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Heavy metals in some commercially fishery products marketed in Saudi Arabia

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Abstract

Seven major commercially important marine fisheries species, *Fenneropenaeus indicus*, *Chaceon quinquedens*, *Lethrinus nebulosus*, *Scomberomorus commerson*, *Plectropomus pessuliferus*, *Pampus argenteus*, and *Epinephelus summana* were seasonally sampled from Jeddah main local fisheries market, Saudi Arabia. The heavy metals, namely arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), nickel (Ni), and zinc (Zn) were assessed. Except for arsenic, the results indicated that the levels of tested heavy elements were within the standard limits. The levels of arsenic were high in *F. indicus*, *C. quinquedens*, *L. nebulosus*, *P. pessuliferus* and *E. summana*. In addition, Pb showed higher mean levels of 0.89 ± 0.14 mg/kg and 5.05 ± 0.86 mg/kg in *S. commerson* and *P. pessuliferus*, respectively, compared to the permissible standard limits. Cd was not found in most samples, except for *F. indicus* and *C. quinquedens* where its detected levels exceeded the acceptable standards. Our results may prove the significant roles of seasonal impacts and species variations in the acquisition mechanisms of heavy metals in marine environments. Therefore, the application of a detection program for cumulative residual levels of heavy metals in marine fisheries products is recommended before marketing to ensure the safety of these products.

Keywords: marine water; marine species; heavy metals; standard parameters.

Pratic Application: Control of fish contamination detection program for cumulative residual levels of heavy metals in marine fisheries products is recommended.

1 Introduction

Heavy metals are the major environmental pollutants in the air, water, and soil. Their existence at high levels in the environment is hazardous to human health due to their high toxic impacts on living bodies (Alnashiri, 2022). Heavy metal contamination in the marine environment is of deep concern as it negatively affects marine and human lives. Factors such as anthropogenic activities, industrialization, and urbanization are the main causes of pollution in the marine environment worldwide (Mahboob et al., 2022). In the Arabian Gulf area of Saudi Arabia, the wastes of refineries and the petrochemical industry are the main sources of heavy metal pollution in the marine environment (Mahboob et al., 2014; Freije, 2015). In the Red Sea coastal area of Saudi Arabia, the increase in developmental activities, gold mining, and industrialization activities are the main reasons for heavy metal contamination of seafood products (Alnashiri, 2022). In recent decades, heavy metal contamination of fish and seafood has been of serious global concern, especially among consumers, health professionals, and seafood traders.

Fishes are important sources of high-quality protein and fat, and consequently, the consumption of these seafood products rapidly increased in recent years (Younis et al., 2021). However, they can be contaminated with various types of toxic heavy metals through the uptake and accumulation of these hazardous metals in muscles, and the concentration of such heavy metals in the fish muscles is regulated by the uptake and discharge mechanisms (Mansour & Sidky, 2002). In addition, the distribution and accumulation levels of heavy metals in fish muscles depend on various factors such as fish type, age, season, and other physiological parameters (Bervoets et al., 2001; Mansour & Sidky, 2002). It has also been reported that heavy metals are taken up and cumulated in different fish organs at different levels. However, such accumulation is recorded to peak in the summer season, followed by autumn, winter, and spring seasons (Bervoets et al., 2001; Mansour & Sidky, 2002).

Based on heavy metals' importance and physiological roles, they are classified into different groups. Iron, cobalt, and zinc are classified as essential, nickel is classified as probably essential, and cadmium (Cd), lead (Pb), and mercury (Hg) are classified as toxic by intentional organizations such as the United States Environmental Protection Agency and World Health Organization (Micheline et al., 2019). The consumption of heavy metals at low or high concentrations could be of high hazard depending on their classes. Consumption of low concentrations of toxic heavy metals (Cd, Pb, and Hg) over a long period can be very dangerous to humans due to the high toxicity of these elements. In addition, consuming high levels of essential heavy metals may also be toxic to humans (Celik & Oehlenschlager, 2004). The toxicity of heavy metals is due to the effect of such metals on cellular membranes, vital organelles, and biochemical processes driving enzymes as well as their contribution to the development of reactive oxygen species (Mahurpawar, 2015). Therefore, consuming toxic heavy metals at doses > the recommended limits could affect the whole body's function and lead to death (Zaynab et al., 2022).

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Despite the specific toxicity reaction signs of individual heavy metals, the general signs of poisoning with aluminum, arsenic, cadmium, cancers, copper, lead, mercury, and zinc are ataxia, causing a rust-red colored stool, convulsions, depression, diarrhea, gastrointestinal disorders, hemoglobinuria, kidney failure, neurological diseases, paralysis, pneumonia, stomatitis, tremors, and vomiting (Alissa & Ferns, 2011). In addition, heavy metals possess cytotoxicity, mutagenic, and carcinogenic properties, are resistant to degradation in the animal cells, accumulate in the animal tissues in excess amounts, and consequently affect human health (More et al., 2003).

Due to increased heavy metal pollution in the marine environment, investigating the levels of heavy metals in fish and seafood products is very important from the standpoints of health professionals, consumers, and traders. In Saudi Arabia, trading fishery products are not regulated by standard limits of heavy metals in these important products (Aljabryn, 2013). Therefore, this study focused on the levels of some heavy metals in some major, commercially important marine fisheries species belonging to three main categories, crustaceans, shellfish, and fish market in Jeddah is the main local fish market in Saudi Arabia. In addition, the possible seasonal impact on the acquisition of heavy metals by different examined species and the public health importance of the detected levels of heavy metals are also discussed.

2 Materials and methods

2.1 Materials

Fisheries samples

Three major and commercially important marine fisheries categories belong to crustaceans species, *Fenneropenaeus indicus*, shellfish species, *Chaceon quinquedens* and five fish species, *Lethrinus nebulosus*, *Scomberomorus commerson*, *Plectropomus pessuliferus*, *Pampus argenteus* and *Epinephelus summana* marketed in Jeddah main fish market, Saudi Arabia, were used in this study. All collected samples (n = 20 of each type) were of the same marketing size and seasons (winter, summer, and fall) during the year 2012 (Table 1). After collection, the samples were kept in an icebox and then transferred under cold conditions to the laboratory at Jeddah Fisheries Research Center. They were kept in a deep freezer at -20 ˚C for further analysis.

Chemicals and glassware

The chemical used in this study were of high chemical grades and were obtained from Sigma Aldrich (Sigma, MO, USA), JB Baker Inc. (Phillipsburg, NJ, USA), or BDH chemicals (Poole, England). All glassware were thoroughly washed with detergent, ddH_2O water, and nitric acid and then dried in an oven (overnight at 130 ˚C) before use for sample preparation and analysis.

Table 1. List of examined fisheries species.

Scientific Name	Common names (English/Arabic)
Fenneropenaeus indicus	Shrimp/Robian
Chaceon quinquedens	Crab/Kaboria
Lethrinus nebulosus	Emperor/Sho'ur
Scomberomorus commerson	Mackerel/Kanaad
Plectropomus pessuliferus	Grouper/Hamour Najel
Pampus argenteus	Silver pomfret/Zobaedy
Epinephelus summana	Grouper/Hamour Samana

2.2 Methods

Sample preparation

Before the analysis of heavy metals, the muscle slices of individual fishery samples were subjected to dry ashing using a muffle furnace (Heraeus, Germany) at 550 °C for 6 h, following the method described by Crosby (1977). After that, the ash was digested with concentrated nitric acid on a sand bath and then subjected to filtration through ash-less filter paper. The clear filtrate was used for the analysis of minerals using an atomic absorption spectrometer (AA-6200, Shimadzu, Kyoto, Japan).

Mineral analysis

The sample filtrates were analyzed for heavy metal content using an atomic absorption spectrometer as described in the instruction manual. The levels of the following trace elements: cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), nickel (Ni), and zinc (Zn) in fishery samples were analyzed and considered as indicators of heavy metal pollution. The concentration of the aforementioned elements was determined on the dry weight base.

2.3 Statistical analysis

Triplicate samples of each fishery product were analyzed, and the results were subjected to statistical analysis using the Statistical Package of Costas Program (CoStat, 1986). The results were subjected to analysis of variance (ANOVA) and were presented as the means ± standard deviations (SD). The significance was accepted at the probability of 0.05 or less ($P \leq 0.05$).

3 Results and discussion

This study highlights heavy metals contents in some major and commercially important marine fisheries species belonging to crustaceans, shellfish, and fish categories in Jeddah are main local fish market, Saudi Arabia, throughout the winter, summer, and fall seasons of the year 2012 (Tables 2-4) respectively.

Regarding As residues, the highest recorded levels were in *C. quinquedens,* with estimated mean values ranging from 3.63 ± 0.09 (Table 4) to 4.30 ± 0.10 mg/kg (Table 2), followed by in *F. indicus* the mean detected levels ranged from 0.59 ± 0.01 (Table 2) to 0.70 ± 0.03 mg/kg (Table 4). Though, the mean estimated levels of As in *L. nebulosus*, *P. pessuliferus*, *E. summana*, *P. argenteus* and *S. commerson* ranged from 0.23 ± 0.02 (Table 2) to 0.26 ± 0.01 (Table 3); 0.21 ± 0.05 (Table 3) to 0.26 ± 0.02 (Table 4); 0.21 ± 0.01(Table 2) to 0.23 ± 0.04 (Table 4); 0.14 ± 0.06 (Table 4) to 0.19 ± 0.02 (Table 2) and 0.16 ± 0.03 (Table 3) to 0.18 ± 0.01 mg/kg (Table 2) respectively. The statistical analysis results revealed high significant differences were shown in As levels between *C. Quinquedens* and all other species at $p \leq 0.05$ level, followed by *F. indicus,* while no significant differences have appeared between

Table 2. Levels of heavy metals in marine fish species (mg/kg fresh weight) in winter season 2012.

	Species	*Fenneropenaeus indicus*	*Chaceon quinquedens*	*Lethrinus nebulosus*	*Scomberomorus commerson*	*Pampus argenteus*	*Plectropomus pessuliferus*	*Epinephelus summana*
As	Range	0.53-0.75	4.25-4.41	0.21-0.25	0.13-0.24	0.15-0.23	0.12-0.22	0.09-0.14
	M ± S.D.	0.59 ± 0.01[b]	4.30 ± 0.10[a]	0.23 ± 0.02[c]	0.18 ± 0.01[c]	0.19 ± 0.02[c]	0.22 ± 0.01[c]	0.21 ± 0.01[c]
Pb	Range	nd	nd	1.45-1.57	0.73-1.00	1.66-1.72	4.19-5.90	2.40-3.04
	M ± S.D.	nd	nd	1.51 ± 0.06[c]	0.89 ± 0.14[d]	1.69 ± 0.04[c]	5.05 ± 0.86[a]	2.80 ± 0.35[b]
Co	Range	2.18-2.35	2.33-2.48	4.29-4098	5.42-5.99	7.43-8.27	2.63-2.78	2.20-2.39
	M ± S.D.	2.28 ± 0.09[d]	2.17 ± 0.04[d]	4.68 ± 0.35[c]	5.67 ± 0.29[b]	7.74 ± 0.45[a]	2.68 ± 0.08[d]	2.32 ± 0.10[d]
Ni	Range	nd	nd	1.97-2.44	2.00-2.33	1.47-2.23	5.55-6.00	0.99-1.15
	M ± S.D.	nd	nd	2.10 ± 0.24[b]	2.17 ± 0.17[b]	1.86 ± 0.23[b]	5.70 ± 0.28[a]	1.09 ± 0.08[c]
Cu	Range	nd	nd	nd	nd	0.00-0.05	0.00-0.16	0.51-2.44
	M ± S.D.	nd	nd	nd	nd	0.04 ± 0.02	0.05 ± 0.09	1.18 ± 1.08
Zn	Range	1.01-2.62	2.19-4.23	3.41-5.50	5.75-6.98	1.06-2.67	2.52-4.53	3.58-4.49
	M ± S.D.	1.94 ± 0.78[d]	3.23 ± 1.02[c]	4.50 ± 1.00[b]	6.29 ± 0.26[a]	1.99 ± 0.83[d]	3.53 ± 1.01[c]	4.04 ± 0.46[b]
Fe	Range	4.60-5.75	4.36-5.94	7.72-9.44	4.80-5.95	4.76-6.34	3.21-3.68	8.20-9.97
	M ± S.D.	5.01 ± 0.40[b]	4.07 ± 0.51[c]	8.70 ± 0.90[a]	5.20 ± 0.60[b]	5.40 ± 0.81[b]	3.50 ± 0.27[c]	9.09 ± 0.89[a]
Cd	Range	0.21-0.25	0.14-0.19	nd	nd	nd	nd	nd
	M ± S.D.	0.23 ± 0.01	0.16 ± 0.02	nd	nd	nd	nd	nd
Cr	Range	1.80-2.50	2.45-3.01	3.48-3.90	4.00-4.50	2.10-2.80	1.51-1.84	2.95-3.51
	M ± S.D.	2.20 ± 0.34[c]	2.66 ± 0.19[c]	3.68 ± 0.20[b]	4.33 ± 0.28[a]	2.50 ± 0.37[c]	1.70 ± 0.17[c]	3.18 ± 0.29[b]

The data are the mean values ± SD. Letters in the same row indicate significant differences at p ≤ 0.05. nd: not detected.

Table 3. Levels of heavy metals in marine fish species (mg/kg fresh weight) in summer season 2012.

	Species	*Fenneropenaeus indicus*	*Chaceon quinquedens*	*Lethrinus nebulosus*	*Scomberomorus commerson*	*Pampus argenteus*	*Plectropomus pessuliferus*	*Epinephelus summana*
As	Range	0.59-0.80	4.18-4.32	0.20-0.24	0.11-0.21	0.14-0.20	0.17-0.28	0.19-0.24
	M ± S.D.	0.66 ± 0.07[b]	4.21 ± 0.06[a]	0.26 ± 0.01[b]	0.16 ± 0.03[b]	0.17 ± 0.01[b]	0.21 ± 0.05[b]	0.22 ± 0.08[b]
Pb	Range	ND	ND	ND	ND	ND	ND	ND
	M ± S.D.	ND	ND	ND	ND	ND	ND	ND
Co	Range	2.11-2.28	2.25-.41	0.50-0.85	0.51-.87	0.59-.12	0.37-.54	0.21-.32
	M ± S.D.	2.20 ± 0.06[a]	2.32 ± 0.07[a]	0.72 ± 0.19[b]	0.70 ± 0.18[b]	0.90 ± 0.27[b]	0.46 ± 0.08[b]	0.26 ± 0.05[b]
Ni	Range	ND	ND	ND	ND	ND	ND	ND
	M ± S.D.	ND	ND	ND	ND	ND	ND	ND
Cu	Range	ND	ND	ND	0.00-.05	ND	0.00-.21	0.00-10
	M ± S.D.	ND	ND	ND	0.02 ± 0.02	ND	0.11 ± 0.07	0.05 ± 0.03
Zn	Range	1.22-2.82	2.21-4.23	4.63-5.14	0.97-1.01	4.25-4.45	4.94-6.21	4.93-6.24
	M ± S.D.	2.14 ± 0.38[d]	3.02 ± 0.21[c]	4.90 ± 0.26[b]	0.99 ± 0.02[e]	4.37 ± 0.10[b]	5.30 ± 0.47[a]	5.40 ± 0.66[a]
Fe	Range	4.52-5.67	4.24-5.82	6.47-6.69	2.47-2.81	4.29-6.05	1.14-1.53	4.66-5.06
	M ± S.D.	4.98 ± 0.37[C]	4.82 ± 0.41[c]	6.58 ± 0.11[a]	2.65 ± 0.17[e]	5.00 ± 0.88[b]	3.00 ± 0.49[d]	4.86 ± 0.20[c]
Cd	Range	0.23-0.28	0.17-0.24	ND	ND	ND	ND	ND
	M ± S.D.	0.26 ± 0.01	0.21 ± 0.02	ND	ND	ND	ND	ND
Cr	Range	1.92-2.34	1.55-1.87	ND	ND	ND	ND	ND
	M ± S.D.	[a]2.24 ± 0.14	1.74 ± 0.16[b]	ND	ND	ND	ND	ND

The data are the mean values ± SD at p ≤ 0.05. Letters in the same row indicate significant differences at p ≤ 0.05. ND: not detected.

the other species at the same level. Also, no significant differences appeared in As levels in the same species of all studied marine fish species in the different seasons at P ≤ 0.05 level.

Compared to the standard permissible limits of 0.5, 0.5, and 0.2 mg/kg for shellfish, crustaceans, and marine fishes, respectively (Saudi Arabia Standards Organization, 1997), *C. quinquedens*, *F. indicus*, *L. nebulosus*, *P. pessuliferus*, and *E. summana* exceeded the permissible standards, however, *P. argenteus* and *S. commerson* are considered border lines. In this sense, Hall et al. (1978) stated that the inorganic form of As, the dangerous component, constitutes about 10% of the total As. However, 85% - 95% of the total As is the form of the non-dangerous organic component. In this regard, the United States Food and Drug Administration (Food and Drug Administration, 1993a) recorded that As levels in clams, oysters, crabs, and crustaceans reached (0.82-6.6 mg/kg), (1.4-2.8 mg/kg), (10-30 mg/kg) and (8.6-10.6 mg/kg), respectively In winter season, the level of Co was higher significantly in *P. argenteus* in compare with the

Table 4. Levels of heavy metals in marine fish species (mg/kg fresh weight) in fall season 2012.

	Species	*Fenneropenaeus indicus*	*Chaceon quinquedens*	*Lethrinus nebulosus*	*Scomberomorus Commerson*	*Pampus argenteus*	*Plectropomus pessuliferus*	*Epinephelus summana*
As	Range	0.57-.84	3.16-.11	0.22-0.28	0.14-0.19	0.11-0.17	0.24-0.28	0.21-0.26
	M ± S.D.	0.70 ± 0.03^{b}	3.63 ± 0.09^{a}	0.25 ± 0.08^{b}	0.17 ± 0.04^{b}	0.14 ± 0.06^{b}	0.26 ± 0.02^{b}	0.23 ± 0.04^{b}
Pb	Range	ND	ND	ND	ND	ND	ND	ND
	M ± S.D.	ND	ND	ND	ND	ND	ND	ND
Co	Range	1.91-2.28	2.05-2.21	1.42-1.61	1.31-1.60	2.16-2.70	0.10-0.63	0.37-.50
	M ± S.D.	2.24 ± 0.02^{a}	2.13 ± 0.05^{a}	1.53 ± 0.10^{b}	1.52 ± 0.19^{b}	2.38 ± 0.28^{a}	0.41 ± 0.28^{c}	0.45 ± 0.07^{c}
Ni	Range	ND	ND	3.78-4.00	2.95-3.70	2.56-3.12	2.00-2.16	2.00-2.96
	M ± S.D.	ND	ND	3.80 ± 0.10^{a}	3.42 ± 0.41^{a}	2.84 ± 0.28^{b}	2.00 ± 0.08^{b}	2.37 ± 0.51^{b}
Cu	Range	ND	ND	ND	0.00-0.72	ND	ND	0.24-0.78
	M ± S.D.	ND	ND	ND	0.41 ± 0.22	ND	ND	0.48 ± 0.42
Zn	Range	1.02-2.62	2.01-3.13	4.38-5.00	1.85-1.89	3.73-3.83	2.40-3.10	5.67-6.16
	M ± S.D.	1.81 ± 0.08^{c}	2.53 ± 0.11^{b}	4.70 ± 0.31^{a}	1.87 ± 0.02^{c}	3.78 ± 0.05^{b}	2.75 ± 0.35^{b}	5.91 ± 0.25^{a}
Fe	Range	3.42-4.57	3.22-4.60	ND	ND	ND	ND	0.09-3.36
	M ± S.D.	3.88 ± 0.27	3.57 ± 0.31	ND	ND	ND	ND	2.30 ± 0.07
Cd	Range	0.19-0.26	0.16-0.21	ND	ND	ND	ND	ND
	M ± S.D.	0.22 ± 0.01	0.19 ± 0.02	ND	ND	ND	ND	ND
Cr	Range	1.81-2.12	1.23-1.82	0.00-0.25	ND	0.00-0.27	ND	ND
	M ± S.D.	1.95 ± 0.14^{a}	1.51 ± 0.02^{a}	0.18 ± 0.07^{b}	ND	0.15 ± 0.08^{b}	ND	ND

The data are the mean values ± SD at p ≤ 0.05. Letters in the same row indicate significant differences at p ≤ 0.05. ND: not detected.

other species, followed by *S. commerson* and then *L. nebulosus*, and in the other species were in the 4th order with no significant differences were appeared between it at p ≤ 0.05 level.

P. pessuliferu showed a significant difference (at p ≤ 0.05) in Ni concentration compared with the other species in winter, followed by *L. nebulosus, S. commerson*, *P. argenteus,* and *E. summana* has come at last. The Zn level in *P. pessuliferu* increased significantly at p ≤ 0.05 level. Followed by both *L. nebulosus and E. summana,* then both *P. pessuliferus C. quinquedens,* and finally *F. indicus*. Statistically, Fe quantities in the winter season were varied with significant differences among E. summana and L. nebulosus and *P. argenteus and S. commerson,* and both *C. quinquedens and P. pessuliferus* respectively at P ≤ 0.05 level. Significant differences have appeared in Cr levels in marine fish species in the winter season between S. commerson and all other species, followed by *L. nebulosus* and *E. summana,* while all other species came at the 3rd order with no significant differences among it at P ≤ 0.05 level.

The results in Table 3 reveal that, in summer season, As the level in *F. indicus* recorded high significant differences in comparison with all other marine fish species at level P ≤ 0.05. Also, *F. indicus* in addition to *C. quinquedens* were surpassed all other species in Co levels at level P ≤ 0.05. The results showed significant differences in Zn between both of *E. summana* and *P. pessuliferus,* and both of *L. nebulosus* and *P. argenteus*, and then *C. quinquedens, F. indicus, S. commerson* respectively at P ≤ 0.05 level.

The levels of Fe have differed significantly between the studied marine fish samples in the summer level at level P ≤ 0.05 in the following order, *L. nebulosus, P. argenteus*, each of (*F. indicus E. summana, C. quinquedens*), *P. pessuliferus* and *S. commerson* respectively. Also, there are significant differences in the Cr level between *F. indicus* and *C. quinquedens* at level P ≤ 0.05.

In the fall season, the results in Table 4 reveal that the level of As in C. quinquedens increased with high significant differences compared with all other marine fish species at level P ≤ 0.05. Likewise, *C. quinquedens* in addition to *F. indicus* and *P. argenteus* were exceeded all other species in Co levels, followed by both *S. commerson* and *L. nebulosus,* and finally *E. summana* at level P ≤ 0.05. The results of Ni levels showed significant differences between both *S. commerson* and *L. nebulosus* compared with all other marine fish species at level P ≤ 0.05. There are significant differences in the Zn level in the fall season between *E. summana* and *L. nebulosus* followed by *(P. argenteus, P. pessuliferus, C. quinquedens*), both *S. commerson* and *F. indicus* at level P ≤ 0.05. The results also reveal that the level of Cr in F. indicus increased with highly significant differences compared with all other marine fish species at level P ≤ 0.05.

Data shown in Table 2 revealed that Pb residues were only detected in the winter season in *P. pessuliferus*, *E. summana*, *P. argenteus*, *L. nebulosus* and *S. commerson*, with mean levels of 5.05 ± 0.86; 2.80 ± 0.35; 1.69 ± 0.04; 1.51 ± 0.06 and 0.89 ± 0.14 mg/kg, respectively, as indicated in Table 2, the levels of Pb were varied with significant differences between at p ≤ 0.05, suggesting the possible impact of low water temperature during the winter season on the acquisition mechanism of Pb by marine fish species. However, it appeared also that seasonal impacts might play a role in the absence of Pb from all other examined marine fisheries species in the summer and fall seasons (Tables 3-4), respectively. Comparatively, the recorded Pb levels are greater than the maximum permissible recorded limit of 0.5 mg/kg for Saudi Arabian marine fisheries species (Saudi Arabia Standards Organization, 1997). The absence of Pb from *F. indicus* and *C. quinquedens* could be attributed to the significant role of feeding habits of these crustaceans and shellfish species as bottom feeders compared to other tested fish species. However, the slightly greater levels of Pb in all fish samples might result from manufacturing and/or natural geochemical activities, the matter that may also reflect the existence of pollution in the marine environment (Belitz et al., 2004; Carvalho et al., 2005).

In contrast, Pb contents were recorded in ranges of 0.09-6.95, 0.22-0.85, and 0.07-0.87 mg/kg in fish species from Iskenderun Bay (Türkmen et al., 2005), fish from the Black Sea (Tüzen, 2003) and Turkish Northeast Atlantic fish (Yılmaz et al., 2007) respectively. However, a Pb level of 0.5 mg/kg was reported as the maximum permissible limit in marine fishes (Nauen, 1983). Lead is known as one of the most hazardous heavy metals. It causes an elevation in hypertension and promotion of cardiovascular disease in adults and reduces intellectual activities in children (Commission of the European Communities, 2006). Therefore, contamination of fishery products with this heavy metal is of great concern from the standpoints of health workers and fishery product consumers.

The mean estimated levels of Co in the winter season ranged from 2.17 ± 0.04 to 7.74 ± 0.45 mg/kg in *C. quinquedens* and *P. argenteus,* respectively Table 2. However, the mean levels in the summer season Table 3 were in the range of 0.26 ± 0.05 to 2.32 ± 0.07 mg/kg in *E. summana* and *C. quinquedens*, respectively. On the other hand, Table 4 showed that Co mean levels in the fall season were within the range of 0.41 ± 0.28 to 2.38 ± 0.28 mg/kg in *P. pessuliferus* and *P. argenteus*, respectively.

Statistically, significant differences have appeared in Co levels of *E. summana*, *P. pessuliferus* between winter and summer and fall seasons at $P \leq 0.05$ level. For *P. argenteus*, *S. commerson,* and *L. nebulosus*, Co levels significantly differed in winter, followed by the fall and summer seasons, respectively. Also, no significant differences were shown in the Co levels in both *F. indicus* and *C. quinquedens* between the seasons.

Similar to our findings, Similar to our findings, Co was reported to be at high and moderate levels in *Oreochromis niloticus*, *Clarias lazera*, and *Cyprinus carpio* from freshwater fish farm in Al-Kharj, Saudi Arabia (Aljabryn, 2013). In addition, high levels of Co were also reported in the muscles of *Euryglossa orientalis* (3.21 mg/kg) and *Otolithes ruber* (1.94 mg/kg) from Arvand River, Iran (Sheikhzadeh & Hamidian, 2021). On the other hand, Co was not detected in the fish samples obtained from Ataturk Dam Lake, Turkey (Karadede et al., 2004). The variations among these studies are likely due to the differences in the fish species, collection location and season, and environmental conditions. Being a part of vitamin B12, Co represents one of the essential heavy metals with high health benefits, which acts as a regulator of blood pressure and is vital for the thyroid gland's proper functioning. However, excessive intake and accumulation of Co in the human body may cause congestive heart failure, anemia, polycythemia, overproduction of erythrocytes, and pulmonary fibrosis (Sheikhzadeh & Hamidian, 2021).

The mean estimated levels of Ni in the winter season in Table 2 revealed ranged from non-detection in *F. indicus* & *C. quinquedens* to 5.70 ± 0.28 mg/kg in *P. pessuliferus*. Meanwhile, Ni was not detected in all examined species in the summer season (Table 3). However, in the fall season (Table 4), Ni means estimated values ranged from non-detection in *F. indicus* & *C. quinquedens* to 3.80 ± 0.10 mg/kg in *L. nebulosus*, suggesting the possible seasonal impact and feeding habitat on the acquisition of Ni by the examined species. The levels of Ni in *E. summana and P. argenteus, S. commerson,* and *L. nebulosus* were significantly higher in fall compared with winterseason, while in *P. pessuliferus* it was significantly higher in winter compared with fall season at $P \leq 0.05$ level. Previously, high levels of Ni were detected in the liver (286.4 mg/kg wet weight basis) and muscle (11.46 mg/kg wet weight basis) tissues of *Johnius belangerii* from Khark Island and Musa Estuary, Iran, respectively (Sheikhzadeh & Hamidian, 2021). In addition, high levels (6.33-10.74 mg/kg DW) of Ni were also reported in muscles of *Clarias lazera*, while moderate levels (3.42-4.15 mg/kg DW) were found *Cyprinus carpio* and *Oreochromis niloticus* from a freshwater fish farm in Al-Kharj, Saudi Arabia (Aljabryn, 2013). In other studies for Turkey, Ni ranges of 0.11-12.90 mg/kg DW and 0.93-2.77 mg/kg DW were reported for fish species from Iskenderun Bay and Dhanmondi Lake, respectively (Türkmen et al., 2005; Begum et al., 2005). Moreover, low levels (0.42-0.85 mg/kg DW) of Ni were detected in canned fish from Bangladesh (Tuzen & Soylak, 2006). The variation in Ni content among these studies could be due to the variations in the fish species, catching season and location, handling and processing methods, and environmental conditions. Despite the lack of data about Saudi Arabian permissible Ni contents in fish, the Ni values of this study are within the acceptable range based on the FDA regulations that set the allowable level of Ni as 70-80 mg/kg (Food and Drug Administration, 1993b). Although Ni and Cr are dangerous metals and maximum allowable limits were set by FDA, the European Union (EC) did not make any regulations about these trace elements in fish and other aquatic products (Aljabryn, 2013).

The mean estimated values of Cu in the winter season Table 2 ranged from non-detection in *F. indicus*, *C. quinquedens*, *L. nebulosus,* and *S. commerson* to 1.18 ± 1.08 mg/kg in *E. summana*. However, data shown in Table 3 revealed that the mean levels of Cu in the summer season ranged from non-detection in *F. indicus*, *C. quinquedens*, *L. nebulosus,* and *P. argenteus* to 0.11 ± 0.07 mg/kg in *P. pessuliferus*. Meanwhile, Cu was only detected in *S. commerson* and *E. summana* samples during the fall season (Table 4), with mean values of 0.41 ± 0.22 and 0.48 ± 0.42 mg/kg, respectively. The Cu contents of *E. summana* and *S. commerson* were significantly increased in fall season compared to that in winter season at $P \leq 0.05$ level, while in *P. pessuliferus* it was was significantly higher in summer compared with winter season at $P \leq 0.05$ level, and in *E. summana* Cu was increased with significant differences in winter compared to fall season in the same level.

However, the recorded Cu levels were lower than the maximum allowable limit of 20 mg/kg reported by Centre for Environment, Fisheries and Aquaculture Science (1995). Copper is an important trace element with various roles in metabolisms and hemoglobin synthesis because it is the main component of the same important enzymes (Sheikhzadeh & Hamidian, 2021). However, the consumption of excess amounts of copper, which is found in high concentrations in seafood, has high health concerns as it may cause damage to the kidney and liver (Yap et al., 2016).

The mean estimated values of Zn in the winter season (Table 2) ranged from 1.94 ± 0.78 to 6.29 ± 0.26 mg/kg in *F. indicus* and *S. commerson*, respectively. However, in the summer season (Table 3), the mean values of Zn were in the range of 0.99 ± 0.02 to 5.40 ± 0.66 mg/kg in *S. commerson* and *E. summana*, respectively. Meanwhile, Zn mean levels in the fall season (Table 4) ranged from 1.81 ± 0.08 to 5.91 ± 0.25 mg/kg in *F. indicus* and *E. summana*, respectively.

The contents of Zn were high with significant differences in *S. commerson* in winter compared with fall and summer seasons. Also, it was high with significant differences *P. pessuliferus* and *F. indicus* summer followed by winter and fall seasons respectively, and in *P. argenteus* it was higher in summer followed by fall and winter seasons respectively, while in *E. summana* it was lowered in winter compared to both summer and fall seasons at $P \leq 0.05$ level.

A previous study has shown high levels (16.79-49.43 mg/kg DW) of Zn in fish species (blackspot, emperors, grouper, and sardines) obtained from different districts in Saudi Arabia (Alturiqi & Albedair, 2012). In addition, comparable levels (1.48-11.9 mg/kg DW) of Zn were found in three fish species obtained from fish farms in the Al-Kharj area, Saudi Arabia (Aljabryn, 2013). Moreover, varied levels of Zn were reported in fish species from Iskenderun Bay (0.60-11.60 mg/kg DW) and Black Sea (9.50-22.90 mg/kg DW) in Turkey (Tüzen, 2003; Türkmen et al., 2005), while Celik & Oehlenschlager (2004) recorded Zn range of 2.1-8.7 mg/kg in North-East Atlantic fish. However, our recorded levels of Zn are the lowest compared to the standard permissible limits of 50.00 and 30.00 mg/kg recorded by Centre for Environment, Fisheries and Aquaculture Science (1995) and Nauen (1983), respectively. The differences in Zn content among the aforementioned studies are probably due to the variations in the fish genotypes, age, season, location, and environmental conditions. From a health point of view, Zn has an important role in human health as it involves various enzymatic activities and metabolic processes to maintain the structural integrity of proteins, maintains the system functions, and possesses antioxidant and anti-inflammation properties (Izah et al., 2017; Choi et al., 2018). The deficiency of Zn is linked to growth retardation, taste loss, anemia, decreased fertility, and cardiovascular diseases (Choi et al., 2018). However, the consumption of excess amounts of Zn is toxic to the human body and organs (Yap et al., 2016).

The mean estimated values of Fe in tested species in the winter season (Table 2) ranged from 3.50 ± 0.27 to 9.09 ± 0.89 mg/kg in *P. pessuliferus* and *E. summana,* respectively. However, in the summer season (Table 3), the mean values of Fe ranged from 2.65 ± 0.17 to 6.58 ± 0.11 mg/kg in *S. commerson* and *L. nebulosus*, respectively. The Fe was only noticed in the fall season (Table 4) in samples of *F. indicus*, *C. quinquedens*, and *E. summana* species with mean values of 3.88 ± 0.27, 3.57 ± 0.31, and 2.30 ± 0.07 mg/kg respectively. No significant differences were appeared in Fe levels in each of *C. quinquedens, P. argenteus,* and *P. pessuliferus* in the three seasons, however, in *F. indicus* it was significantly higher in both winter and summer compared to fall seasons, in *E. summana* and *L. nebulosus* it increased significantly in winter compared to the summer season at $P \leq 0.05$ level.

Significantly high levels (81.60-188.60 mg/kg DW) of Fe were detected in fish species collected from Jeddah Coast, Red Sea, Saudi Arabia (Younis et al., 2021). In addition, the Fe content of farmed fishes from the Al-Kharj area, Saudi Arabia, ranged from 1.1-20.45 mg/kg DW (Aljabryn, 2013). Moreover, Fe of different fishes from the Caspian Sea, Iran, was in the wide range of 2.1-1343.5 mg/kg DW (Sheikhzadeh & Hamidian, 2021). The variations among these studies could be due to the differences in fish species, season, location, and environmental conditions. Data are missing regarding the acceptable standards of Fe in fisheries species in Saudi Arabia (Aljabryn, 2013). Fe is one of the most important essential heavy metals for the human body. It has significant roles in various physiological and biochemical pathways as a cofactor of some enzymes and the synthesis of blood cells (Abarshi et al., 2017).

Cadmium was only detected in *F. indicus* and *C. quinquedens* with mean levels in winter, summer and fall seasons reached 0.23 ± 0.01 & 0.16 ± 0.02 (Table 2); 0.26 ± 0.01 & 0.21 ± 0.02 (Table 3) and 0.22 ± 0.01 & 0.19 ± 0.02 mg/kg (Table 4) respectively. No significant differences appeared in Cd levels in *C. quinquedens* in the three seasons, while it was increased significantly in *F. indicus* in both winter and summer compared to fall season at $P \leq 0.05$ level.

These detected levels exceeded the permissible standard limits of 0.1 mg/kg recorded for Cd in Saudi Arabian crustaceans and shellfish (Saudi Arabia Standards Organization, 1997). Meanwhile, Centre for Environment, Fisheries and Aquaculture Science (1995) reported a 2.0 mg/kg Cd permissible limit for fisheries products. The only detection of Cd in *F. indicus* and *C. quinquedens* may highlight the existence of environmental pollution. It may be explained on the bases of the existed differences in the acquisition mechanism of Cd by crustaceans and shellfish as bottom feeders in contrast to other examined marine fish species.

The estimated mean levels of Chromium in the winter season (Table 2) ranged from 1.70 ± 0.17 to 4.33 ± 0.28 mg/kg in *P. pessuliferus* and *S. commerson*, respectively. However, Data shown in (Table 3) revealed only detection of Cr in the summer season in *F. indicus* and *C. quinquedens* with mean values of 2.24 ± 0.14 and 1.74 ± 0.16 mg/kg, respectively. Meanwhile, in the fall season (Table 4), Cr was only detected in *F. indicus*, *C. quinquedens*, *L. nebulosus*, and *P. argenteus* samples with mean values of 1.95 ± 0.14, 1.51 ± 0.02, 0.18 ± 0.07 and 0.15 ± 0.08 mg/kg respectively. The level of Cr in *C. quinquedens* was high significantly in winter compared with both fall and summer seasons, where no significant differences were appeared in Cr levels in the two seasons, and in *F. indicus* it was higher with significant differences in both winter and summer compared to fall season, while in both *L. nebulosus* and *P. argenteus* it was higher significantly in winter compared to fall season at $P \leq 0.05$ level.

These variations may reflect the seasonal impact and nutritional habitat on the acquisition of Cr by marine species. Our results are comparable to those documented for fish species obtained from Iskenderun Bay, Turkey (0.07-6.46 mg/kg DW) and in canned fish (0.97-1.70 mg/kg DW) as reported by Türkmen et al. (2005) and Tuzen & Soylak (2006), respectively. In the human body, Cr is involved in insulin function and lipid metabolism, however, excess Cr can cause damage to the liver, kidney, DNA, and nervous tissues (Yuan et al., 2020).

The cumulative impacts of different amounts of heavy elements on the health status and vital body systems as well as their role as mediators of some human cancers, have been studied (Hertz-Picciotto, 2000; Silbergeld et al., 2000; Bal et al., 2000). However, additional research is required to highlight the acquisition mechanisms of these metal contaminants in different aquatic environments by crustaceans, fish, and shellfish species.

4 Conclusion

In conclusion, this study demonstrated that the mean values of most detected metals in seasonally examined marine fisheries species from Jeddah main fish market, Saudi Arabia, were within the standard allowable limits except for the recorded high mean values of As in *F. indicus*, *C. quinquedens*, *L. nebulosus*, *P. pessuliferus*, and *E. summana* compared to the standard permissible limits. In addition, Pb showed higher mean levels in *S. commerson* and *P. pessuliferus* compared to the standard permissible limits. However, Cd was not detected in all examined species, except for *F. indicus* and *C. quinquedens* where their levels exceeded the permissible standards. It appeared that seasonal impacts and species variations might play significant roles in the acquisition mechanisms of heavy metals in marine environments. Therefore, from a public health standpoint, applying a detection program for cumulative residual levels of heavy metals in marine fisheries species, especially crustaceans and shellfish, are recommended before marketing to ensure its safety.

Conflict of interest

There is no conflict of interest that I should disclose, having read the above statement.

Availability of data and material

The data used to support the findings of this study are included within the article.

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