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MINERAL CONTENT OF SOME CRUSTACEANS AND MOLLUSCS IN TURKIYE AND RISK ASSESSMENTS FOR PUBLIC HEALTH

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Abstract: This study examined the mineral and heavy metal content of nine different seafood sold in retail markets in Türkiye. Frozen ring squid, frozen Chilie mussel meat, frozen clam meat, frozen shrimp meat, frozen octopus, fresh Mediterranean mussel, frozen cuttlefish, frozen squid pan and frozen crab delight were used in the study. Mineral matter analysis of the samples was performed by ICP-MS - inductively coupled plasma-mass-spectrometry.
The highest Na, Ca and Mg contents were found in frozen clam meat, and the K content was found in fresh Mediterranean mussels. The main microelements detected in all seafood examined in the study are Zn, Fe and Al. The minimum Na/K ratio was determined in the frozen octopus and fresh Mediterranean mussel meat groups. The estimated daily intake values of the groups are below the World Health Organization recommended daily allowance. The heavy metal content of all seafood examined in the study was found to be posing no risk to public health.

Keywords: *crustaceans, heavy metals, mineral, public health, squid*

INTRODUCTION

Seafood contains a lot of protein, vitamins and minerals and is part of a healthy diet. Additionally, seafood is beneficial in many aspects such as heart health, skin health and bone health. However, consumer safety should also be considered when consuming aquatic products. Particular attention should be paid to consumer safety as toxic substances such as heavy metals can accumulate in the tissues and organs of seafood [1]. Considering the metabolic needs of living beings, metals are divided into essential and non-essential metals. Iron, zinc and copper are essential metals that are present in low concentrations in living things and enable many metabolic activities [2]. The most well-known essential metals include elements such as cobalt, manganese, magnesium, molybdenum, selenium, sodium, zinc and iron [3]. These elements are used as building blocks of various enzymes and proteins in the body. In addition to elements, non-essential metals such as mercury (Hg), cadmium (Cd), lead (Pb), lithium (Li), rubidium (Rb), strontium (Sr), zirconium (Zr), some such as gold (Au) and uranium (U) which are not normally found in living organisms but are still likely to be present in negligible amounts. These elements are generally taken from food, water and air because of their chemical and characteristic similarities to major essential metals, their proximity to the same donor atoms and chemical binding sites of essential metals [3]. These elements can cause harmful effects on living things and may have toxic effects. Aquatic organisms have some heavy metal load due to their natural environment, and the concentrations of heavy metals vary from element to element in aquatic organisms [4]. It should be noted that all metals above a certain concentration can be a potential source of poisoning for humans. However, it should be noted that Cd, Pb, Hg and As are toxic especially in low doses. In particular, people who frequently consume aquatic products containing high levels of one or more of these toxic substances may be exposed to health risks. These heavy metals accumulate in the human body over time and, individually or together, can cause various health problems or diseases [5]. Heavy metal contamination may be higher in fish caught in waters exposed to environmental pollutants, particularly where industrial waste is concentrated. Determining the mineral contents of seafood provides important information for a healthy diet. Minerals are macro and micro substances that the body uses and needs. For example, minerals such as iron, calcium, magnesium and potassium are necessary for healthy body functions and can cause health problems if they are deficient. Because of their high mineral content, seafood can be part of a healthy diet. Therefore, determining the amount of minerals in seafood can also help determine the amount of seafood that should be included in a healthy diet plan. In addition, it can be used to determine the mineral content of seafood, to assess the quality of the products, and to label and market the products. Therefore, determining the mineral content of seafood is of great importance, particularly for the health of the organisms that consume them.

Inductively coupled plasma mass spectrometry (ICP–MS) analysis is a sensitive and validated technique used for trace element analysis. ICP-MS is an effective quantitative analytical method for measuring trace elements in food samples due to its high sensitivity and selectivity. This technique effectively measures concentrations down to micrograms per liter ($\mu g \cdot L^{-1}$) in foods through effective ionization in plasma [6]. ICP-MS is a fully validated method for the simultaneous analysis (including participation

in proficiency tests) of the content of cadmium, lead, mercury, arsenic (in standard mode), chromium, iron and selenium (in CCT mode) in foods of animal origin [7, 8].
When reviewing the literature, studies to determine the mineral and heavy metal composition of crustaceans and molluscs remained based on meat/fresh products [9 – 16] and no research has been found on the basis of the processed products currently sold. For this reason, given the increasing importance of food safety, it is important to determine the mineral content of processed crustaceans and molluscs offered for sale worldwide. The aim of this study is to determine the mineral amounts of the sampled products, evaluate the heavy metal concentrations in accordance with the upper limits permitted by the Turkish Food Codex [17], and assess whether they pose a risk for human consumption.

MATERIALS AND METHODS

Materials

The study examined processed crustacean molluscs and an imitation product offered for sale in gross markets in Ankara (Türkiye). Frozen ring squid, frozen Chilie mussel meat, frozen clam meat, frozen shrimp meat, frozen octopus, fresh Mediterranean mussel meat, frozen cuttlefish meat, frozen squid pan, frozen crab delight samples were used. The groups in the study and the number of samples in the package, average weight, length, origin, species and content information on the product label are listed in Table 1.
Nine different products were delivered in 3 batches. The seafood products were delivered to the laboratory in Styrofoam boxes and ice. Frozen samples were thawed in cold water within 2 hours without being removed from their packages.
Following these procedures, the edible tissues of the samples were homogenized and analyzed.

Table 1. *Number of samples, average weight and length, origin and content information of the study groups*

Samples	Number of samples	Average weight	Average length	Origin	Contents
Frozen ring squid *Loligo vulgaris* Lamarck 1798	57	54.19±0.40		Türkiye	
Frozen Chile mussel meat *Mytilus chilensis* Hupé 1854	120	20.57±0.19		Chile	
Frozen clam meat *Ruditapes philippinarium* Adams & Reeve 1850	30	90.10±2.13	14.06±0.05	Türkiye	
Frozen shrimp meat *Parapenaus longirostis* Linnaeus 1758	120	5.35±0.04		Türkiye	
Frozen octopus *Octopus vulgaris* Cuvier 1797	9	361.59±4.61		Türkiye	
Fresh Mediterranean mussel meat *Mytilus galloprovincialis* Lamarck 1819	30	22.33±0.53	15.20±0.04	Türkiye	
Frozen cuttle fish *Sepia officinalis* Linnaeus 1758	9	836.42±6.07		Türkiye	
Frozen squid pan *Illex argentines* Castellanos 1960	46	59.77±0.74		Spain	Squid, wheat flour, vegetable oils, whey powder, corn starch, thickener, salt, raising agents, water, spices
Frozen crab delight *Imitation product*	60	90.79±1.06		Türkiye	Surimi (49 %) (haddock), stabilizers (sorbitol, sodium polyphosphate), water, bread crumbs, crab legs, starch, vegetable oil, egg white, flour, crab flavor, sugar, salt.

Methods

Mineral Analysis

EPA Method 200.3 was taken into account for the mineral measurements. The samples were prepared for analysis using the HPR-FO-67 microwave digestion system [18].
The procedure is as follows: A sample not exceeding 1.5 g, but close to this value was weighed into heat and pressure resistant Teflon containers with a capacity of 90 mL. 7 mL of suprapur purity 65 % HNO_3 and 1 mL of suprapur purity 30 % H_2O_2 were added. Microwave programming: A maximum of 1000 W energy and 45 bar pressure limits are set. From room temperature 200 °C was reached in 15 minutes. A constant temperature of 200 °C was maintained for 15 minutes and heating was stopped. It was allowed to come to room temperature for half an hour. The microwave-dissolved samples were transferred from Teflon containers to 50 mL polyethylene Falcon tubes. Ultrapure water was added up to the 50 mL mark.
The concentrations of the elements were measured using ICP-MS (Agilent 7700X). Quality assurance and control was carried out using triple measurements and certified

reference material (UME CRM 1201 spring water, UME CRM 1204 wastewater, Lobster TORT-2, BCR-185r liver, SEM 2016). The ICP-MS settings are as follows: RF power = 1550 W; number of points per peak = 6; Carrier gas = 1.05 $L{\cdot}min^{-1}$; Dilution mode = ON; Dilution gas = 0.1 $L{\cdot}min^{-1}$; He gas = 4.3 $mL{\cdot}min^{-1}$; ISIS-DS setting as follows: Load time = 10 s; Load speed = 1.0 rps; Probe rinse time = 23 s; Post rinse time = 10 s; Post rinse speed = 1.0 rps; Loop length = 120 cm; Loop tubing ID = 0.8.mm. Sampling was carried out in 3 parallel repetitions. During sampling, the content of 23 elements (sodium, magnesium, potassium, calcium, aluminum, vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc, arsenic, selenium, rubidium, strontium, antimony, cesium, barium, cadmium, mercury, lead) was examined. Results are reported as mean standard error ($mg{\cdot}kg^{-1}$, wet weight). All analyzes were performed on edible meat tissue.

Public Health Risk Analyzes

Metal Pollution Index (MPI)

When calculating the MPI, all metal contents in the samples were taken into account. This index is calculated using the geometric average of the metals following the equation (1) [19].

$$MPI = (C_1 \times C_1 \times \cdots \times C_n)^{1/n} \tag{1}$$

where:
C_n = metal concentration in the sample ($mg{\cdot}kg^{-1}$)
n = number of samples

Estimated Daily Intake (EDI), Estimated Weekly Intake (EWI)

The weekly seafood consumption amount used in calculating the EDI and EWI values was calculated using the average per capita seafood consumption amount in Türkiye in 2021. This value is approximately 0.125 $kg{\cdot}week^{-1}$ (6.5 kg/52 weeks annually) and about 0.0179 $kg{\cdot}day^{-1}$, daily [20].
The USEPA [21] equation (2) below was used to calculate the EDI value:

$$EDI = \frac{M \times W}{BW} \tag{2}$$

where:
M = metal concentration in the sample ($mg{\cdot}kg^{-1}$)
W =daily seafood consumption amount (kg)
BW = body weight (kg)

The relation between the EWI and EDI is presented in the equation (3).

$$EWI = EDI \times 7 \tag{3}$$

In the study, the average weight of an adult was taken to be 70 kg (from18 years old) and 32 kg for children (from 10 years old) [22].
To assess public health risks, EWI values of Cd, Hg and Pb were compared with the Provisional Tolerable Weekly Intake (PTWI). The PTWI values were assumed to be 0.007 mg for Cd, 0.004 mg for Hg [22] and 0.025 mg for Pb [23].

Statistical Analysis

The data obtained at the end of the research is Minitab Release 21.1.0. It was evaluated by ANOVA with the package program, and the Tukey test was used to determine the significance of the differences between the packages. Figures and tables were created using the MS Office 2020 software.

RESULTS AND DISCUSSION

Minerals and heavy metal contents of samples

The study examined the mineral and heavy metal contents of 9 different seafood products retailed sale in Türkiye. For this purpose, 3 different packs of the same product group were taken as samples. The mineral and heavy metal contents of frozen ring squid, frozen oyster meat, frozen shrimp meat, frozen crab delight, frozen octopus, fresh Mediterranean mussel meat and frozen cuttlefish are shown in Table 2.

Table 2. *Mineral and heavy metal contents (mg·kg^{-1}, ww)*

Samples	***Frozen ring squid*** *Loligo vulgaris* Lamarck 1798		***Frozen Chile mussel meat*** *Mytilus chilensis* Hupé 1854		***Frozen clam meat*** *Ruditapes philippinarium* Adams & Reeve 1850		***Frozen shrimp meat*** *Parapenaus longirostis* Linnaeus 1758		***Frozen octopus*** *Octopus vulgaris* Cuvier 1797	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Na	2220.99	79.39^{e}	5223.28	186.71^{abc}	6092.27	105.67^{a}	4247.15	107.52^{bcd}	6073.00	54.50^{a}
Mg	396.15	17.34^{d}	927.55	39.33^{ab}	993.56	13.77^{a}	226.59	2.77^{e}	822.71	45.86^{b}
K	461.26	41.42^{d}	2169.01	139.06^{ab}	1836.32	11.03^{bc}	317.50	13.99^{d}	1870.83	197.65^{b}
Ca	387.66	70.26^{cd}	527.00	74.76^{cd}	2444.85	197.60^{a}	629.61	11.34^{c}	282.65	8.59^{cd}
Al	0.57	0.10	7.24	0.63	76.94	13.53	27.70	5.03	4.76	1.93
V	0.01	0.00	2.72	0.31	0.21	0.01	0.32	0.28	0.02	0.01
Cr	0.03	0.01	0.05	0.00	0.61	0.05	0.09	0.02	0.03	0.01
Mn	0.15	0.02	1.10	0.06	1.44	0.07	0.83	0.10	0.42	0.09
Fe	1.65	0.29^{e}	21.21	0.86^{cd}	111.01	3.28^{a}	22.10	4.94^{c}	3.50	1.43^{e}
Co	0.00	0.00	0.04	0.00	0.49	0.07	0.01	0.00	0.07	0.03
Ni	0.08	0.01	0.17	0.01	4.16	0.44	0.14	0.02	0.33	0.12
Cu	1.20	0.18	1.50	0.05	1.33	0.31	0.83	0.01	10.13	3.26
Zn	12.90	0.46	28.32	3.98	20.54	1.21	4.94	0.08	24.57	2.70
As	0.58	0.06	4.38	0.16	5.48	0.47	3.94	0.11	38.70	3.12
Se	0.29	0.03	0.59	0.10	0.53	0.02	0.26	0.05	0.32	0.02
Rb	0.40	0.02	0.80	0.14	0.74	0.01	0.11	0.02	0.44	0.04
Sr	27.52	5.24	6.71	1.38	23.08	0.77	7.28	1.03	3.08	0.14
Sb	0.01	0.00	0.01	0.00	0.02	0.00	0.02	0.00	0.01	0.00
Cs	0.01	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.01	0.00
Ba	0.21	0.04	0.38	0.10	1.22	0.13	0.36	0.09	0.08	0.01
Cd	0.25	0.14^{ab}	0.43	0.11^{a}	0.07	0.00^{b}	0.01	0.00^{b}	0.08	0.05^{b}
Hg	0.16	0.12^{a}	0.00	0.00^{a}	0.00	0.00^{a}	0.03	0.01^{a}	0.14	0.01^{a}
Pb	0.02	0.00^{b}	0.01	0.01^{b}	0.12	0.01^{a}	0.03	0.01^{b}	0.00	0.00^{b}

Mean ± Standard error (SE)

a, b, ..f (→): Separately for each minerals and heavy metals according to the arrow direction, the difference between groups with different small letters are significant ($p \leq 0.05$)

Table 2. *Mineral and heavy metal contents (mg·kg^{-1}, ww)(continuation)*

Samples	***Fresh Mediterranean mussel meat*** *Mytilus galloprovincialis* Lamarck 1819		***Frozen cuttle fish*** *Sepia officinalis.* Linnaeus 1758		***Frozen squid pan*** *Illex argentinus* Castellanos 1960		***Frozen crab*** delight *Imitation product*	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Na	3925.63	59.88^{d}	4128.64	407.27^{cd}	6041.67	87.67^{a}	5461.14	574.58^{ab}
Mg	678.39	8.45^{c}	418.59	6.26^{d}	234.71	6.15^{e}	126.95	7.26^{e}
K	2420.61	80.89^{a}	1401.99	133.92^{c}	646.54	21.82^{d}	591.31	42.50^{d}
Ca	1129.39	47.71^{b}	346.28	25.97^{cd}	379.82	25.86^{cd}	181.87	5.13^{d}
Al	105.81	1.01	0.39	0.01	7.66	5.47	1.58	0.12
V	0.34	0.00	0.01	0.00	0.01	0.00	0.08	0.01
Cr	0.23	0.01	0.02	0.01	0.24	0.04	0.11	0.02
Mn	1.97	0.05	0.14	0.02	2.10	0.18	1.08	0.07
Fe	85.79	3.70^{b}	0.79	0.07f	12.26	7.16^{cde}	4.57	0.36^{de}
Co	0.17	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Ni	0.54	0.02	0.06	0.00	0.20	0.02	0.12	0.01
Cu	1.16	0.03	2.18	0.07	0.83	0.03	0.33	0.02
Zn	19.12	1.24	11.73	0.62	9.05	0.51	2.09	0.12
As	3.15	0.07	14.87	1.07	0.19	0.01	0.12	0.02
Se	0.75	0.11	0.31	0.02	0.14	0.01	0.06	0.01
Rb	1.08	0.15	0.44	0.04	0.48	0.02	0.22	0.03
Sr	7.97	1.10	4.01	0.30	3.53	0.17	1.46	0.22
Sb	0.02	0.00	0.01	0.00	0.01	0.00	0.01	0.00
Cs	0.02	0.00	0.01	0.00	0.01	0.00	0.01	0.00
Ba	1.95	0.35	0.37	0.04	0.41	0.03	0.20	0.04
Cd	0.42	0.07^{a}	0.01	0.00^{b}	0.02	0.00^{b}	0.01	0.00^{b}
Hg	0.01	0.00^{b}	0.32	0.19^{a}	0.01	0.00^{b}	0.01	0.00^{a}
Pb	0.19	0.05^{a}	0.02	0.00^{b}	0.03	0.00^{a}	0.01	0.01^{b}

Mean ± Standard error (SE)
a, b, ..f (→): Separately for each minerals and heavy metals according to the arrow direction, the difference between groups with different small letters are significant ($p \leq 0.05$)

Squids, whose consumption is increasing day by day, are of great importance for a healthy and balanced diet as that contain many nutrients with low fat content and high and quality protein [1, 24, 25]. When the macro element contents of frozen ring squid were compared, it was found that the Na and K contents were higher than other macro elements. Remyakumari [26] reported that macro elements K, Na and Ca were found at similarly high levels in Indian squid. Squid has been found to be a good source of Ca, P and Fe and contains B group vitamins [27]. Squid meat contains higher amounts of Zn, Mn and Cu compared to other marine life [24]. It contains large amounts of microelements Sr, Zn and Fe. Raimundo *et al.* [28] reported that the Cu, Zn, Cd and Pb contents in muscle tissue of *Dosidicus sgigas* caught in the Gulf of California ranged from 3.7 - 13, 71 - 98, 0.13 - 2.4 and 0.032 - 0.48 mg·kg^{-1}, respectively. Compared to this literature, the Cu, Zn and Pb contents of the squid used in our study are lower, while the Cd content is between the reported mean values.

The frozen mussel (*M. chilensis*) meat used in the study is products imported from Chile. España *et al.* [29] reported the Na and K content of *M. chilensis* as 2980 and 2010 mg·kg^{-1}, respectively. These values are below the study results. The Zn and Fe content of frozen mussel meat are higher than other microelements. Similar results were reported by España *et al*. [29].

Clam (*R. philippinarium*) is a product obtained from the waters of Türkiye, which are offered for sale, processed and consumed in different ways. Compared to other groups, the highest Na content was found in clam. It is rich in Fe and Al. The Fe content of clam meat is over 100 $mg \cdot kg^{-1}$. The Zn content of clam meat exceeds 20 $mg \cdot kg^{-1}$.

In Türkiye, shrimps (*P. longirostis*) are offered for consumption through freezing and canning. Frozen shrimps were used in the study. Shrimp are expensive shell products belonging to the Decapoda order of the Crustacea class [30]. Shrimps are more expensive to sell to consumers than other aquatic products because they are collected from specific regions, are caught less often, and contain less edible tissue than other aquaculture products. In Türkiye, pink deep-water shrimp (Çimçim) and other shrimps are exported to other countries fresh, chilled, frozen and steam-cooked [31]. Shrimp meat has a high Al and Fe content.

Octopus is also found on the Marmara, Aegean and Mediterranean coasts of Türkiye, and is a coastal benthic cephalopod species with very high economic [32, 33]. In Türkiye, octopus is a food generally consumed grilled, as a salad, boiled and fried in restaurant and hotel kitchens. When comparing the microelement content of frozen octopus (*O. vulgaris*) meat, As and Zn contents are higher compared to other groups. The As content of octopus samples is over 32.75 $mg \cdot kg^{-1}$.

In the present study, the fresh mussel, scientifically known as *Mytilus galloprovincialis* (Lamarck, 1819) also known as Mediterranean mussel [34, 35] was used. Since its price is cheaper than other protein sources, it is preferred as a cheap but high-quality protein source accessible to people in low-income countries, while in countries with a better economic situation, it is used as a main source of protein due to its taste, its easy transportability, and its aphrodisiac effect. It is commonly eaten in meals [36]. Mussels can be consumed as a source of Na, Se and Zn [37]. Rodríguez-Hernández *et al.* [14] stated that mussels contain many essential minerals and providing 70 % of daily Se requirement and they stated that it provides 30 - 35 % Mo, Zn and Co and 15 % Fe. Likewise, the Zn and Fe contents of the fresh Mediterranean mussels examined in this study are quite high.

Although cuttlefish is one of the easiest cephalopods species to farm, catching it and preparing it for consumption is not as delicate as other aquatic products [38, 39]. The frozen cuttlefish (*S. officinalis*) examined in the study originates from Türkiye. Lawal-Are *et al.* [40] reported that the Ca, Mg and Fe contents of *S. officinalis* were 342.16, 368.81 and 1.22 mg/100 g, respectively. This difference between this study and the literature may be due to feeding conditions, size, season, hunting location, etc. It can be due to many reasons such as.

Frozen squid (*I. argentinus*) pan, which contains squid, wheat flour, vegetable oils, whey powder, corn starch, thickener, salt, raising agents, water and spices, is a food commonly consumed alongside fish dishes in Turkish cuisine. The frozen squid pan used in the study was imported from Spain and breaded and frozen in Türkiye.

Caglak *et al.* [41] reported that there was no heavy metal accumulation in the edible parts of imported frozen *I. argentinus* to a level that would endanger human health.

Crab delight is also called ocean delight (breaded coated ocean delight) and its contents are surimi (40 %) (whiting), additives (40 %) and is an imitation product with a crab flavor. Compared to the seafood products examined, crab delight contains lower amounts of Mg, Ca and Zn. It is low due to the additives added in the production of crab delight

and the fact that the product consists of 40 % surimi. Crab delight has high mineral content like Na and K which increases with the addition of spices like salt added to the food.
Magnesium is an essential element for the human body and is defined as a cofactor of more than 300 enzymatic reactions throughout the body's metabolism [42]. Magnesium deficiency appears to be associated with the occurrence of a variety of diseases such as ischemic cardiopathy, hypertension, osteoporosis, glucose intolerance and diabetes or myocardial infarction [43, 44]. Calcium is an essential macronutrient for humans and makes up about 2 % of body weight in an adult human. It primarily has a structural function in bones and teeth [45]. The Mg and Ca contents of the groups are listed in Table 2. The most Mg-rich samples are frozen clam meat and frozen Chile mussel meat ($p > 0.05$). The minimum Mg content was determined in frozen crab delight and frozen shrimp meat ($p > 0.05$). The Food and Nutrition Board [46] stated that the daily recommended RDA for Mg in healthy adult men and women is 420 and 320 $mg \cdot day^{-1}$, respectively, and for Ca is 1000 $mg \cdot day^{-1}$. According to this, consumption of 200 grams of clam meat provides 62 % of women's daily Mg needs and 47 % of men's daily Mg needs. Consuming 200 g of clam meat covers 40 % of the daily Ca requirement; fresh Mediterranean mussels provide 23 %.

Na/K ratio of the seafoods

Sodium is an essential micronutrient and stimulates the appetite through the salty taste. However, high sodium consumption is associated with adverse health effects such as high blood pressure, cardiovascular disease, and stroke [47]. In the body, sodium balances extracellular volume, acid-base balance, nerve conduction, renal function, cardiac output and myocyte contraction [48]. When comparing the Na contents of the seafoods, the highest Na content was found in frozen clam meat. The Na contents of groups frozen octopus' meat, frozen crab delight, frozen clam meat, frozen Chilie mussel meat and frozen squid pan are statistically similar ($p > 0.05$). Minimum Na content was determined in frozen ring squid ($p < 0.05$). The World Health Organization (WHO) states that to prevent chronic diseases, the daily upper limit sodium intake for an adult should be less than 87 mmol Na/day (< 5 $g \cdot day^{-1}$) [49]. From this point of view, it may be advisable to consume small amounts of octopus, clam, squid pan and Chile mussel meat, which are high in Na. Low potassium intake has been liked to various diseases, including cardiovascular disease, chronic kidney stone formation, and low bone mineral density [50]. The K contents of the groups are given in Table 2. Maximum amount of potassium was found in Chile and Mediterranean mussels ($p > 0.05$). Minimum K content was determined in groups frozen shrimp meat, frozen crab delight, frozen clam meat and frozen squid pan ($p > 0.05$). The European Food Safety Authority (EFSA) considers a daily potassium intake of 3510 mg to be sufficient for men and women over 14 years of age [51, 52]. Due to the safety of increased dietary potassium intake, no upper limit has been recommended [50]. The Na/K ratios of the groups are shown in Figure 1. The maximum Na/K ratio is in frozen shrimp meat, the minimum ratio was found in frozen octopus and fresh Mediterranean mussel meat. Although the WHO does not focus on an optimal sodium-potassium ratio, the target molar ratio of sodium to potassium should be around 1 assuming recommendations for potassium and sodium consumption are met

[53]. From this perspective, it can be said that octopus and Mediterranean mussel meat are more effective in protecting heart health.

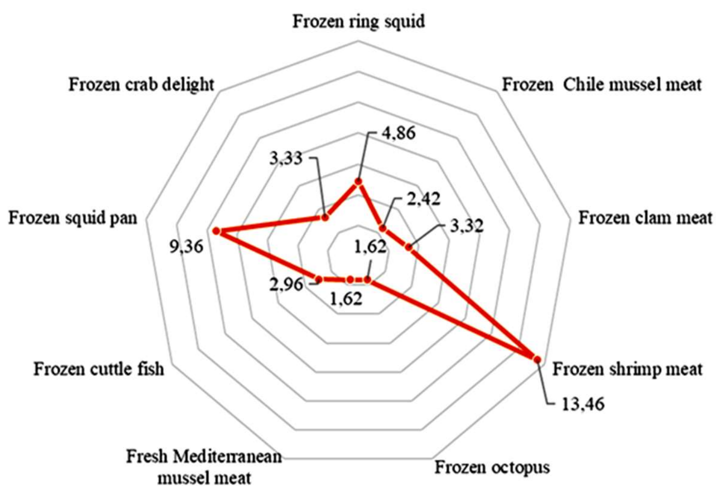

Figure 1. *Na/K ratio of samples*

Public Health Risk Analyzes

Heavy metal contents of groups

Mercury, lead and cadmium are non-essential metals because they are toxic even in trace amounts [54]. The heavy metal contents of the samples are shown in Table 2.

The maximum lead content is in frozen clam meat and fresh Mediterranean mussels; maximum mercury content in frozen cuttlefish meat and the maximum Cd was found in frozen Chilie mussel and fresh Mediterranean mussel meat ($p > 0.05$). The Turkish Food Codex [17] specifies the maximum acceptable Pb limit values for crustaceans, bivalve molluscs and cephalopods are respectively; 0.30, 0.50, 1.50 and 1.00 mg·kg^{-1} (ww). The average Pb levels of all groups examined in the study were below these established limits. In the same regulation, the maximum Cd content that may occur in fish meat, crustaceans, bivalve molluscs and cephalopods is given as 0.05, 0.50, 1.00 and 1.00 mg·kg^{-1} (ww). The Cd content of Chile mussel and Mediterranean mussel meat from the groups is above 0.40 mg·kg^{-1}, but is below the specified limits. The maximum limit value that may occur in fish meat and shellfish muscle meat is 0.50 mg·kg^{-1}. As shown in Table 1, the highest Hg content was detected in cuttlefish meat, but as in other groups, this value was below acceptance limits. It was found that the average heavy metal exposure across all groups examined in the study did not pose a threat to public health.

Metal Pollution Index (MPI) of samples

The metal pollution indices calculated depending on the metal concentrations of the groups in the study are shown in Table 3. The higher the MPI value, the higher the level of heavy metal contamination in the samples. The MPI values of all groups were between

0.16 and 1.16. The maximum metal pollution index was found in frozen clam meat from Türkiye. Haseeb-ur-Rehman *et al.* [55] reported in a study that the MPI values of various seafood products varied between 0.62 and 2.78.

Table 3. *Metal Pollution index and estimated daily intake (EDI), weekly intake (EWI) for adults and children based on consumption of some shelled molluscs available for sale in Türkiye*

Groups		Adult (70 kg)			Child (32 kg)			
		Cd	Pb	Hg	Cd	Pb	Hg	MPI
Frozen ring squid *Loligo vulgaris,* Lamarck 1798	EDI	6.40E-05	4.10E-05	5.10E-06	2.90E-05	1.90E-05	2.30E-06	0.25
	EWI	4.50E-04	2.90E-04	3.60E-05	2.00E-04	1.30E-04	1.60E-05	
Frozen Chile mussel meat *Mytilus chilensis,* Hupé 1854	EDI	1.10E-04	0.00E+00	3.40E-06	5.10E-05	0.00E+00	1.60E-06	0.58
	EWI	7.80E-04	0.00E+00	2.40E-05	3.50E-04	0.00E+00	1.10E-05	
Frozen clam meat *Ruditapes philippinarium,* Adams & Reeve 1850	EDI	1.90E-05	0.00E+00	3.10E-05	8.60E-06	0.00E+00	1.40E-05	1.16
	EWI	1.30E-04	0.00E+00	2.10E-04	6.00E-05	0.00E+00	9.80E-05	
Frozen shrimp meat *Parapenaus longirostis,* Linnaeus 1758	EDI	2.60E-06	6.80E-06	6.80E-06	1.20E-06	3.10E-06	3.10E-06	0.26
	EWI	1.80E-05	4.80E-05	4.80E-05	8.20E-06	2.20E-05	2.20E-05	
Frozen octopus *Octopus vulgaris,* Cuvier 1797	EDI	2.00E-05	3.50E-05	0.00E+00	9.00E-06	1.60E-05	0.00E+00	0.35
	EWI	1.40E-04	2.40E-04	0.00E+00	6.30E-05	1.10E-04	0.00E+00	
Fresh Mediterranean mussel meat *Mytilus galloprovincialis,* Lamarck 1819	EDI	1.10E-04	1.70E-06	4.80E-05	4.90E-05	7.80E-07	2.20E-05	0.88
	EWI	7.60E-04	1.20E-05	3.30E-04	3.50E-04	5.50E-06	1.50E-04	
Frozen cuttle fish *Sepia officinalis,* Linnaeus 1758	EDI	3.40E-06	8.10E-05	5.10E-06	1.60E-06	3.70E-05	2.30E-06	0.19
	EWI	2.40E-05	5.70E-04	3.60E-05	1.10E-05	2.60E-04	1.60E-05	
Frozen squid pan *Illex argentinus,* Castellanos 1960	EDI	6.00E-06	2.60E-06	6.80E-06	2.70E-06	1.20E-06	3.10E-06	0.23
	EWI	4.20E-05	1.80E-05	4.80E-05	1.90E-05	8.20E-06	2.20E-05	
Frozen crab delight *Imitation product*	EDI	2.60E-06	1.70E-06	2.60E-06	1.20E-06	7.80E-07	1.20E-06	0.16
	EWI	1.80E-05	1.20E-05	1.80E-05	8.20E-06	5.50E-06	8.20E-06	

EWI and EDI values of samples

To assess the public health risks of the samples, the EWI values of Cd, Hg and Pb were compared with the Provisional Tolerable Weekly Intake (PTWI) amounts (Table 3). The

PTWI values assumed were 0.007 mg for Cd, 0.004 mg for Hg [22] and 0.025 mg for Pb [23]. The Estimated weekly intake (EWI) values for metals are based on an adult's weekly consumption, and the groups' EDI and EWI values were found to be well below the recommended standard reference values. EDI measures daily exposure to the metal based on the oral reference dose (RfD). The EDI values of the groups are below the WHO recommended daily allowance (RDA), indicating that all groups pose a low health risk to consumers.

CONCLUSION

Seafood such as mussels, squid, shrimp, and octopus are available for sale in chain markets in Türkiye, and these products are consumed in restaurants, hotels, and homes. Although the heavy metal content of all seafood examined in the study are below the limit values, the Hg content in frozen cuttlefish, in particular, is significantly higher compared to other products. From a health perspective, it is recommended that such seafood be consumed in balanced and limited quantities, especially by children, pregnant women, and individuals with compromised immune systems. Additionally, it is essential that these seafood products are sourced from clean waters and stored/processed under appropriate conditions.

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DECLARATION

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Competing interest

Not applicable.

Ethics approval

Not applicable.

Availability of data and material

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