + EPA was carried out using the same fish samples used in Zamora-Arellano et al. (2018). To improve the reproductibility and reduce interferences of Se analyses, a reduction from selenate (VI) to selenite (IV) is commonly made using HCl, due to its ease of handling and because it does not generate secondary reactions (Diaz-Alarcon et al., 1994; Chasteen, 2000). Therefore, before Se analyses, 2 mL of HCl (J.T. Baker; trace metal grade) was added to the digestion solutions and standards (calibration curve 2, 4, 6, 8, and 20 ppb) and placed in a polyethylene container in a water bath at 120 °C for 45 min (Vega-Sanchez et al. 2020). Quantification of Se was performed using a hydride generation atomic absorption spectrophotometry (HG-AAS) in a Varian (SpectrAA FS-240) instrument. The concentration of Se is expressed as μg g^{-1} wet weight basis. For DHA + EPA analysis, a sample of 150 g of fresh muscle was processed according to Folch et al. (1957) method. The fatty acid identification was performed by comparing with Supelco 37 FAME mix standard (CRM47885) using pentadecane as an internal standard. The quantification was made using a BRUKER SCION 456-GC gas chromatographer, and the results were expressed as mg g^{-1}.

Risk and Benefit of Fish Consumption Associated to Hg, Se and Fatty Acids

A non-carcinogen risk model was considered to determine the risk of fish consumption using the US EPA (2000) procedure and described in Zamora-Arellano et al. (2018), which consists of assessing Hg exposure and Se intake using the following equation:

$$E_{m,j} = \frac{\sum \left(C_{m,j} \cdot CR_j \cdot P_j\right)}{\mathrm{BW}} \quad (1)$$

where *Em,j* is the individual exposure to a chemical *m* from ingesting fish species *j* (μg/kg body weight per day), *Cm,j* is the concentration of a chemical (*m*) in the edible portion of fish species *j* (μg/kg wet weight basis), CR*j* is the consumption rate of fish species *j* (kg/d), *Pj* is the proportion of a given fish species in an individual's diet (unitless), and *BW* is the body weight (kg) of a consumer.

The individual risk ratio for Hg was estimated considering the individual exposure (*Em,j*) and the oral reference dose (RfD) in its methylated form (assuming the 100% of Hg is this form)-0.1 μg MeHg per kg/d (NAS 2000).

$$\text{Risk ratio} = \frac{E_{m,j}\left(\mu g\,\mathrm{kg\,bw^{-1}\,d^{-1}}\right)}{\mathrm{RfD}\left(\mu g\,\mathrm{kg\,bw^{-1}\,d^{-1}}\right)} \quad (2)$$

When risk ratios greater than 1 (i.e., when MeHg exposure exceeds the RfD), **it** indicates that a potential risk to human health exists (US EPA 2001). Additionally, to

integrate selenium-specific nutritional benefits related to potential Hg exposure risks derived from fish consumption, two scenarios were carried out: considering only Hg (as reported in Zamora-Arellano et al. 2018), and taking into account the Hg:Se molar ratio calculated by dividing the concentrations in mg per kg by the molecular weight (78.96 for Se and 200.59 for Hg) and an adjusted risk ratio (Hg/Se risk ratio).

Other variables of interest were: (a) individual EPA + DHA intake (in mg g^{-1}) from ingested fish (Eq. 3),

$$\text{EPA} + \text{DHA} = \text{food}\left(\text{g d}^{-1}\right) \cdot \text{EPA} + \text{DHA} \tag{3}$$

and (b) health benefit value of selenium (HBV_{Se}-Eq. 4) Se and Hg are given in µmol kg^{-1}.

$$\text{HBV}_{\text{Se}} = \left(\frac{[\text{Se}] - [\text{Hg}]}{[\text{Se}]}\right) \cdot \left([\text{Se}] + [\text{Hg}]\right) \tag{4}$$

The sign of the HBV_{Se} value indicates whether food might improve or reduce Se status, while the scale of the value is proportional to the excess or deficit of Se (Ralston et al. 2016).

All determinations were made using a probabilistic approach via the Oracle Crystal Ball 11.1.2.3.500 software to estimate the range of exposure to mercury and the intake of Se and DHA + EPA in the population groups, with a Monte Carlo analysis using 10,000 iterations (US EPA 2001). This technique is a tool that helps to estimate the distribution of Hg, Se, and EPA + DHA among populations (US EPA 2000); besides, this type of analysis reduces uncertainty, using the natural fluctuations and the variability of the data caused by differences in body weight, fish consumption rates, chemical concentration fluctuations, and frequency of exposure (Dong et al. 2015).

Quality Control

Precision and accuracy of Hg and Se determinations were assessed by using a certified reference material of fish muscle (DORM-3). Recovery percentages of mercury were 98–102% (Zamora-Arellano et al. 2018), and the limit of detection was 0.012 µg g^{-1}; for selenium, the recovery percentage ranged from 99 to 101% and limit of detection was 0.01 µg g^{-1}; both elemental concentrations are given as µg g^{-1} wet weight basis. The minimum accepted correlation coefficient of the calibration curve for each metal was 0.995. All samples were made in duplicates, and blanks and reference materials ($n = 8$) were included with every batch of 30 samples.

For fatty acids, a Supelco 37 FAME mix (CRM 47885) was used for the analytical determination. Significant differences ($P < 0.05$) of Se and DHA + EPA among the fish products were identified by Kruskall–Wallis non-parametric ANOVA using Graph Pad Prism 7.0 (Graph Pad Software, San Diego, CA). All the results are expressed as mean ± standard deviation.

Results and Discussion

Mercury, Selenium, and EPA + DHA in Fish

Analyzed fish products were canned yellowfin tuna (light and oil presentation), frozen yellowfin tuna (*Thunnus albacares*), smoked striped marlin (*Tetrapturus audax*), fresh Pacific sierra (*Scomberomorus sierra*), fresh dolphinfish (*Coryphaena hippurus*), fresh tilapia (*Gerres cinereus*), and fresh bullseye puffer (*Sphoeroides annulatus*). Mercury levels (µg g^{-1} ww) ranged from 0.01 (dolphinfish) to 0.23 (bullseye puffer), with an average of 0.13 (Table 1); all Hg values were below the maximum permissible limits (0.5 µg g^{-1} ww) in the Mexican Legislation (NOM 2009). Though Hg levels were variable, significant differences were found; Hg in bullseye puffer was significantly ($p < 0.05$) higher than in canned yellowfin tuna (in oil), fresh dolphinfish, and fresh + Pacific sierra. On the contrary, Hg concentrations in fresh dolphinfish were significantly ($p < 0.05$) lower than in all fish products except fresh Pacific sierra. In comparison with other studies with the same fish products of the current study, average concentrations of Hg were comparable to concentrations reported in canned tuna in oil and water (Ruelas-Inzunza et al. 2011), fresh tuna (Adams 2004), and fresh dolphinfish (Sellanes et al. 2002; Cai et al. 2007). In the case of fresh Pacific sierra, our results were lower than Hg concentrations reported by Ruelas-Inzunza et al. (2008). Levels of Se (µg g^{-1} ww) ranged from 0.12 to 0.25; similar to Hg, concentrations of Se were variable but significant differences ($p < 0.0001$) were found. Levels of Se in fresh yellowfin tuna and fresh tilapia were significantly higher than in canned tuna (in oil), canned tuna (in water), and fresh Pacific sierra (Table 1). Our Se values are lower than reported in different brands of tuna in Mexico of 0.52 ± 22 µg g^{-1} ww (Ordiano-Flores et al. 2012) and in other studies in fresh tuna (range 0.27–0.96 µg g^{-1} ww) worldwide (Burger et al. 2011; Fang et al. 2011; Polak-Juszczak 2015). With respect to Se levels in dolphinfish in our study (0.20 µg g^{-1} ww), concentrations are lower than in another study (0.6 µg g^{-1} ww) with *C. hippurus* (Bergés-Tiznado et al. 2019) in the region, and in other areas (range 0.37–0.647 µg g^{-1} ww) of the world (Kaneko and Ralston 2007; Burger et al. 2011; Bodin et al. 2017). Normally, Se is present in fish and may protect against Hg toxicity (Yang et al. 2008; Khan and Wang 2009); however, at high levels it may produce negative effects on growth, survival, and reproduction in fish (Janz 2011). Nevertheless, the effects of the interaction between

Se and Hg on reproduction are limited and poorly understood (Penglase et al. 2014).

Levels of lipids, polyunsaturated fatty acids (PUFA), and EPA + DHA in the different fish products are also included in Table 1. The percentage of lipids ranged from 13.1 (tuna canned in oil) to 0.7 (bullseye puffer); the concentrations of PUFA ranged from 80.01 mg g^{-1} (tuna canned in oil) to 3.86 mg g^{-1} (bullseye puffer). Levels of PUFA in canned tuna (in oil) were significantly ($p < 0.0001$) more elevated than in all other fish products; contrastingly, the fresh bullseye puffer had significantly ($p < 0.0001$) lower amounts of PUFA than the rest of the studied fishery products (except fresh yellowfin tuna). Lipid content in our study was comparable to values (range 1.40–18.8 g/100 g) reported in 15 marine fish species from the southeast coast of Brazil (Visentainer et al. 2007) and in four marine fish (range 1.06–7.72 g/100 g) from the eastern central Pacific coast of Panama (Murillo et al. 2014). With respect to PUFA's in fish species similar to our study, the value (28.13) in *Scomberomorus sierra* from Panama (Murillo et al. 2014) was similar to the concentration (32.84) reported the fresh Pacific sierra in our research. Similarly, PUFA concentration (43.4) in tuna *Thunnus thynnus* from Brazil (Visentainer et al. 2007) was in the same magnitude order to our result (80.01) in canned (in oil) yellowfin tuna. The concentration of EPA + DHA ranged from 1.16 to 10.72 mg g^{-1}. Levels of EPA + DHA were significantly ($p < 0.0001$) more elevated in two fishery products (dolphinfish and Pacific sierra) than in the rest of the compared products. Ginsberg and Toal (2009) reported levels of EPA + DHA in commonly eaten fish in USA ranging from 1.45 to 21.5 mg g^{-1}; Cardoso et al. (2010) reported levels from 0.50 to 43.3 mg of EPA + DHA g^{-1} in fishes that represent specific European diet patterns.

Fish Consumption and Intake of Se, Hg and EPA + DHA

The rate of fish consumption (CR*j*) was estimated according to Zamora-Arellano et al (2018) in four subgroups: children A (2–10 years old), children B (11–15 years old), women in childbearing age (16–40 years old), and rest of population (men > 16 years old and women > 41 years old). Results of CRj, daily intake ($E_{m,j}$) of Hg, Se, and EPA + DHA are provided in Table 2 and Fig. 2. The rate of fish consumption (CR*j*) ranged from 126 to 391 g d^{-1} in the following order, children A < women in childbearing age < children B < rest of population. The rate of consumption in women in the present study was comparable to women from a urban coastal community in the USA (Hollman and Newman 2012) with an average consumption of 137 g d^{-1} and by females (18–49 years old) from coastal rural communities

Table 2 Rate of fish consumption (CR*j*), daily intake of Hg, Se and EPA + DHA risk ratio of exposure to MeHg in different population groups of NW Mexico

	Children A (2–10 year old, $n = 20$)	Children B (11–15 years old, $n = 39$)	Women in childbearing age (16–40 years old, $n = 100$)	Rest of population (men > 16 years old and women > 41 years old, $n = 211$)
Weight (kg)[a]	28 ± 14	51 ± 7	62 ± 11	77 ± 13
Age (years)[a]	7 ± 3	13 ± 2	23 ± 6	38 ± 18
CR_{food} ($g\ d^{-1}$)[a]				
Canned yellowfin tuna	14 ± 17	38 ± 65	30 ± 33	44 ± 88
Fresh yellowfin tuna	11 ± 7	6	14 ± 22	91 ± 176
Smoked yellowfin tuna	–	–	7 ± 5	42 ± 41
Bullseye puffer	10 ± 11	33 ± 206	11 ± 28	29 ± 110
Dolphinfish	16 ± 20	7 ± 8	13 ± 24	38 ± 95
Striped marlin	9 ± 5	34 ± 60	22 ± 29	35 ± 41
Tilapia	34 ± 70	19 ± 41	19 ± 67	52 ± 83
Sierra	23 ± 80	26 ± 30	22 ± 42	59 ± 82
CR_j ($g\ d^{-1}$)[a]	126 ± 103	164 ± 186	139 ± 95	391 ± 286
Daily intake ($E_{m,j}$)				
Hg ($\mu g\ kg^{-1}\ bw^{-1}\ d^{-1}$)[a]	0.1063 ± 0.2544	0.0805 ± 0.1147	0.04 ± 0.04	0.1100 ± 0.1409
Se ($\mu g\ kg^{-1}\ bw^{-1}\ d^{-1}$)	0.1668 ± 0.2548	0.1000 ± 0.1020	0.0601 ± 0.045	0.1494 ± 0.1660
EPA + DHA ($mg\ d^{-1}$)	552.65 ± 682.02	640.41 ± 501.44	588.23 ± 496.35	1,478.21 ± 1,360.19
MeHg risk ratio[a,b]	1.06 ± 3.47 (25)	0.80 ± 1.12 (22)	0.42 ± 0.38 (5)	1.10 ± 1.41 (32)
Hg/Se Molar risk ratio[b]	0.24 ± 0.25 (< 1)	0.32 ± 0.31 (< 1)	0.41 ± 0.42 (< 1)	0.29 ± 0.29 (< 1)
Free µmolar Se–Hg	1.60 ± 0.99	1.25 ± 1.30	0.76 ± 0.63	1.84 ± 1.27

[a]Data obtained from Zamora-Arellano et al. (2018)

[b]Data in parenthesis indicate percentage at risk

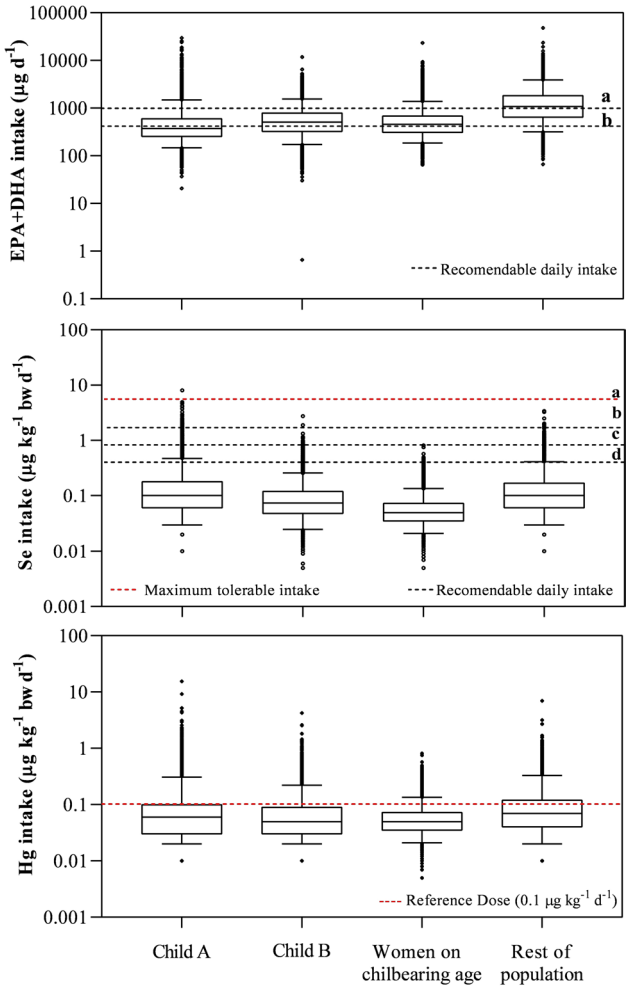

Fig. 2 Daily intake of EPA + DHA, Se, and Hg in different population groups from Mazatlán harbor (NW Mexico). Boxes represent the 5 to 95 confidence levels. For DHA + EPA section, line a represents recommendable daily intake (1000 µg d^{-1}) for people at high risk of developing coronary heart disease (CHD) and line b represents recommendable daily intake (0.3–0.5 µg d^{-1}) in adults (Kris-Etherton et al. 2002). For Se section, line a represents the maximum tolerable intake (400 µg d^{-1} or 5.7 µg kg^{-1} d^{-1}), and lines b, c and d represent the recommendable daily intake for children A (30 µg d^{-1} or 1.27 µg kg^{-1} d^{-1}, adults (55 µg d^{-1} or 0.76 µg kg^{-1} d^{-1}) and children B (40 µg d^{-1} or 0.67 µg kg^{-1} d^{-1}) respectively. For Hg section, line represents the reference dose of MeHg (0.1 µg kg^{-1} d^{-1}), assuming that 100% of Hg is in methylated form (MeHg)

of Malaysia (136.4 g d^{-1}), the highest fish consumer country in Southeast Asia (Jeevanaraj et al. 2016). However, these results are lower compared to women from fishing communities of Sonora (Mexico) (average 307 ± 325 g day^{-1}) reported by García-Hernández et al. (2018).

The daily intake of Hg ($E_{m,j}$) ranged from 0.04 µg kg^{-1} bw^{-1} d^{-1} in women in childbearing age to 0.1100 µg kg^{-1} bw^{-1} d^{-1}, in the group rest of population. In Fig. 2 Hg section, line represents the reference dose of MeHg (0.1 µg kg^{-1} d^{-1}). According to Zamora-Arellano et al. (2017), tuna products (canned and fresh presentation), tilapia, and smoked marlin are the main contributors of Hg in diet. In the general population, contribution of the referred fish products was variable depending on the subgroups (84% in children A, 90% in children B, 65% in women in childbearing age, and 75% for the rest of population); in the fishing-related population contribution was also variable (85% in children A, 63% in children B, 93% in women in childbearing age, and 84% in the rest of population). In a recent study in Mexico (Cantoral et al. 2018), it was estimated that 75% of Hg in diet comes from school shark and tuna; however, they reported a seafood consumption of 10.36 g d^{-1} that represents an annual intake of 4 kg, and such figure is lower than our results and the domestic fish consumption of 38 g d^{-1} (CONAPESCA 2018).

With respect to the daily intake of Se, women in childbearing age had the lowest Se intake (0.0601 µg kg^{-1} bw^{-1}) while children A had the highest (0.1668 µg kg^{-1} bw^{-1}) values (Table 2, Fig. 2). In Fig. 2 Se section, line *a* represents the maximum tolerable intake of Se (400 µg d^{-1}), and lines *b*, *c*, and *d* represent the recommendable daily intake for children A (30 µg d^{-1}), adults (55 µg d^{-1}), and children B (40 µg d^{-1}), respectively. According to the Institute of Medicine (2000), the daily recommended intake rates of Se are 2.0, 1.5, and 0.8 µg kg^{-1} bw^{-1} for infants (0–12 months), children (1–18 years), and adults (19–50 years), respectively; i.e., in all population groups the average $E_{m,j}$ was lower than recommended. For EPA + DHA, the American Heart Association (AHANC 2009) recommends a daily intake of 500 mg (Kris-Etherton et al. 2002) and sets a safe value of 3 g d^{-1} of total intake of EPA + DHA, including diet and supplements (FDA 1997). In Fig. 2 EPA + DHA section, line *a* represents recommendable daily intake (1000 µg d^{-1}) for DHA + EPA for people at high risk of developing coronary heart disease (CHD) and line *b* represents recommended daily intake (0.3–0.5 µg d^{-1}) for DHA + EPA in adults (Kris-Etherton et al. 2002). An excess of EPA + DHA consumption can cause adverse effects, including bleeding episodes, impaired immune function, increased lipid peroxidation, and impaired lipid and glucose metabolism (EFSA 2012). In the present study, the daily EPA + DHA intake in children A was 552.65 mg d^{-1}, in children B 640 mg d^{-1}, in women in childbearing age 588.23 mg d^{-1}, and in the rest of population 1478.21 mg d^{-1}; in all cases, the adult groups (> 16 years) are ingesting more than the recommended intake of 500 mg of EPA + DHA (Table 2, Fig. 2), but not exceeding the safe intake. Mean daily intake of EPA + DHA varies depending on the age and gender in different countries (see EFSA 2012), and the highest values (2.70 g d^{-1}) were found in adults from France, and in Norwegian children of 1–3 years old (range 0.40–0.60 g d^{-1}). For the Mexican population, an average of 0.169 g d^{-1} of EPA + DHA was found (Cantoral et al. 2018). Omega-3 counteracts cardiovascular and brain

development alterations. Clinical evidence demonstrated that an EPA + DHA intake above 250 mg d^{-1} decreased coronary heart disease mortality in 20 combined prospective cohort studies; on the contrary, with omega-3 intakes below 250 mg d^{-1} (100 mg d^{-1}) there was a 14.6% increase in CHD mortality (Mozaffarian and Rimm 2006). DHA has been associated with a number of beneficial effects on neurocognitive and ocular function in early and late life stages (Ginsberg and Toal 2009); e.g., an increase in visual acuity in newborns (Uauy et al. 2003). An increase of 2.0 points in visual scores was observed in infants for every 100 mg d^{-1} DHA of ingestion, measured as neurodevelopmental test batteries as VRM (visual recognition memory) (Oken et al. 2005, 2008). In adults, a prevention of neuropsychiatric disorders and attention deficit disorders (Calon and Cole 2007; Young and Conquer 2005) has been related to DHA.

Risk and Benefits of Hg and Nutrients

HBV_{Se} in Fish

Selenium health benefit value is maybe the only tool that can identify those fish products that can be consumed without restriction, because it considers the simultaneous concentration of Hg and Se in fish. The HBV_{Se} value provides a reliable, easily understood, and consistent index for identifying healthy seafood choices (Ralston et al. 2016). Average HBV_{Se} values in the analyzed fish products were positive (Table 3, Fig. 3), with the exception of three samples of tuna products (canned in oil $n = 2$ and canned in water $n = 1$) where HBV_{Se} figures were negative (−2.25, −1.39, and −0.25, respectively). No clear trend was observed in the different fish species according to the trophic level; i.e., the highest HBV_{Se} values did not correspond with the top predators; similarly, the fish species with the lowest trophic level had higher HBV_{Se} than other species of higher trophic level. Comparing these benefit values with those reported in other regions, our results are much lower than reported in tuna ($HBV_{Se} = 15.6$) from Hawaii (Ralston et al. 2016),

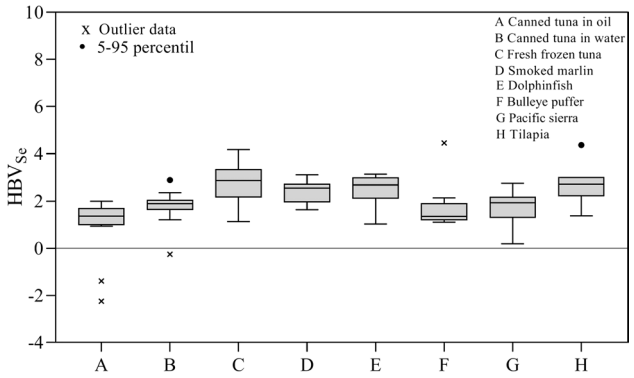

Fig. 3 Selenium health benefit values (HBV_{Se}) in eight fish products consumed in Mazatlán harbor (NW Mexico). Boxes represent the 5 to 95 confidence levels. HBV_{Se} values above cero indicate "beneficial to consume" according to Ralston et al. (2016)

dolphinfish ($HBV_{Se} = 31.0$) from India (Bodin et al. 2017), and tuna ($HBV_{Se} = 9$) from the Mexican Pacific (Ruelas-Inzunza et al. 2018). Overall, according to the average HBV_{Se}, the consumption of all the fish species from the present study is beneficial to human.

Hg/Se Ratio Versus Hg in Diet

Food is the major source of exposure to essential and non-essential metals. The levels of chemicals in fish tissue provide only part of the exposure profile. To accurately assess potential risk associated with exposure, the amount of fish consumed and the concentrations of Hg must be considered. Considering MeHg content (risk ratio) in the edible portion of fish and the fish consumption rate (Table 2), the percentage of population at risk ranged from 5 to 32%, where groups with the highest values were children A and the rest of population (25% and 32% respectively); however, the protection of Se against Hg was not considered. According to the above, a Hg/Se molar ratio was calculated (Table 2), and the results in all populations groups were below the unit (Fig. 4), which means a protective effect of Se to human

Table 3 Hg and Se concentrations (μmol kg^{-1}), Hg/Se and Se/Hg molar ratios, free Se, and Se health benefit values (HBV_{Se}) in the analyzed fish products

Fish product	Hg	Se	Hg/Se	Se/Hg	Free Se	HBV_{Se}
Canned yellowfin tuna (in oil)	0.58 ± 0.60	1.49 ± 0.34	0.43 ± 0.52	6.47 ± 6.94	0.91 ± 0.71	0.97 ± 1.18
Canned yellowfin tuna (in water)	0.63 ± 0.35	2.06 ± 0.40	0.33 ± 0.24	4.43 ± 2.93	1.43 ± 0.60	1.78 ± 0.68
Fresh yellowfin tuna (frozen)	0.97 ± 0.36	3.15 ± 0.70	0.32 ± 0.14	3.56 ± 1.08	2.18 ± 0.69	2.80 ± 0.79
Fresh dolphinfish	0.06 ± 0.04	2.49 ± 0.62	0.03 ± 0.03	67.55 ± 40.11	2.44 ± 0.63	2.49 ± 0.62
Fresh bullseye puffer	1.05 ± 0.51	2.28 ± 0.38	0.47 ± 0.24	2.67 ± 1.27	1.23 ± 0.63	1.68 ± 0.72
Fresh Pacific sierra	0.34 ± 0.07	1.74 ± 0.82	0.22 ± 0.07	5.25 ± 2.58	1.40 ± 0.82	1.67 ± 0.84
Fresh tilapia	0.72 ± 0.64	2.93 ± 0.46	0.24 ± 0.21	7.91 ± 6.62	2.24 ± 0.79	2.65 ± 0.66
Striped marlin (smoked)	0.76 ± 0.20	2.67 ± 0.36	0.29 ± 0.10	3.72 ± 1.17	1.90 ± 0.45	2.42 ± 0.45

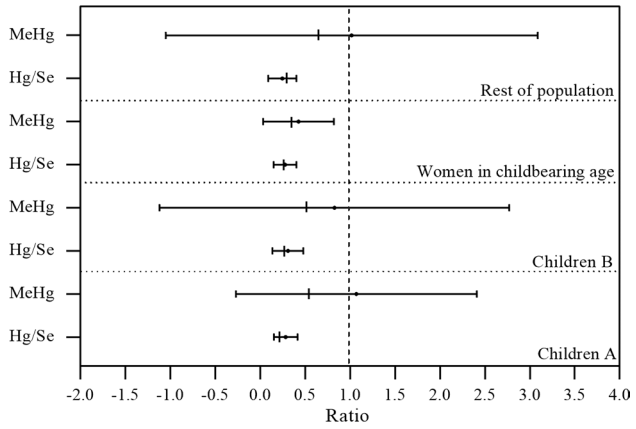

Fig. 4 Mean (●), median (|) and 5–95 confidence intervals of MeHg risk ratio versus Hg/Se molar ratio for different population groups from Mazatlan harbor (NW Mexico). Risk was calculated assuming that 100% of Hg is in methylated form (MeHg). Vertical dotted line indicates the threshold for risk ratio, where > 1 indicates a potential health risk

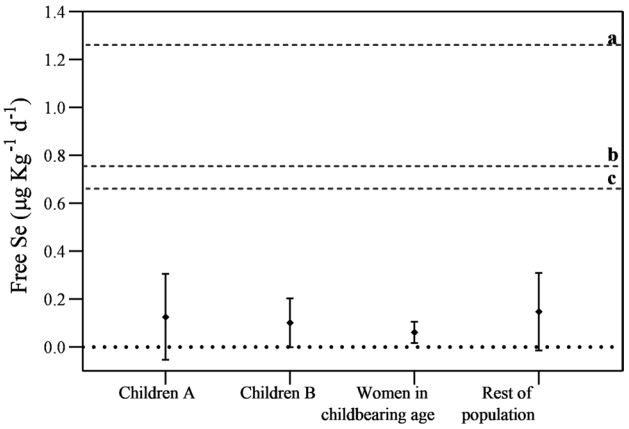

Fig. 5 Free selenium (mean ± standard deviation) after forming the complex Se–Hg. Dotted lines a, b and c represent the recommended daily intake of Se for children A (2–10 years old), adults (women and rest of population) and children B (11–15 years old) respectively. The results are in µg of free Se per kg of body weight per day

health. Using the Hg/Se criterion, a new risk was calculated and the percentage of population at risk decreased to < 1% in all populations groups (Table 2).

Perspectives

The risk assessment of Hg exposure through fish consumption is a challenge, considering that the relationship between maternal fish intake and infant neurodevelopment is complex and not clear (Valent et al. 2013). Reviewed data on global Hg exposure from seafood consumption revealed that populations from coastal areas may have an elevated risk of adverse Hg health effects (Sheehan et al. 2014) so international trades for fishery products are a matter of concern. Though several studies have demonstrated that the molar ratio of Hg:Se with low Hg content is favorable (Grgec et al. 2020; Sobhanardakani, 2017), there is still a controversy on how much Se (based on Hg:Se molar ratio) is needed to protect against Hg toxicity in humans (Burger and Gochfeld 2012; Gochfeld et al. 2012), so the importance of including other sources of Se in our diet. In Mexico, the use of soy as an additive in canned tuna has resulted in the replacement of up to 60% of the net content of tuna (PROFECO 2019). Although soy addition is not generally accepted by consumers, this measure may indirectly reduce Hg bioavailability since soy is a food with high selenium content (0.14 µg g^{-1} dry weight) that may reduce Hg toxicity (Vinchira and Muñoz-Ramírez 2010). Nevertheless, the consequences of elevated Se levels in human populations chronically exposed to MeHg have not been well established. In the present study, the amount of free selenium after forming the complex Se/Hg is not enough to fulfill the metabolism needs (Fig. 5). Besides, we have to consider that Se also has affinity to others metals as As, Cd, and Pb and may compete with Hg, so the protection against these metals will decrease. Establishing the balance of risk and benefits on a fish diet is a topic of concern to health professionals and public policy-makers. Use solely Hg to establish the risks without considering the antagonism of Se, which could lead to incomplete information to make choices for the consumer, and considering only its benefits as Se or EPA + DHA may be also misleading. In Mexico, the information of Hg and Se levels in commercial fish is limited, and the regulatory dependencies promote the increasing in fish consumptions based mainly on its benefits and do not consider the potential health risk of Hg and other contaminants. With the implementation of the Minamata Convention, our country needs to integrate research, development, and monitoring programs between governmental and nongovernmental agencies to inform and educate the public about Hg and its effects, and include fish consumption advisories.

Conclusions

Though Hg levels were variable, concentrations in bullseye puffer were significantly higher than in canned yellowfin tuna, dolphinfish, and Pacific sierra; in the case of Se, fresh yellowfin tuna and fresh tilapia had the highest concentrations. Levels of PUFA in canned tuna (in oil) were higher than in all other fishery products. Levels of EPA + DHA were more elevated in dolphinfish and Pacific sierra than in the rest of the compared products. Intake of EPA + DHA was comparable or above the recommended daily intake; Hg intake was below the reference dose but Se intake was

below than recommended values for the different population groups. Considering the HBV_{Se}, all fishery products had positive values; i.e., they are healthy food items. According to the interaction of Hg and Se and the rate of fishery product consumption, the risk for all population groups is below 1 percent.

Acknowledgements We acknowledge laboratory support by Migdalia Sarahy Navidad and Gabriela Aguilar Zárate.

Funding This work was supported by the Ministry of Public Education of Mexico under grant number 7596.20-P.

Declarations

Conflict of interest The authors report no conflict of interest.

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