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Total Mercury and Selenium in wild Shrimp from Coastal Lagoons of Northwest Mexico: Human Health risk Assessment

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Abstract

This study analyzed total mercury (THg), and selenium (Se) in edible tissues of white shrimp (*Litopenaeus vannamei*), blue shrimp (*L. stylirostris*) and brown shrimp (*F. californiensis*), from three states of the Northwest of Mexico in September and October 2017. Concentrations of THg and Se in the muscle were between 0.026 and 0.829 and 0.126–1.741 µg/g dry weight (dw), respectively. Significant differences were observed among Hg concentration of Sonora and Nayarit and among Se concentration of Sinaloa and Nayarit. In addition, the health risk assessment (HQ) in the three species of shrimp was between 0.550 and 0.607. All Se:Hg molar ratios were >1 and positive HBV_{Se} values that showed that shrimp from Northwest of Mexico does not represent a risk to human health.

Keywords Shrimp · Mercury · Selenium · Northwest Mexico · Risk assessment

Introduction

Coastal ecosystem pollution is an environmental problem. Heavy metals are present in coastal ecosystems worldwide, and these inorganic contaminants are a growing concern for human health since they are highly toxic, persistent, and bioaccumulate along the trophic web (Siddiqui and Saher 2022). Coastal ecosystems are critical for metal pollution because they are impacted by urban waste discharges, agro-industrial effluents, and other human activities (Aydi et al. 2022).

Coastal fisheries provide valuable food for human populations. Mexican shrimp fishery has a commercial interest, such as *Litopenaeus vannamei, L. stylirostris*, and *Farfantepenaeus californiensis*, which have nutritional components for coastal communities in NW Mexico and their consumption is widespread and frequent. Of these shrimp species, *L. stylirostris*, and *F. californiensis* are exported to USA and Europe, respectively. Moreover, marine crustaceans have been considered excellent metal biomonitors due to its close contact with sediments (Rodrigues et al. 2022).

Mercury (Hg) is a toxic and non-essential element emitted into the environment by natural processes or several human activities (Rodrigues et al. 2022). Hg consumption

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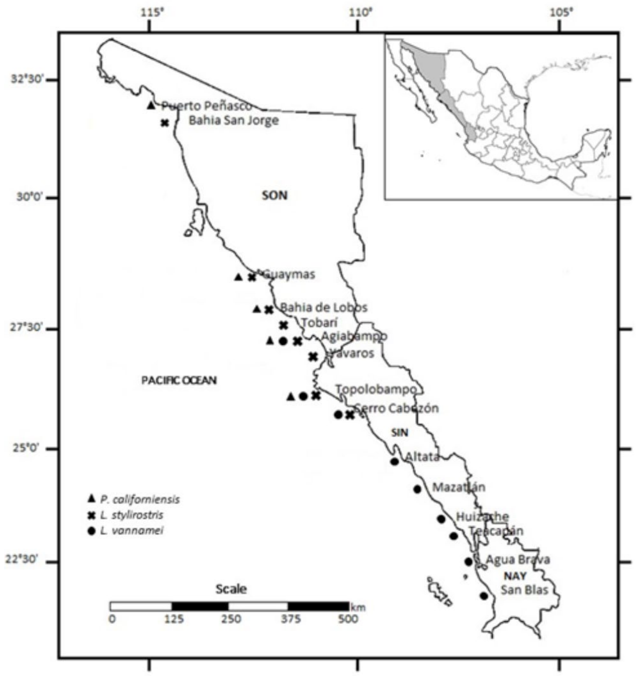

Fig. 1 Study Area. SON: Sonora State, SIN: Sinaloa State, NAY; Nayarit State

from seafood could have harmful effects on nervous, immune, and reproductive systems due to its bioaccumulation and biomagnification along trophic levels, showing a critical threat to human health, particularly in the development of fetuses and young children (Issifu et al. 2022). On the other hand, selenium (Se) is a metalloid considered an essential element for life, Se trace concentrations are required for normal growth and development, and moderate concentrations are used for homeostatic functions, but in high concentrations is also toxic for organisms (Zhang et al. 2020). Studies indicate a high affinity and binding interaction between Hg-Se (Raymond and Ralston 2020). Selenium sequesters Hg and reduces its biological availability and it is known as the antagonistic of Hg; because this element neutralizes Hg toxicity if it is in a 1:1 molar ratio (Hoang et al. 2017). While Hg reduces the activity of Se dependent enzymes by formation of insoluble mercury-selenides (Raymond and Ralston 2020). Research into Hg-Se interactions in fish and seafood species is useful understand the protection or risk level to Hg's toxic effects.

The objectives of this study were (i) to determine total mercury (THg) and Se concentrations in the edible muscle of shrimp species from coastal lagoons in NW Mexico, and (ii) to provide Se:Hg molar ratio and the human health risk assessment.

Methods and Materials

Shrimp samples were obtained from industrial shrimp vessels caught between September and October 2017 from seven coastal lagoons in Sonora, six in Sinaloa, and two in the Nayarit State (NW Mexico, Fig. 1). Samples of 15 organisms/shrimp species (*L. vannamei, L. stylirostris*, and *F. californiensis*) in the same total length (TL) range of 12 and 16 cm, were collected at each coastal lagoon, according to their availability. Specimens were placed in double ziplock plastic bags and immediately transported in coolers (at 4 °C) to the laboratory.

At the laboratory, organisms were identified using their phenotypic characteristics and carefully dissected (to avoid contamination with other organs/tissues) to obtain edible muscle. Composite samples (by shrimp species) were used for each lagoon. Tissues were lyophilized (72 h at 80×10^{-3} mbar at -45 °C). Subsequently, the samples were ground in a teflon mortar and stored in polyethylene containers until analysis. Each composite sample was analyzed in triplicate (approximately 0.25 g) and digested overnight in 60 ml SAVILLEX Teflon containers with 5 ml of concentrated HNO_3. Digestion was carried out in the same container on a ceramic plate at 120 °C for 4 h. Subsequently, each digested sample was diluted to 25 ml with Milli-Q water. For THg quantification, a Buck Scientific model 410 mercury analyzer was used after reduction with $SnCl_2$ (Loring and Rantala 1992); and a Thermo Element XR high-resolution ICP-mass spectrometer (HR-ICP-MS) was used for Se determination (Soto-Jiménez et al. 2008).

For QA/QC, blanks were used to check contamination, all materials were acid-washed, and trace metal grade reagents were used. Certified reference material TORT-3 gave 104.34 and 112% recovery for THg and Se, respectively. Detection and quantification limits were 0.01 and 0.07, and 0.03 and 0.23 µg/g for THg and Se, respectively.

For statistical analysis, since data were not normally distributed (Kolmogorov-Smirnov and Bartlett tests), they were compared with non-parametric ANOVA. The metal concentrations were compared with Kruskal-Wallis tests, and differences were identified with multiple comparisons of Dunn's tests. All tests used were performed with a confidence level of 0.05.

The risk to human health was determined using the hazard quotient (HQ) according to Newman and Unger (2002), which was also calculated as HQ = E/RfD. Relating the level of exposure E, obtained as E = C I/W, where C is Hg concentration (µg/g w.w.) of the food item, I is its apparent daily consumption (1.93 kg/person/year for shrimp, equivalent to 5.29 g/day, respectively: CONAPESCA 2020), W is the bodyweight (bw) of the average Mexican consumer: 70.7 kg (CANAIVE 2012) and the reference dose for total

Table 1 Mean (±standard error) total mercury concentrations (µg/g, dw) in the muscle of *L. vannamei*, *L. stylirostris* and *F. californiensis* from NW Mexico

Zone	*L. vannamei*	*L. stylirostris*	*F. californiensis*
Puerto Peñasco	ND	ND	0.134 ± 0.178 a
San Jorge	ND	0.124 ± 0.085 a	ND
Guaymas	ND	0.181 ± 0.196 a	0.375 ± 0.369 a
Bahía de Lobos	ND	0.079 ± 0.024 a	0.123 ± 0.043 a
Tóbari	ND	0.131 ± 0.100 a	ND
Agiabampo	0.026 ± 0.072 a	0.224 ± 0.031 a	0.264 ± 0.186 a
Yavaros	ND	0.151 ± 0.085 a	ND
Topolobampo	0.051 ± 0.030 a	0.127 ± 0.126 a	0.829 ± 0.417 a
Cerro Cabezón	0.117 ± 0.050 a	0.229 ± 0.176 a	ND
Altata	0.154 ± 0.106 a	ND	ND
Mazatlán	0.047 ± 0.015 a	ND	ND
Huizache	0.429 ± 0.097 b	ND	ND
Teacapán	0.060 ± 0.027 a	ND	ND
Agua Brava	0.109 ± 0.088 a	ND	ND
San Blas	0.362 ± 0.108 b	ND	ND

ND = No determined; one-way ANOVA. Different letters indicate significant differences ($p < 0.05$) among zone for the same shrimp species.

Table 2 Mean (±standard error) selenium concentrations (µg/g, dw) in the muscle of *L. vannamei*, *L. stylirostris* and *F. californiensis* from NW Mexico

Zone	*L. vannamei*	*L. stylirostris*	*F. californiensis*
Puerto Peñasco	ND	ND	0.890 ± 0.567 a
San Jorge	ND	0.153 ± 0.144 a	ND
Guaymas	ND	0.839 ± 0.308 a	0.884 ± 0.053 a
Bahía de Lobos	ND	1.136 ± 0.089 a	0.851 ± 0.042 a
Tóbari	ND	1.480 ± 0.531 a	ND
Agiabampo	0.772 ± 0.483 a	0.240 ± 0.295 a	1.022 ± 0.358 a
Yavaros	ND	0.809 ± 0.778 a	ND
Topolobampo	0.677 ± 0.102 a	0.652 ± 0.688 a	0.502 ± 0.748 a
Cerro Cabezón	1.036 ± 0.244 a	1.134 ± 0.710 a	ND
Altata	0.373 ± 0.107 a	ND	ND
Mazatlán	1.156 ± 0.051 a	ND	ND
Huizache	0.482 ± 0.713 a	ND	ND
Teacapán	1.741 ± 0.263 a	ND	ND
Agua Brava	0.352 ± 0.078 a	ND	ND
San Blas	0.126 ± 0.096 a	ND	ND

ND = No determined; one-way ANOVA. Different letters indicate significant differences ($p < 0.05$) among zones for the same shrimp species.

Hg (RfD: 0.1 µg/kg/day for an adult: EPA 2010), respectively. The Burger and Gochfeld (2013) methodology was used to calculate the Se: Hg molar ratio; Furthermore, Selenium Health Benefit Values (HBV_{Se}) were calculated according to Ralston et al. (2016).

Results and Discussions

Total mercury mean intervals were 0.026–0.429, 0.079–0.229 and 0.123–0.829 µg/g (dw) for *L. vannamei*, *L. stylirostris* and *F. californiensis*, respectively (Table 1). For *L. vannamei*, only the THg content of organisms collected from Huizache and San Blas (south Sinaloa to north Nayarit) were significantly different ($p < 0.05$) than others coastal ecosystems. However, no significant differences ($p > 0.05$) were observed for *L. stylirostris* and *F. californiensis* among their respective coastal lagoons (Table 1). These differences among coastal lagoons could be different Hg anthropogenic sources to each lagoon. Furthermore, these shrimp species have differences in feeding habits and biological activities (Francesconi and Lenanton 1992), which contributes to differences in Hg bioaccumulation (Frías-Espericueta et al. 2016).

For Se content along NW coastal zone, the intervals were 0.126–1.741, 0.153–1.480, and 0.502–1.022 µg/g (dw) for *L. vannamei*, *L. stylirostris* and *F. californiensis*, respectively; and no significant differences ($p > 0.05$) were observed among coastal lagoons for each shrimp species (Table 2). As an essential element, Se levels tended to be higher (close to one order of magnitude) than the respective Hg values (Plessi et al. 2001).

Regarding comparison among the NW Mexican States, only the THg content was significantly different ($p < 0.05$) between Sonora and Nayarit States for *L. vannamei*. For Se, significant difference was between Sinaloa and Nayarit States of the same shrimp species. For *L. stylirostris* and *F. californiensis*, no significant differences ($p > 0.05$) were observed (Table 3). These differences could be by differences in environmental THg levels (Frías-Espericueta et al. 2016). Delgado-Alvarez et al. (2015) also reported higher THg levels in shrimp farms from Nayarit State. The relatively high THg values were related to the riverine inputs that flow from the mineral-rich Sierra Madre Occidental Mountain chain and the high use of agrochemicals (i.e. pesticides and fungicides) by the intensive agriculture in the NW Mexico. Other important Hg sources are the artisanal small-scale gold mining and the aerial Hg transportation from other NW Mexico states (Maíz-Larralde 2008).

Table 4 shows Hg concentrations in shrimp from different zones around the world. All values are lower than data from present study, except for *P. semisulcatus* from Turkey.

Table 3 Average concentration (±SD) (µg/g, dw) of total Hg and Se in the muscle of *L. vannamei, L. stylirostris* and *L. californiensis* in Northwest Mexico

Element	Species	NW Mexican States		
		Sonora	Sinaloa	Nayarit
THg	*L. vannamei*	0.0261±0.007a	0.143±0.148ab	0.235±0.164b
	L. stylirostris	0.148±0.098a	0.178±0.148a	NA
	F. californiensis	0.224±0.221a	0.829±0.417a	NA
Se	*L. vannamei*	0.772±0.483ab	0.893±0.525a	0.216±0.147b
	L. stylirostris	0.728±0.589a	0.942±0.664a	NA
	F. californiensis	0.903±0.235a	0.502±0.748a	NA

Different letters show significant differences ($p<0.05$) between study area for each metal. NA: not available data.

Table 4 Mercury content (µg/g, dw) from different areas

Shrimp species	Zone	Hg content	Reference
P. semisulcatus	Iskenderun Bay, Turkey	0.91*	Kaya and Turkoglu (2017)
P. merguiensis	Gresik coast, Indonesia	0.002–0.033*	Soegianto et al. (2010)
F. indicus	Persian Gulf	0.012	Rahimi and Gheysari (2016)
Shrimps	Nai Thung, Thailand	0.01–0.04	Rattikansukha et al. (2021)
L. stylirostris	NW Mexico	0.46	Frías-Espericueta et al. (2016)
F. californiensis	NW Mexico	0.31	Frías-Espericueta et al. (2016)
L. vannamei	NW Mexico	0.73	This study
L. stylirostris	NW Mexico	0.78	This stud
F. californiensis	NW Mexico	0.81	This study

* Transformed to dry weight.

This shrimp species was collected from an area considered to be one of the most polluted coastal of Turkey, with high industrial, agricultural and other chemical factories.

For Hg toxicity neutralization, the molar ratio between Hg and Se must be 1:1 (Se:Hg) (Kaneko and Ralston 2007). The molar ratios obtained in this study were higher than 1 for the three shrimp species, indicating no risk due to the consumption of these shrimp species. This is verified by the HBV_{Se} (Ralston et al. 2016) positive values, which expresses a Se health benefit from shrimp consumption (Table 5). This data coincides with the results of Frías-Espericueta et al. (2016), who reported molar ratios > 1 for *L. stylirostris* and *F. californiensis* from marine zones of NW Mexico. This is of ecological concern because Hg affects healthy marine/coastal environments (Issifu et al. 2022).

Table 5 HQ, molar ratio of Hg and Se in shrimp tissue and selenium health benefit value (HBV_{Se})

Shrimp species	HQ	µ mol Hg	µ mol Se	Se/Hg	HBV_{Se}
L. vannamei	0.550	0.751	9.309	12.400	9.249
L. stylirostris	0.583	0.776	9.866	12.709	9.805
F. californiensis	0.607	1.721	10.266	5.964	9.977

Due to shrimp exportation, shrimp fishery has a high social and economic importance in Mexico. The Hg content of the muscle of all shrimp species were lower than 0.5 µg/g ww (2 µg/g dw), which is the level for safe consumption published by FAO-WHO (2003).

As a general conclusion, THg levels in shrimp muscle of NW Mexico coastal lagoons are lower than permissible limit. Furthermore, the high Se:Hg molar ratio (> 1) in the edible muscle of three commercially important shrimp species evidenced that shrimp consumption is beneficial for coastal communities, and for exportation. In this context, the coastal ecosystems in the NW Mexico are still little impacted by Hg pollution.

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Declarations

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

Financial Interests The authors declare they have no financial interests.

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