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Original article

Nutritional value and bioaccumulation of heavy metals in muscle tissues of five commercially important marine fish species from the Red Sea

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ABSTRACT

The study evaluated the nutritional quality and investigated the heavy metals concentration in muscle tissues of five commercially important marine fish species, including brownspotted grouper (Epinephelus chlorostigma), squaretail coralgrouper (Plectropomus areolatus), black pomfret (Parastromateus niger), goldbanded jobfish (Pristipomoides multidens), and blueskin seabream (Polysteganus coeruleopunctatus) from the Red Sea, Jeddah Coast, Saudi Arabia. Significant differences ($p < 0.05$) were observed in the proximate chemical composition of fish muscles in these species. The highest protein content (17.66 ± 0.58%) was achieved in blueskin seabream while the lowest (15.28 ± 0.46%) was observed in brownspotted grouper. The highest lipid content (2.97 ± 0.45%) was recorded in squaretail coralgrouper while the lowest (1.52 ± 0.26%) was observed in blueskin seabream. Heavy metal concentrations varied significantly within and between fish species under study ($p < 0.05$). Significant differences in the concentration of heavy metals among fish species were recorded. Results revealed that the bioaccumulation of Cr, Fe, Ni, and Cd in muscles of fish species under study was higher than the standard concentration, but that of Mn, Cu, and Pb were less than the standard concentration recommended in the EU, FAO, and WHO guidelines. In conclusion, these fish species represent a high-quality food source but is unsafe due to the level of certain minerals in their tissues. Results also indicated that the Red Sea environment is contaminated with heavy metals, which was reflected in the tissues of fishes used in this study.

1. Introduction

Fishes are an important protein source for human health, and globally, the quantity of fish consumed has rapidly increased because of its high protein, low saturated fat, and high omega-3 fatty acids contents (Bosch et al., 2016; Golden et al., 2016). However, fishes can be contaminated with toxic metals from many natural and anthropogenic sources, including agricultural evacuation, industrial effluent discharge, and petrol from fishing boats (Velusamy et al., 2014; Liu et al., 2015; Arulkumar et al., 2017). Heavy metals in the marine environment and fish contamination are not only a threat to fish health but also a risk to human health as a result of fish consumption (Gu et al., 2016; Griboff et al., 2017; Makedonski et al., 2017). Many researchers have investigated the heavy metal contamination in different marine fish species (Murthy et al., 2013; Javed and Usmani, 2013; Elnabris et al., 2013; El-Moselhy et al., 2014; Kulawik et al., 2016).

Heavy metals, including manganese (Mn), iron (Fe), cobalt (Co), and copper (Cu) are necessary minerals in fish metabolism (Tuzen and Soylak, 2007) but are toxic in high concentrations (Gulec et al., 2011), whereas cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), and nickel (Ni) are toxic metals even in trace concentrations in both humans and animals (Gu et al., 2017). However, serious toxic heavy metals discharged into marine ecosystems could harm the biodiversity of aquatic organisms and the environment, owing to their toxicity, persistence, and accumulative behavior (Saha and Zaman, 2013). Heavy metal accumulation in marine fish species

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depends on many factors, including environmental condition, season, location, distribution, environmental preference, trophic level, feeding habit, age, sex, exposure duration to metals, and physiological regulation activity (Velusamy et al., 2014; Arulkumar et al., 2017). Additionally, heavy metal accumulation in fishes can generate long-term influences on biogeochemical cycling (Gu et al., 2017; Yi et al., 2011). Heavy metals accumulate as they flow up the natural food chain and can reach dangerous levels for human health (Yi et al., 2011; Ip et al., 2005). Thus, it is necessary to determine the accumulated chemical content (primarily ocean pollutants, such as heavy metals) in widely consumed fish species.

Jeddah is located on the central western coast in the kingdom of Saudi Arabia and is an important area for shipping, industry, and urbanization. Studies have focused on heavy metal bioaccumulation in some fish species from the Jeddah coast of Saudi Arabia (Ali et al., 2011; Younis et al., 2015). This study aimed to evaluate the nutritional value of five commercial marine fish species (brownspotted grouper, squaretail coralgrouper, black pomfret, goldbanded jobfish, and blueskin seabream) collected from the Red Sea Coast of Saudi Arabia by determining their proximate composition of moisture, protein, lipids and ash. Also to estimate the impact of pollution in coastal water in terms of accumulation of heavy metals (chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), cadmium (Cd), and lead (Pb) the fish muscles.

2. Materials and methods

2.1. Study area and fish collection

Five fish species were collected directly from the landing site for fishing boats operating in the Red Sea, Jeddah, Saudi Arabia (21°29′24″N, 39°10′23″E). Fish samples were immediately washed thoroughly with fresh water and placed in clean ice boxes for transportation to the fisheries research laboratory at the Zoology Department, College of Science, King Saud University. After which, fishes were identified according to their English, local, and scientific names (Table 1).

2.2. Physical measurements

The total length (TL) of each fish species was measured to the nearest 0.1 cm and the total body weight (TBW) was determined using an electronic balance to the nearest 0.01 g. Condition factors of fish samples were evaluated using the following equation: Condition Factor (K) = [body weight (g)/body length^3 (cm^3)] × 100.

2.3. Chemical composition of fish muscles

Muscle tissues removed from five fishes of each species were weighed and stored at −20 °C for further analysis. The proximate composition of fish muscles (moisture, protein, lipids and ash) was determined according to the standard methods of AOAC (2016).

Table 1
English, scientific, and local names of fish species collected from the Jeddah Coast, Red Sea, Saudi Arabia.

English name	Scientific name	Local name
Brownspotted grouper	*Epinephelus chlorostigma*	Hamour
Squaretail coralgrouper	*Plectropomus areolatus*	Najel
Black pomfret	*Parastromateus niger*	Zebedi
Goldbanded jobfish	*Pristipomoides multidens*	Faresi
Blueskin seabream	*Polysteganus coeruleopunctatus*	Morgan

2.4. Heavy metals determination

The heavy metals concentration (Cr, Mn, Fe, Co, Ni, Cu, Cd, and Pb) in fish muscles was determined using the inductively coupled plasma mass spectrometry (ICP- MS) according to the method as described by AOAC (2015.01).

2.5. Statistical analyses

Collected results (TL, TBW, K, proximate composition, and metals concentratio) were subjected to statistical analysis using one-way Analysis of Variance (ANOVA). The average values (means ± standard deviation) were compared by using Fisher's Least Significant Differences test (LSD-test) as described by Snedecor and Cochran (1989).

3. Results

3.1. Physical measurements of the fish

Data of total length; total body weight; condition factor; habitat; feeding and fishery importance of fishes under study are shown in Table 2. The total length was ranged from 24.17 to 35.33 cm. The total length was significantly higher in Goldbanded jobfish (35.33%), whereas was lower in Black pomfret (29.50%) and Blueskin seabream (24.17%) than in other fish species. The total body weight of fish species was varied between 208.16 and 611.34 g. The total body weight of Squaretail coralgrouper (611.34%) and Goldbanded jobfish (509.39%). In contrast, the total body weight of Blueskin seabream (208.16%) was significantly lower than that of other fish species. The condition factor of fish species was 1.23 up to 1.78. The condition factor of Squaretail coralgrouper (1.78%) and Black pomfret (1.74%) was significantly higher, whereas that of Goldbanded jobfish (1.23%) was significantly lower than the factor of other fish species.

3.2. Chemical composition of fish muscles

The chemical composition of fish muscles is presented in Table 3. The moisture content in Black pomfret (80.65%) was significantly higher than that in the other species, followed by Brownspotted grouper (79.87%), Squaretail coralgrouper (79.55%), and Blueskin seabream (79.29%) whereas the moisture content in Goldbanded jobfish was the lowest (77.90%).The muscle protein content of Blueskin seabream had significantly higher protein content (17.66%), while Brownspotted grouper had significantly lower protein content (15.28%) than that of other species. The muscle lipid of Squaretail coralgrouper (2.97%) was significantly higher, while that of Blueskin seabream (1.52%) was significantly lower than that of other fish species. The ash content of Blueskin seabream (6.72%) was significantly higher, while that of Black pomfret (3.42%) was significantly lower than that in other fish species.

3.3. Bioaccumulation of heavy metals in the fish muscles

The heavy metals concentrations in muscle tissue samples of the fish (mg/kg dry wt.) are shown in Table 4. In fish samples from various organizations/countries the normal regulatory limits (ppm or mg/kg) for heavy metals are presented in Table 5. The accumulation of metals by different fish species in this study was compared with samples from various regions/oceans (Table 6). In this study the heavy metal concentration analyzed increased increased in the following order: Fe > Cr > Ni > Cu > Mn > Cd > Pb. The Cr level in Goldbanded jobfish (113.60 mg/kg) was significantly higher, while that of Brownspotted grouper (38.60 mg/kg) was signifi-

Table 2
Total length, total body weight, condition factor, habitat, feeding behavior, and economic importance of five fish species collected from the Jeddah Coast, Red Sea, Saudi Arabia.

Fish species	TL (cm)[1]	TBW (g)[2]	(K)[3]	Habitat	Feeding	Fishery importance
brownspotted grouper	31.33 ± 1.89^{b}	449.72 ± 110.00^{ab}	1.44 ± 0.08^{b}	Demersal	Carnivorous	Commercial
squaretail coralgrouper	32.33 ± 3.01^{ab}	611.34 ± 160.50^{a}	1.78 ± 0.03^{a}	Demersal	Carnivorous	Commercial
black pomfret	29.50 ± 0.87^{c}	323.42 ± 22.55^{bc}	1.74 ± 0.11^{a}	Pelagic	Carnivorous	Commercial
goldbanded jobfish	35.33 ± 0.58^{a}	509.39 ± 88.65^{a}	1.23 ± 0.04^{c}	Pelagic	Carnivorous	Commercial
blueskin seabream	24.17 ± 0.76^{c}	208.16 ± 9.58^{c}	1.48 ± 0.08^{b}	Pelagic	Carnivorous	Commercial

Values (mean ± SD of replication) in the same column having different superscript letters are significantly different (P < 0.05).
[1] TL (cm): Total length.
[2] TBW (g): Total body weight.
[3] Condition factor (K) = [fish weight (g)/fish length (cm)^3] × 100.

Table 3
The chemical composition in the fish muscles of five fish species collected from the Jeddah Coast, Red Sea, Saudi Arabia.

Fish species	Moisture	Protein	Lipid	Ash
Brownspotted grouper	79.87 ± 0.01^{a}	15.28 ± 0.46^{d}	2.05 ± 0.61^{c}	5.04 ± 0.78^{b}
Squaretail coralgrouper	79.55 ± 0.01^{a}	17.28 ± 0.48^{ab}	2.97 ± 0.45^{a}	5.03 ± 0.54^{b}
Black pomfret	80.65 ± 0.01^{a}	17.21 ± 0.25^{b}	1.66 ± 0.15^{d}	3.42 ± 1.23^{c}
Goldbanded jobfish	77.90 ± 0.01^{b}	16.74 ± 0.51^{c}	2.53 ± 0.40^{b}	5.07 ± 0.49^{b}
Blueskin seabream	79.29 ± 0.01^{a}	17.66 ± 0.58^{a}	1.52 ± 0.26^{d}	6.72 ± 1.41^{a}

Values (mean ± SD of replication) in the same column having different superscript letters are significantly different (P < 0.05).

Table 4
Heavy metal concentrations (mg/kg dry wt.) in the fish muscles of five fish species collected from the Jeddah Coast, Red Sea, Saudi Arabia.

Fish species	Cr	Mn	Fe	Ni	Cu	Cd	Pb
Brownspotted grouper	38.60 ± 4.00^{b}	3.30 ± 1.00^{bc}	81.60 ± 7.00^{c}	17.30 ± 3.00^{b}	11.00 ± 2.00^{bc}	3.00 ± 1.00^{bc}	0.80 ± 0.30^{a}
Squaretail coralgrouper	68.60 ± 8.00^{ab}	3.40 ± 1.00^{bc}	142.20 ± 11.00^{b}	30.70 ± 11.00^{b}	14.50 ± 1.00^{b}	4.10 ± 1.00^{ab}	0.70 ± 0.20^{a}
Black pomfret	96.30 ± 16.00^{ab}	5.40 ± 1.00^{a}	188.60 ± 57.00^{a}	53.50 ± 20.00^{ab}	18.90 ± 6.00^{a}	5.10 ± 2.00^{a}	0.80 ± 0.10^{a}
Goldbanded jobfish	113.30 ± 19.00^{a}	4.80 ± 3.00^{ab}	121.70 ± 58.00^{bc}	92.10 ± 75.00^{a}	8.20 ± 3.00^{c}	1.70 ± 1.00^{d}	0.70 ± 0.10^{a}
Blueskin seabream	49.40 ± 35.00^{b}	3.10 ± 1.00^{c}	83.60 ± 20.00^{c}	35.80 ± 12.00^{b}	7.70 ± 4.00^{c}	2.20 ± 1.00 ^{cd}	0.80 ± 0.20^{a}

Values (mean ± SD of replication) in the same column having different superscript letters are significantly different (P < 0.05).

Table 5
Standard regulatory limits (ppm or mg/kg) of heavy metals in fish samples, as reported in the literatures.

Organization/country	Cr	Mn	Fe	Ni	Cu	Cd	Pb	References
FAO	–	–	–	–	30	0.005	0.5	FAO (1983)
FAO/WHO	0.05	12.97	186	8.97	30	0.5	0.05	FAO/WHO (1989)
USFDA	–	–	–	–	–	0.5	0.3	USFDA (2001)
ANHMRC	–	–	–	–	30	2	2.0	Plaskett and Potter (1979)
European Union	0.5	–	–	–	–	0.5	0.3	EU (2008)
UK Food Standard Committee	–	–	–	–	20	–	2.0	Cronin et al (1998)
Western Australian Food and Drug Regulations	–	–	–	5.5	–	–	–	Plaskett and Potter (1979)

cantly lower compared to other fish species. Black pomfret was significantly higher at Mn concentrations (5,40 mg/kg), compared with those of other fish species and Blueskin seabream recorded the significant lowest Mn concentratiom (3.10 mg/kg). Of all the elements examined, the concentration of Fe in tissues of fishes was the highest. Black pomfret has the highest level of Fe (188.60 mg/kg), while significantly low concentration was found in Brownspotted grouper (81.60 mg/kg). Goldbanded jobfish were highest accumulation of Ni (92.10 mg/kg/species), followed by Black pomfret (53.50 mg/kg) then the Blueskin seabream (35.80 mg/kg) and the Squaretail coralgrouper (30.70 mg/kg) while the Brownspotted grouper (17.30 mg/kg) was the lowest Ni concentrations detected. The highest Cu level (18.90 mg/kg) was detected in Black pomfret, while the lowest (7.70 mg/kg) was recorded in Blueskin seabream. The Cd concentration was significantly higher in Black pomfret (5.10 mg/kg), while it was significantly lower in Goldbanded jobfish (1.70 mg/kg) than in other fish species. The Pb concentrations determined were ranged from 0.7 to 0.8 mg/kg. No significant differences were recorded in Pb concentrations.

4. Discussion

The physical measurements of the fish showed a wide and significant difference. The variability in the total length, body weight, and condition factor in this study is considered a normal difference due to the variation of fish species, age, sex, and size. The results of moisture content in the muscles of the studied fishes was ranged between 78% up to 81%. Younis et al. (2011) concluded that the highest and lowest moisture content in marine fishes was found in emperors (Lethrinus lentjan, 79.59%) and the kingfish (*Scomberomorus commerson*, 76.49%), respectively. However, Ali et al. (2013) reported the highest moisture content in emperors (*Lethrinus lentjan*, 78.8%), followed by groupers (*Cephalopholis aurantia*), yellowfin goatfish (*Mulloidichthys flavolineatus*), and

Table 6
Comparison of heavy metal concentrations in fish muscles with reported values in the literatures.

Area	Samples	Cr	Mn	Fe	Ni	Cu	Cd	Pb	References
Jeddah Coast[a] (Present work)	Dry wt	38.6–113.3	3.1–5.4	81.6–188.6	17.3–92.1	7.7–18.9	1.7–5.1	0.7–0.8	This research
Jeddah Coast[b] (Saudi Arabia)	Dry wt	NA	NA	NA	NA	0.13–0.91	0.13–1.06	1.03–6.4	Ali et al. (2011)
Red Sea[a] (Jordan)	Dry wt	1.0–10.3	1.0–3.3	2.5–20.5	1.0–5.0	0.5–2.0	0.5–2.0	1.5–8.3	Ahmed and Naim (2008)
Bangshi River[a] (Bangladesh)	Dry wt	0.5–2.1	9.4–51.2	N/A	0.7–4.4	8.3–43.2	0.1–0.9	1.8–10.3	Rahman et al. (2012)
Bonny and Finima Rivers[c] (Nigeria)	Dry wt	NA	9.3–43.7	102.0–565.6	5.3–30.0	3.5–15.8	ND	0.2–5.0	Abarshi et al. (2017)
Iskenderun Bay[c] (Turkey)	Wet wt	1.0–1.8	NA	29.1–93.6	0.3–1.7	0.7–2.0	NA	0.7–10.9	Yilmaz (2003)
Northern East Mediterranean Sea[a] (Turkey)	Dry wt	1.3–2.7	1.3–2.2	4.2–13.2	1.4–6.5	1.2–2.2	0.8–1.3	1.8–3.5	Turkmen et al. (2005)
Kabul River[c] (Pakistan)	Wet wt	489.0–703.0	NA	NA	74.7–135.0	46.3–303.0	53.3–71.7	226.3–599.3	Ahmad et al. (2015)
Mumbai Harbor[c] (India)	Dry Wt	0.1–1.6	1.4–7.8	32.1–240.5	NA	0.9–6.5	0.02–0.57	0.01–0.26	Velusamy et al. (2014)

ND: not detectable; NA: not analyzed.
[a] Values present the ranges expressed as mg/kg.
[b] Values present the ranges expressed as mg/g.
[c] Values present the ranges expressed as µg/g.

seabream (*Argyrops spinifer*), and the lowest moisture content in longtail tuna (*Thunnus tonggol*, 72.8%) followed by yellowfin tuna (*Thunnus albacores*). The moisture level of fishes is influenced by the season, age, and environment (Küçükgülmez et al., 2010). The muscle protein content of fish species in this study was significantly differed and ranged from 15.28% to approximately 18%. Younis et al. (2011) reported that the higher protein concentration observed in coral trout (*Plectropomus maculates*, 21.51%) was due to its diet and feeding habits. The differing protein contents of rohu (9.53%), catla (10.11%), panga (13.60%), and magur (14.87%) were found to be possibly due to their ecological condition and food availability (Jakhar et al., 2012). Nath et al. (2014) stated that lipid content is affected by the environment, life cycle, topographical origin. In the current study, the muscle lipid content of fishes ranged from 1.52% to approximately 3% where it was significantly varied and higher than the recorded levels in other studies. The lipid content in the muscle of scad (0.45%), emperor (0.79%), kingfish (1.12%), jobfish (0.49%), coral trout (0.98%), and grouper (0.43%) (Younis et al., 2011). This study, therefore suggested that lipid levels may be influenced by the territorial food and feeding habits of fish species. The ash content of fish species in was significantly differed and ranged from 3.42% to approximately 7%. In comparison, Younis et al. (2011) estimated ash contents in scad (1.20%), emperor (1.18%), kingfish (1.27%), jobfish (1.38%), coral trout (1.21%), and grouper (1.07%). The overall differences in the chemical composition of investigated marine fishes in this study may be attributed to the difference in species, food availability, and geographical location and this agrees with the study (Ali et al., 2013; Saeed, 2013).

In many countries, heavy metal exposure through waste disposal in the sea by industrial waste is an important problem. Chromium is a vital chemical element that plays an important role in glucose, fat, and protein metabolism (Mertz, 1993). The Cr values from this study were lower than those reported by Ahmad et al. (2015) in fish species from the Kabul River, Pakistan (489–703 µg/) and higher than those recorded by Sankar et al. (2006) in Calicut, India (0.47 µg/g); Raja et al. (2009) in Parangipetti waters, India (0.65–0.92 µg/g); Yilmaz (2003) in Iskenderun Bay, Turkey (1.03–1.79 µg/g); Ahmed and Naim (2008) in the Gulf of Aquba, Red Sea (1.0–10.3 µg/g); Rahman et al. (2012) in the Bangshi River, Bangladesh (0.47–2.07 mg/kg); Türkmen et al., 2005 in the northeast of Mediterranean Sea, Turkey (0.07–6.64 mg/kg); and Demirezen and Uruç (2006) in Kayseri, Turkey (8.44–9.51 µg/g). The United States Food and Drug Administration (USFDA) set a maximum permissible Cr content of 12–13 mg/kg for fishes (USFDA, 1993). The European Union (EU) set the permissible level of Cr at 0.5 mg/kg wet weight (EU, 2008) but the Cr concentration in fish species used in this study did not meet this permissible level. Our findings indicated that Jeddah on the Red Sea coast has a higher Cr concentration than that in studies mentioned above. These results suggested that the high Cr levels in this study may be due to long-term contamination in this area.

Manganese concentrations in this study were similar to those reported by Ahmed and Naim (2008). Kumar et al. (2011) recorded Mn concentrations (2.9 µg/g) in several fish species collected from Indian waters. A concentration of 0.5 mg/kg Mn in marine fish species gathered from Kochi Waters has been documented by Sankar et al. (2006). Rahman et al. (2012) recorded Mn concentrations in several fish species of 9.43–51.17 mg/kg in the Bangshi River, Bangladesh. Yilmaz et al. (2007) reported a 0.11–24.33 µg/g Mn concentration in *Leuciscus cephalus* and 1.07–12.43 µg/g in *Lepomis gibbosus* in the Saricay Stream, Turkey. The level of Mn permissible as set by FAO/WHO is 12.97 mg/kg (FAO/WHO, 1989). In this study, Mn levels in fish used were less than permitted levels and other studies reported in the Bangshi River, Bangladesh (Rahman et al., 2012) and Saricay Stream, Turkey (Yilmaz et al., 2007).

Iron concentration may have been high in this study because of decreased grain sizes, increased organic matter, and the nearby industrial pollution input of anthropogenic metal. In the Yangtze Estuary, China (Zhang et al., 2007) and in Mumbai Harbor, India (Velusamy et al., 2014) similar findings have been reported. In the North Eastern Mediterranean Sea, iron concentrations collected were 60–73 µg/g (Kalay et al., 1999), while in several marine species from the harbor of Mumbai, India the levels were 32–240 µg/g (Velusamy et al., 2014). Iron levels of species of the fish used in this study have been higher than in the studies in Iskenderum Bay, Turkey (Turkmen et al., 2005), the Black Sea middle (Tuzen, 2003), western Indian Ocean (Kojadinovic et al., 2007), Tokat Lakes, Turkey (Mendil et al., 2005), Tuzla Lagoon (Dural et al., 2007), and the Caspian Sea (Fariba et al., 2009). A stressful environment was revealed by High Fe values in various fish species used in this study. Iron concentrations were higher than acceptable FAO and WHO limits (FAO/WHO, 1989).

Nickel is an environmental factor that occurs at a very low level and can cause severe pulmonary health problems, such as lung cancer, fibrosis, emphysma, tumors and kidney diseases (Forti et al., 2011). In this review, Nickel values in this study were lower than those reported by Ahmad et al. (2015) (75–135 μg/g) in the Kabul River, Pakistan and higher than those reported by Turkmen et al. (2005) in Iskenderun Bay, Turkey (0.11–12.9 μg/g); Tuzen (2003) in the Black Sea, Turkey (1.14–3.60 μg/g); Uluozlu et al. (2007) in the Black and Aegean seas, Turkey (1.92–5.68 μg/g); and Leung et al. (2014) in the Peral River Delta, China (0.44–9.75 μg/g). The Western Australian Food and Drug Regulations set the permissible level of Ni to 5.5 mg/kg wet weight (Plaskett and Potter, 1979). In this study, the investigated fish species were contaminated by Ni, indicating that there has been a long period of untreated industrial waste discharge, which could have contaminated the marine environment. However, Ni is an accretive body toxin and its concentration in the environment should remain as low as possible.

The determined copper concentrations in this study were low compared to the findings of Rahman et al. (2012) in fishes collected from the Bangshi River, Bangladesh (8.33–43.18 mg/kg) and Ahmad et al. (2015) in the River Kabul, Pakistan (46–303 μg/g), but higher than those reported by Raja et al. (2009) in Parangipettai waters, India (0.12–0.31 μg/g); Velusamy et al. (2014) in Mumbai Harbor, India (0.87–6.51 μg/g); Kalay et al. (1999) in the Northeast Mediterranean Sea (3.40–5.88 μg/g); Türkmen et al. (2008) in Marmara, in the Aegean and Mediterranean seas (0.32–6.48 mg/kg), and Türkmen et al. (2009) in the central Aegean and Mediterranean seas (0.34–7.05 mg/kg). In this study, Cu concentrations observed in fish tissues did not exceed permissible levels. The ANHMRC and the FAO suggested approved concentrations of Cu 30 mg/kg fresh weight for the Australian National Health and Medical Research Council (Velusamy et al., 2014). The UK Food Standards Committee Report indicates that a concentration of Cu in foods should not exceed 20 mg/kg wet weight (Cronin et al., 1998). Copper is an important trace element in fish metabolism and is important for hemoglobin synthesis in many enzyme reactions (Sivaperumal et al., 2007). But hepatic and kidney damage can occur at high Cu concentrations (Ikem and Egiebor, 2005; Satheeshkumar et al., 2011).

Cadmium is an anthropogenic metal contaminant that is particularly toxic to aquatic animals and can cause both hepatic and renal injuries in fishes and mammals (Mai et al., 2006). It may also cause coronary artery disease, high blood pressure, and chronic human pulmonary disorders. The cadmium levels evaluated in this study were greater than those recorded for fish from Daya Bay, China (0.002–0.083 μg/g) Gu et al. (2016); Peral River Delta, China (0.02–0.06 μg/g) Leung et al. (2014); the Northeast and eastern Central Atlantic Ocean (0.0017–0.0151 μg/g) Vieira et al. (2011) and Bangshi River, Bangladesh (0.09–0.87 mg/kg) Velusamy et al. (2014) but less than those reported in fish from the Kabul River, Pakistan (53–72 μg/g) Ahmad et al. (2015). A concentration limit for the Cd of 0.01–0.21 μg/g for fish was recommended by the Food and Drug Administration (USFDA, 2001) and the Cd limit was set by the EU (2008) (0.05–0.1 mg/kg). The concentrations of cadmium recorded in this study in marine fish species exceeded the allowable ANHMRC levels of 2 μg/g (Velusamy et al., 2014). Based on the results of this study, the high Cd concentration in tissues of fish species could be due to anthropogenic activities in the aquatic environment of the Jeddah Coast of Saudi Arabia.

Lead is an adverse metal harmful to humans causing neurotoxicity, nephrotoxicity, and several others (García-Lestón et al., 2010). Lead level of the fish under study was most similar to that of Tuzen (2003) for fishes from the middle Black Sea, Turkey (0.22–0.85 mg/kg); Tuzen (2009) in the Black Sea, Turkey (0.28–0.87 μg/g) and Uluozlu et al. (2007) in the Black and Aegean Seas, Turkey (0.33–0.93 μg/g). They are lower than those in Yilmaz (2003) of Iskenderun bay, Turkey (1.3–7.45 μg/g), as well as in Türkmen et al. (2009) in the Aegean and Mediterranean seas, Marmara (0.14–1.28 μg/g). As recommended by the ANHMRC, the maximum permissible Pb level is 2.0 mg/kg wet weight (Plaskett and Potter, 1979). According to the UK Food Standard Committee Pb should not exceed 2 mg/kg fresh weight (Cronin et al., 1998). The concentration of Pb in tissue samples in this study was found to be lower than the human intake limit acceptable. The results of this study revealed that heavy metal accumulation was higher in pelagic than demersal fishes and pelagic fish species, Black pomfret and Goldbanded jobfish showed the highest heavy metal concentration. Cr, Fe, Ni, Cd, and Hg levels in the investigated fish samples were higher than the permissible limits (FAO/WHO, 1989). However, Mn, Cu, and Pb concentrations were found to be within the acceptable limits (Plaskett and Potter, 1979; FAO, 1983; FAO/WHO, 1989; Cronin et al., 1998; USFDA, 2001; EU, 2008; Velusamy et al., 2014). In this analysis, heavy metal concentrations may have been accumulated in fish samples from sewage runoff and industry effluent, habitat-based and ecological variation among fish intakes of the fish species' food and their physical metabolism, and food habits (Yilmaz, 2003; Chi et al., 2007; Singh et al., 2007; Arulkumar et al., 2017; Velusamy et al., 2014).

5. Conclusion

The results of this research have shown that all five fish species are a good source of protein and lipids. The findings also provide useful information on heavy metal contamination in fish species of the Jeddah Coast, Red Sea, and compared with those of different countries. The concentrations of Cr, Fe, Ni and Cd, analyzed in this study were higher than other heavy metals due to the overloading of industrial waste and the disposal of the water from Jeddah. Mn, Cu, and Pb concentrations, however, were far below the levels recommended by various authorities (FAO, FAO/WHO, and FDA). It was concluded that the fishes captured from Jeddah Coast, Red Sea, are still safe for human consumption, but the amount consumed should be controlled under the FAO/WHO guidelines.

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Declaration of Competing Interest

All of this work (conception; acquisition, analysis, data interpretation; drafting of the manuscript; critical review of the manuscript and statistical analysis) were done by the authors. Also, the authors have declared that there is no competing interests exist.

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