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تراكيز العناصر الثقيلة في بعض الأسماك ذات الأهمية التجارية و مدى تعرض الفلسطينيين من سكان قطاع غزة (فلسطين) لهذه العناصر

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الملخص:

أجريت هذه الدراسة لمعرفة تراكيز العناصر الثقيلة في عضلات ستة من أنواع الأسماك المتوفرة في أسواق قطاع غزة، ولتقييم الخطر المحتمل نتيجة إستهلاك تلك الأسماك. في هذه الدراسة، تم تحديد تراكيز كل من الكادميوم والرصاص والنحاس والمنجنيز والنيكل والزنك في عضلات الأنواع التالية من الأسماك Merluccius hubbsi و Micropogonias furnieri و Pangasius hypothalamus و Oreochromis niloticus و Sparus aurata و Mugil cephalus. ولقد تم قياس مستويات العناصر الثقيلة باستخدام جهاز مطياف الامتصاص الذري وذلك بعد هضم العينات باستخدام وحدة الهضم الحراري الخاصة بجهاز كيلدال. أظهرت نتائج الدراسة بأن هناك اختلافا كبيرا بين مستويات العناصر المختلفة في عضلات الأسماك قيد الدراسة بحيث احتوى النوع M. cephalus على أعلى المستويات من عناصر النحاس والمنغنييز والنيكل وأما النوع M. furnieri فقد احتوى على أعلى المستويات من عناصر الزنك والكادميوم والرصاص. لقد وجد بأن تراكيز العناصر الثقيلة في عضلات الأسماك كانت متغيرة كما يلي: النحاس: 0.251–0.907، الزنك: 3.705–20.535، المنغنييز: 0.376–0.834، النيكل: 0.453–0.978، الرصاص: غير محسوس–0.552، جميعها بوحدات الميكروجرام/جم من الوزن الرطب. بالنسبة إلى عنصر الكادميوم، فقد عثر علية فقط في النوع M.furnieri بتركيز 0.09 (ميكروجرام/جم من الوزن الرطب). أن مستويات جميع تراكيز العناصر الثقيلة المقدرة في هذه الدراسة هي أقل من المستويات المسموح بها من قبل العديد من المنظمات والهيئات الدولية مثل FAO/WHO وغيرها. أما في حال تراكيز عنصري الرصاص والكادميوم في M. furnieri ، فلقد وجد بأنها قد تجاوزت الحد المقترح به بناء على المفوضية الأوروبية. كما وجد أيضا بأن تقدير كمية التناول اليومي (ميكروجرام/يوم/شخص) لكل العناصر نتيجة إستهلاك الأسماك قيد الدراسة من قبل الفلسطينيين في قطاع غزة هو أقل بكثير من كمية التناول اليومي المحتمل والمسموح به لشخص يزن 70 كجم حسب الحد المعتمد من قبل الـ FAO/WHO. بناء على هذه النتائج فإنه من غير المتوقع نشوء مشاكل صحية ناتجة عن العناصر الثقيلة من خلال إستهلاك الأسماك المتوفرة في أسواق قطاع غزة.

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Heavy metal concentrations in some commercially important fishes and their contribution to heavy metals exposure in Palestinian people of Gaza Strip (Palestine)

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Abstract This study was carried out to provide information on heavy metal concentrations in the muscles of six commercial fish species available in Gaza Strip markets and to evaluate the possible risk associated with their consumption. The concentrations of cadmium (Cd), lead (Pb), copper (Cu), manganese (Mn), nickel (Ni) and zinc (Zn) were determined in the muscles of *Merluccius hubbsi*, *Micropogonias furnieri*, *Pangasius hypothalamus, Oreochromis niloticus*, *Sparus aurata* and *Mugil cephalus*. The levels of heavy metals were measured by atomic absorption spectrophotometry after digestion of the samples using kjldahl heating digester. There were great variations among heavy metal levels in the muscles of the six fish species. *M. cephalus* accumulated the highest levels of Cu, Mn and Ni, while the highest levels of Zn, Cd and Pb were detected in *M. furnieri*. The heavy metal concentrations found in muscles varied for Cu: 0.251–0.907, Zn: 3.705–20.535, Mn: 0.376–0.834, Ni: 0.453–0.978 and Pb: Nd-0.552 μg/g wet weight. Cadmium was only detected in *M. furnieri* (0.09 μg/g wet wt). The estimated levels of all metals in the present study were lower than the limits permitted by Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO), European Community Regulation (EU), the United Kingdom Ministry of Agriculture, Fisheries and Food (MAFF), Turkish and Saudi guidelines. Lead and cadmium concentrations in *M. furnieri* however, exceeded the permissible limits in fish proposed by European Commission (EC). The estimated daily intakes (EDI) of all metals (μg/day/person) through consumption of the fish species by Palestinian people in the Gaza Strip were well below the permissible tolerable daily intake for 70 kg person ($PTDI_{70}$) set by FAO/WHO. Therefore, it can be concluded that no problems on human health would be raised at present from the consumption of commercial fish from the Gaza Strip markets.

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1. Introduction

Fish is a vital source of food for hundreds of millions of people worldwide. In 2008, about 81% (115 million tones) of estimated world fish production was used as human food with an average per capita of 17 kg (FAO, 2010a). Consuming fish provides an important source of protein, polyunsaturated fatty acids (PUFA), liposoluble vitamins and essential minerals, which are associated with health benefits and normal growth (Daviglus et al., 2002; Wim et al., 2007). According to FAO statistics, fish accounted for about 16% of the global population's intake of animal protein and 6% of all protein consumed (FAO, 2010b).

People in the Gaza Strip consume a considerable amount of fish. Based on information obtained from the Directorate General of Fisheries-Palestine Ministry of Agriculture, the total amount of fish consumed by people in the Gaza Strip was estimated to be 6389.7 tones in 2010.

As fish constitute an important part of human diet, it is not surprising that the quality and safety aspects of fish are of particular interest. Over the past several decades, the concentrations of heavy metals in fish have been extensively studied in various places around the world. Since the diet is the main route of human exposure to heavy metals (Castro-Gonzeza and Méndez-Armentab, 2008), the major interest was in the edible commercial species.

Although, most people in the Gaza Strip obtain their fish from fish markets, the original sources of commercially available fish in these markets are variable. Most are imported as frozen fish, while others are captured from the coastal waters of the Gaza Strip, and still few are cultured in the few fish farms recently established in the Gaza Strip.

Large sector of people in the Gaza Strip depend on the relatively cheap, frozen fish, which are imported from different countries around the world such as Argentine, Uruguay and Vietnam. There is presently, however, little or no information on the heavy metals status of fishes imported from these countries (Orban et al., 2008). Thus, the knowledge about the potential accumulation of heavy metals in these fish is very important for the health of the consumers. Another important issue that should be addressed concerning imported fish is the potential substitution of one species by others of a different price or origin through the commercial chain. Such illegal issue of seafood substitution, which sometimes reached high levels, has been documented by several authors in different countries around the world (Filonzi et al., 2010; Garcia-Vazquez et al., 2011).

The second source of commercial fish in the Gaza Strip is the wild caught fish which are usually captured along the coasts of the Gaza Strip. In the last few decades however, more concerns were raised about the potential accumulation of heavy metals in fish captured from this region due to coastal pollution.

Poorly treated municipal wastewater from various wastewater treatment plants and the flooding of Wadi Gaza are the main sources of pollution of the coastal zone of the Gaza Strip (Ali, 2002; EEA, 2006). In addition to wastewater, it was also reported that, seawater in the Gaza Strip is polluted to a large extent by pesticides, litter and toxic wastes (Abou-Auda and Shahin, 2005).

Previous studies and monitoring programs have shown that heavy metals were detected in wastewater samples collected in different occasions from different regions of the Gaza Strip (MEnA, 2001; Nejem et al., 2009; UNEP, 2009).

Farmed fish represent the third source of fish in Gaza Strip markets. In recent years, some fish farms were established in the Gaza Strip in order to achieve self-sufficiency in fish production, supplementing capture fishery production, and substituting the deficiency of quantities of fish sold in local markets of the Gaza Strip. This is especially true after the last war on Gaza (2008–2009) where fishing became, in addition to the limited fishing zone (less than three nautical miles off the shore of the Gaza Strip), a real threat to fishermen lives (PCHR, 2002). Cultured fishes may absorb dissolved elements and trace metals from its feeding diets and surrounding water leading to their accumulation in various tissues in significant amounts (McCarthy and Shugart, 1990) and exhibit eliciting toxicological effects at target organisms (Ali and Abdel-Satar, 2005).

Irrespective of their source, the potential accumulation of heavy metals in fish available in the Gaza Strip market to such a degree that may constitute a potential threat to human health when ingested is of great concern. Hence, it is important to determine the concentrations of heavy metals in commercial fishes in order to evaluate the possible risk of fish consumption.

Accordingly, the objective of current study was to determine the levels of heavy metals like cadmium (Cd), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb) and zinc (Zn) in the muscles of some important commercial fish available in Gaza Strip market. These concentrations were then compared against the recommended maximum levels allowed in food. In addition, the quality of the fish for human consumption was assessed.

2. Materials and methods

2.1. Sample collection

A total of six fish species were purchased in August, 2010. They were placed immediately in poly-ethylene bags, put into isolated container of polystyrene icebox and, then, brought to the Chemistry Laboratory of Islamic University of Gaza.

2.2. Measurements of the basic biological parameters

Fishes were first identified, and then the total lengths (cm) and the body-wet weights (g) of each fish specimens were measured. The detailed information is listed in Table 1.

2.3. Types and origins of fish species

Fish from different water bodies and geographical regions were used in the present study. They include: *Frozen fish*: The Argentine hake (*M. hubbsi*), the croaker fish (*M. furnieri*) and sutchi catfish (*P. hypothalamus* also known as *P. Pangasius*). They are originally imported from Argentine, Uruguay and Vietnam, respectively and purchased frozen from local markets in Gaza city. *Cultured fish*: The two fish species; sea bream (*S. aurata*) and Nile tilapia (*O. niloticus*) were purchased from a fish farm in the Gaza Strip. *Wild caught fish*: The grey mullet (*M. cephalus*) was purchased from local fishermen who caught them from the coastal waters of

Table 1 List of fish species, number and size of fishes used in this study.

Scientific name	Local name	Common name	No.	TL (cm) mean ± S.D.	BW (g) mean ± S.D.
Merluccius hubbsi[a]	Pakala	Argentine hake	10	18.36 ± 1.63	194.35 ± 27.10
Micropogonias furnieri	Jaraa	Croaker fish	10	29.84 ± 1.40	314.49 ± 37.31
Mugil cephalus	Bory	Grey mullet	9	35.04 ± 2.02	381.58 ± 71.56
Oreochromis niloticus	Bolty	Nile tilapia	10	25.11 ± 0.89	311.45 ± 14.30
Pangasius hypothalamus[b]	Filleah	Sutchi catfish	10	25.31 ± 1.40	357.6 ± 55.65
Sparus aurata	Danese	Sea bream	10	27.05 ± 0.70	360.02 ± 23.40

TL = total length, BW = body weight.
[a] Headed and gutted.
[b] Skinless and boneless filet fish.

Mediterranean sea at Wadi Gaza region by using cast or throw fishing net.

2.4. Fish handling and preservation

After taking the measurements and identification, fish were washed with deionized water, sealed in poly-ethylene bags and kept in a freezer at −20 °C until chemical analysis.

2.5. Digestion and analytical procedures

Before analysis, the fish were thawed and the muscular tissues from dorsal, abdominal and tail regions of each fish were taken out and homogenized. Four grams of the homogenized muscles (without skin) were taken from each specimen and placed in 300 ml kjldahl digestion tubes. A digestion mixture containing 6.0 ml of high purity nitric acid (Merck), 2 ml of hydrochloric acid (10 M) and 4 ml of hydrogen peroxide (35%) (Manutsewee et al., 2007) was added to each tube.

The samples were then heated at 130 °C by kjldahl heating digester until clear solution was obtained. The digested portions were filtered through Whatman filter paper (No. 42) and diluted to a final volume of 50 ml using deionized water. The analytical technique used to determine heavy metal levels in all samples was thermoelement Solaar S4 Atomic Absorption Spectroscopy (International Equipment Trading Ltd, USA).

At each step of digestion processes, acid blanks (laboratory blank) were prepared in order to ensure that the samples and chemicals used were not contaminated. They were analyzed by atomic absorption spectrophotometry before the samples and their values were subtracted to ensure that the equipment read only the exact values of heavy metals. Each set of digestion has its own acid blank and was corrected by using its blank.

The absorption wavelengths and detections limits for the heavy metals were, respectively 217.0 nm and 0.001 ppm for Pb, 228.8 nm and 0.002 ppm for Cd, 279.5 nm and 0.01 ppm for Mn, 213.9 nm and 0.001 ppm for Zn, 324.7 nm and 0.02 ppm for Cu and 232.0 nm and 0.01 ppm for Ni.

2.6. Precautions followed to avoid contamination

Several precautions were taken in order to prevent contamination during investigation. Fish samples were washed by deionized water prior cutting to remove adsorbed metals on skin. De-ionized water was used to prepare all aqueous solutions. All plastic and glassware used were rinsed and soaked in 10% (v/v) HNO_3 overnight. They were rinsed with deionized water and dried prior using. All acids and oxidants were of high quality from Merck, Germany.

2.7. Analytical quality control and ensuring the accuracy (recovery studies)

In the present study, to check the efficiency of digestion procedures and the subsequent recovery of the metal, homogeneous mixtures of six samples of fish muscles were spiked with multi-element solution which contains standard solutions of all metals considered in the present study. The element solution was spiked in a manner to attain final concentrations of 1.0 and 3.0 μg/g. A mixture without any metal was used as control. All mixtures were then subjected to the digestion procedure. The resulting solutions were analyzed five times for metal concentrations according to the same procedures as the samples to establish confidence in the accuracy and reliability of data generated. The amount of spiked metal recovered after the digestion of the spiked samples was used to calculate percentage recovery as follows: % recovery = $[(t\text{-}c)/t]100$. Where t = concentration of a metal in treatment sample, and c = concentration of a metal in control sample.

Procedural blanks and standard solutions were also included for analytical quality control to assure the accuracy and reproducibility of the results.

2.8. Health-risk assessment of fish consumption

According to the Directorate General of Fisheries in Palestinian Ministry of Agriculture, the average quantity of fish consumed per Palestinian person (assuming average body weight of 70-kg) per day in the Gaza Strip is 11.66 g. Multiplying this value by the average concentration of each metal in analyzed fish, the average daily intake of metals per person can be estimated.

2.9. Data analysis

Mean concentrations ± S.E.M. (the standard error of the mean) in μg/g wet weight were calculated. One-way analysis of variance (ANOVA) was used after the logarithmic transformation was done on the data to improve normality followed by Duncan multiple range test as multiple comparison procedure to assess whether the means of metal concentrations varied significantly among fish species. Possibilities less than 0.05 were considered statistically significant ($P < 0.05$). All statistical calculations were performed with SPSS 13.0 for Windows.

Table 2 Recovery of various metals from fish muscles.

Metal	Concentration of metal added (μg/g)	Concentration of metal recovered (μg/g)	Recovery %	Average percentage (%)
Pb	1.0	0.99	99	95.5
	3.0	2.78	92	
Mn	1.0	0.96	96	92.0
	3.0	2.65	88	
Cu	1.0	0.94	94	90.5
	3.0	2.62	87	
Cd	1.0	0.90	90	90.5
	3.0	2.73	91	
Ni	1.0	1.03	103	97.0
	3.0	2.72	91	
Zn	1.0	0.96	96	96.5
	3.0	2.90	97	

3. Results

3.1. Recovery test

The results of recovery test used in present investigation are given in Table 2. The recovery percentages results ranged from 89% to 103%, using a solution of 1.0 μg/g and from 87% to 104% using a solution of 3.0 μg/g concentration.

3.2. Metal concentrations in different fish species

The concentrations of Cu, Zn, Mn, Ni, Cd and Pb in the muscles of the analyzed six fish species are presented in Table 3 by mean values and standard errors. All results are expressed as μg/g wet weight.

There were vast differences among the heavy metal concentrations in the muscles of different fish species. The highest concentrations were for zinc, and the lowest were for lead and cadmium.

No single type of fish was consistently high for all metals. While *M. furnieri* had the highest levels of cadmium, lead and zinc; *M. cephalus* had the highest levels of copper, manganese and nickel.

Calculation of the overall average concentrations of Zn, Ni, Cu, Mn, Pb, and Cd in the muscles of the six fish species gave the following results: Zn 9.05, Ni 0.696, Cu 0.481, Mn 0.480, Pb 0.135, Cd 0.0139. This leads to the following ranking: Zn > Ni > Cu > Mn > Pb > Cd. The metal levels in the muscles of each fish species yield a similar ranking, except for *M. furnieri*, in which metal concentrations followed the order Zn > Pb > Ni > Mn > Cu > Cd.

Cu concentration in *M. cephalus* was significantly higher ($P = 0.001$) than all other fish types with average value of 0.907 ± 0.17 μg/g followed by *O. niloticus* with average of 0.638 ± 0.08 μg/g. The pattern of the average Cu concentration in the muscles of the remaining fish types in order of decreasing contents was *S. aurata* > *M. furnieri* > *M. hubbsi* > *P. hypothalamus* with values of 0.399 ± 0.03, 0.345 ± 0.03, 0.318 ± 0.01 and 0.251 ± 0.02 μg/g, respectively.

The mean concentration of Zn in *M. furnieri* was significantly higher than all other species ($P = 0.001$) with value of 20.35 ± 3.1 followed by *M. cephalus* with average concentration of 12.78 ± 3.61. Average concentration of Zn was in *O. niloticus* > *M. hubbsi* > *S. aurata* > *P. hypothalamus* with values of 7.52 ± 0.96, 5.821 ± 0.44, 4.946 ± 0.90, 3.705 ± 0.32 μg/g, respectively.

Average concentration of Mn was in *M. cephalus* > *M. hubbsi* > *M. furnieri* > *O. niloticus* > *P. hypothalamus* > *S. aurata* with values of 0.834 ± 0.31, 0.519 ± 0.07, 0.396 ± 0.020, 0.386 ± 0.03, 0.381 ± 0.04 and 0.376 ± 0.02 μg/g, respectively. There were no significant differences in manganese concentrations among fish species.

The average concentration of Ni can be ordered as follows: *M. cephalus* > *O. niloticus* > *M. hubbsi* > *S. aurata* > *P. hypothalamus* > *M.furnieri*, with average values of 0.978 ± 0.19, 0.892 ± 0.15, 0.707 ± 0.04, 0.634 ± 0.03, 0.511 ± 0.02 and 0.453 ± 0.04, respectively. From Table 3, the average concentration of Ni in *M. cephalus* was significantly higher ($P = 0.003$) than that of *M. furnieri*, *P. hypothalamus* and *S. aurata* .

Lead was detected only in three fish species; *M. furnieri*, *M. cephalus* and *O. niloticus*. The greatest value of Pb was detected in *M. furnieri* fish with average concentration of 0.552 ± 0.40 followed by *M. cephalus* and *O. niloticus* with average concentrations of 0.172 ± 0.09 and 0.115 ± 0.07 μg/g, respectively. No significant difference was detected among these fish species ($P > 0.05$).

Except in *M. furnieri*, with an average of 0.09 ± 0.04 μg/g, the Cd concentration was below the detection limit in all fish species. *M. furnieri* was the only fish species which contains the six metals under study.

3.3. Health-risk assessment for fish consumption

The average daily intake of metals per person was estimated and presented in Table 5. The daily consumption of Cd, Cu,

Table 3 The average metal concentrations (μg/g wet weight) ± standard error in muscle of various fish.

Scientific name	Metals					
	Cd	Cu	Mn	Ni	Pb	Zn
Merluccius hubbsi	<LD	$0.318^{ab} \pm 0.009$	$0.519^{a} \pm 0.069$	$0.707^{ab} \pm 0.044$	<LD	$5.821^{ab} \pm 0.436$
Micropogonias furnieri	0.090 ± 0.039	$0.345^{ab} \pm 0.029$	$0.396^{a} \pm 0.024$	$0.453^{b} \pm 0.041$	$0.552^{a} \pm 0.479$	$20.535^{c} \pm 3.081$
Mugil cephalus	<LD	$0.907^{c} \pm 0.171$	$0.834^{a} \pm 0.414$	$0.978^{a} \pm 0.192$	$0.172^{a} \pm 0.092$	$12.783^{bc} \pm 3.61$
Pangasius hypothalmus	<LD	$0.251^{a} \pm 0.017$	$0.381^{a} \pm 0.04$	$0.511^{b} \pm 0.02$	<LD	$3.705^{a} \pm 0.325$
Oreochromis niloticus	<LD	$0.638^{bc} \pm 0.084$	$0.386^{a} \pm 0.031$	$0.892^{ab} \pm 0.148$	$0.115^{a} \pm 0.07$	$7.522^{ab} \pm 0.963$
Sparus aurata	<LD	$0.399^{ab} \pm 0.031$	$0.376^{a} \pm 0.024$	$0.634^{ab} \pm 0.035$	<LD	$4.946^{ab} \pm 0.904$

Values with different letters in the same column are significantly different ($P < 0.05$).
<LD = values were below the limits of detection by spectrophotometry, 0.001 ppm for Pb and 0.002 ppm for Cd.

Mn, Ni, Pb and Zn in all fish species in this study ranged from Nd-1.0, 2.9–10.6, 4.4–9.7, 5.3–11.40, Nd-6.4 and 43.2–239.4 μg/day/person, respectively. The average daily intake of metals through fish consumption can be ordered as follows: Zn > Ni > Mn ≈ Cu > Pb > Cd.

4. Discussion

4.1. Heavy metals concentration in the muscles of the different fish species

This study was undertaken to investigate heavy metal concentrations in edible parts (muscle) of six commercially important fish species in Gaza Strip market because the concentration of heavy metals in commercial fish available in this region was rarely investigated. To our knowledge, so far, only one study has been reported on the heavy metal concentrations in three marine fish species namely, Grey mullet (*Mugilus* sp.), Barracuda (*Sphyraena* sp.) and Sigan (*Siganus* sp.), caught from four locations along the Gaza Strip coast (Mourtaja, 2008). The average metal concentrations from the aforementioned study were found to be, respectively for Zn, Cd, Pb and Cu as follows: 4.675, 0.096, 2.606, 0.3743 in Grey mullet; 6.030, 0.092, 2.618, 0.247 in Barracuda and 6.258, 0.123, 2.389, 0.570 (μg/g dry wt.) in Sigan. It is also worth to mention that, the contribution of fish consumption to heavy metal exposure in Palestinian people of the Gaza Strip has never previously been the subject of any study.

Results from the recovery process showed good recoveries of spiked samples of ratios ranged from 89% to 103%, using a solution of 1.0 μg/g, and from 87% to 104% using a solution of 3.0 μg/g (Table 2). These values indicate an accuracy of analytical methodology.

Although it is well known that fish muscle is not an active tissue in accumulating heavy metals (Bahnasawy et al., 2009), the present study concerned with the heavy metal concentrations in the fish muscles because it is the most consumed portion by the Palestinian people. Furthermore it was documented that some fish in polluted regions may accumulate substantial amounts of metals in their tissues which sometimes exceeded the maximum acceptable levels (Kalay et al., 1999).

While a large number of literature are available on heavy metal concentrations in fish, the majority of them were concerned either in different fish species collected from the same water body or in the same fish species collected from different localities. In the present investigation however, we are dealing with different fish species from different water bodies and geographical regions. Therefore, comparing our results with other studies is difficult and should be taken in precaution.

This investigation showed that the different fish species contained different mean concentrations of heavy metals in their muscles (Table 3). Many researchers indicated that heavy

Table 4 Maximum and standard levels in (μg/g wet weight) of metals in fish described in literature and range of concentrations found in muscle of commercial fishes from Gaza Strip market.

Organization/country	Metal						Reference
	Cd	Cu	Mn	Ni	Pb	Zn	
European Community	0.05	–	–	–	0.2	–	EC (2005)
England	0.2	20	–	–	2.0	50	MAFF (2000)
FAO (1983)	–	30	–	–	0.5	30	FAO (1983)
Turkish guidlines	0.1	20	20	–	1	50	Dural et al. (2007)
FAO/WHO limits	0.5	30	–	–	0.5	40	FAO/WHO (1989)
EU lmits	0.1	10	–	–	0.1	–	EU (2001)
Saudi Arabia	0.5	–	–	–	2.0	–	SASO (1997)
Range of metals in the present study	Nd-0.090	0.251–0.907	0.376–0.834	0.453–0.978	Nd-0.552	3.705–20.535	Present study

All tissue concentrations are in μg/g wet weight.
–, data were not available in publication or variable was not studied.
Nd, not detected.

Table 5 The estimated daily intakes (EDI) of heavy metals (μg/day/person) through consumption of economically important fish species by adult people (assuming 70 kg person) in the Gaza Strip.

	Fish species						PTDI[a]	$PTDI^{b}_{70}$
	M. cephalus	*M. furnieri*	*M. hubbsi*	*O. niloticus*	*P. hypothalamus*	*S. aurata*		
Cd	Nd (Nd)	1.0 (778)[c]	Nd (Nd)	Nd (Nd)	Nd (Nd)	Nd (Nd)	1.0	70
Cu	10.6 (3859)	4.0 (10,145)	3.7 (11,006)	7.4 (5486)	2.9 (13,944)	4.7 (8772)	500	35,000
Mn	9.7 (11,751)	4.6 (24,747)	6.0 (18,882)	4.5 (25,389)	4.4 (25,722)	4.4 (26,064)	140	9800
Ni	11.4 (358)	5.3 (773)	8.2 (495)	10.4 (392)	6.5 (685)	7.4 (552)	5.0	350
Pb	2.0 (1453)	6.4 (453)	Nd (Nd)	1.3 (2173)	Nd (Nd)	Nd (Nd)	3.57	250
Zn	149 (5476)	239.4 (3409)	67.9 (12,025)	87.7 (9306)	43.2 (18,893)	57.7 (14,153)	1,000	70,000

[a] PTDI: provisional permissible tolerable daily intake (μg/kg body weight/day), calculated from provisional permissible tolerable weekly intake (PTWI) cited in Türkmen et al. (2009) after FAO/WHO (2004).
[b] $PTDI_{70}$: permissible tolerable daily intake for 70 kg person (μg/day) = PTDI × 70 kg.
[c] Values between brackets are the daily intake (in grams) of each fish species that should be consumed in order to attain the permissible tolerable daily intake of metal for 70 kg person (= $PTDI_{70}$ (μg/day) /metal concentration (μg/g)) according to FAO/WHO (2004).

metal bioaccumulation of fish is species-dependent. Feeding habits (as carnivores, herbivores, omnivores and limnivores) and habitats of species are strongly related to accumulation level (Al-majed and Preston, 2000; Yilmaz, 2005). In addition to species differences, variations of heavy metal concentrations in the different fish species can be also attributed to variety of reasons including; size (body weight and length), gender, age and growing rates of the of fish species as well as types of tissues analyzed, and physiological conditions (Canli and Atli, 2003; Raja et al., 2009; Naeem et al., 2011). The differences in the aquatic environments concerning the type and level of water pollution, chemical form of metal in the water, water temperature, pH value, dissolved oxygen concentration, water transparency, are other factors influence heavy metal concentrations in the different fish species. It is also documented that the geographical locations and season of catch could lead to different metal concentrations even in the same fish species (Dural et al., 2007; Bahnasawy et al., 2009).

Among fish species studied, the maximum mean concentrations of heavy metals were found in *M. furnieri* and *M. cephalus*. The Mediterranean fish species, *M. cephalus* displayed the highest mean concentrations of Cu, Mn and Ni in their muscles and the second highest concentrations of Zn and Pb after *M. furnieri* (Table 4). This result may confirm previous studies of several authors who reported that *M. cephalus* usually accumulates higher levels of heavy metals than other species (Yilmaz, 2003; Dural et al., 2007; Bahnasawy et al., 2009).

The high levels of heavy metals in *M. cephalus* have been usually attributed to their habitat and feeding behavior. Grey mullet tend to be near the sediment region (Bahnasawy et al., 2009), feeding on detritus, diatoms, algae, microscopic invertebrates and fish parts (Olukolajo, 2008). Kilgour (1991) indicated that animals which have close relationship with sediment, show relatively high body concentrations of metals.

As data on heavy metals in fish are related to the pollution status of the regions (Hamza-Chaffai et al., 1996), the relatively high levels of metals in *M. cephalus* caught from the costal water of Gaza may indicate potential pollution at least in the area where they are caught (Wadi Gaza).

Due to interspecific differences however, when assessing the levels of heavy metals in fish, it is often more interesting to compare the results of the same species with studies performed in the same water body.

The metal concentrations from other studies along the Mediterranean coasts well agreed with our findings. Specifically, Yilmaz (2005) found higher levels of Cu, Zn, Fe, Pb, Ni and Cr in *M. cephalus* than those detected in *Sparus aurata* from Iskenderun Bay of the Eastern Mediterranean coast of Turkey. Similarly, the total mean concentrations of Iron, copper, Nickel, Chromium, Lead and zinc in *M. cephalus* were found to be higher than that of *Trachurus mediterraneus* caught at three stations in Iskenderun Bay (Yilmaz, 2003). In another study in Turkey, Canli and Atli (2003) found higher levels of Cu and Zn in muscles of *M. cephalus* than other fish species from the northeast Mediterranean Coast of Turkey and the second highest concentration of Cd after the red gurnard, *Trigla cuculus*. In El-Mex Bay, western of Alexandria Mediterranean Coast, Egypt, Khaled (2004) recorded the highest concentrations of Cr and Fe in the muscle of *M. cephalus* and the second highest concentrations of Cd, Mn and Ni after *Siganus rivulatus* and *Caranx crysos*, respectively.

Considering that the dry weight represents 23–33% of the corresponding wet weight (Burgera and Gochfeld, 2005), the levels of Cu and Zn recorded for *M. furnieri* in the present study were in average comparable to those determined by Viana et al. (2005) for Uruguayan croaker fish who indicted that the mean of Cu is <1.0 and Zn ranged 8.9–30 (values are expressed as μg/g dry weight). In Argentine Marcovecchio (2004), determined zinc concentration of *M. furnieri* by 20.5 μg/g which was very similar to our value (20.53 μg/g).

Neither cadmium nor lead was detected in the Vietnamese suchi catfish, *P. hypothalamus*. It also exhibited the least concentration of copper and zinc. We could therefore conclude that this fish species is safe to consume. The aspects of safe consumption of the Vietnamese suchi catfish was confirmed elsewhere by Orban et al. (2008), who indicated a good quality of the fish samples analyzed, at least with regard to residual levels of mercury, organochlorine pesticides and polychlorinated biphenyls.

The present investigation detected considerable levels of metals in the muscle tissues of farmed fish species, *O. niloticus* and *S. aurata*. Similar results were reported by Bin-Mokhtar (2009) and Minganti et al. (2010). In intensive culture systems, fish are usually fed on artificial diets that are usually supplemented with various metals including copper, iron, zinc, manganese, cobalt, arsenic, magnesium and selenium to fulfill their mineral requirements (CIESM, 2007). On the other hand, previous works have detected high concentrations of these metals–which sometimes exceeded the permissible levels- in the potential water sources (either fresh or seawater) used in aquaculture in the Gaza Strip (MEnA, 2001; El-Nahhal, 2006).

Since it was reported that, cultured fishes may absorb dissolved elements and trace metals from their feeding diets and surrounding water leading to their accumulation in various tissues in significant amounts (McCarthy and Shugart, 1990), we could therefore suggest that the detected amounts of metals in both cultured fish species may be accumulated from these sources.

The results of the present study showed that the Argentina's hake (*M. hubbsi*) occupies almost a median range of heavy metal concentrations between analyzed fish species. Our results however are hard to compare with other investigations, because only limited literature data exist (Carvalho et al., 2000).

It is well known that, copper, manganese, nickel and zinc are essential elements, required by a wide variety of enzymes and other cell components and having vital functions in all living organisms, but very high intakes can cause adverse health problems (Demirezen and Uruc, 2006). On the other hand, Cd and Pb, have no biological role and hence they are harmful to living organisms even at considerably low concentrations. In this study, the overall average concentrations of metals were found to accumulate in the order of Zn > Ni > Cu > Mn > Pb > Cd, with concentrations of essential elements were higher than non-essential elements. These results may confirm the essential role of the former metals to fish species. Although it is not always the rule, these results were in conformity with the observations of Chen and Chen (2001) (Zn = Fe > Cu = Mn > Cd) and Bahnasawy et al. (2009) (Zn > Cu > Pb > Cd).

4.2. Heavy metal concentrations vs. international dietary standards and guidelines

To our knowledge, no Palestinian food safety standards are currently available regarding metal concentration in fish, consequently, the results obtained for muscle samples were compared with limit values and guidelines found in the bibliography using wet weights (Table 4).

The levels of Cu, Mn, Ni and Zn determined in the muscles of the six studied fish species were lower than the maximum levels and guidelines values described in the literature (Table 4).

On the other hand, the maximum levels of Cd and Pb in this study were 0.090 and 0.552 μg/g wet wt, respectively. These levels were higher than the limit values for fish proposed by the European Community (EC, 2005). Although, such high levels were detected in *M. furnieri*, it cannot be said that this species is not fit for human consumption, because (as illustrated below) large quantities (ca. 452.90–777.78 g) of this fish species have to be eaten daily by a person to be harmful to human health.

4.3. Daily consumption safety

As consumption of fish is a possible source of metal accumulation in humans, there is great interest in estimation of the daily intakes of heavy metals through fish consumption.

The estimated daily intakes (EDI) of heavy metals (μg/day/person) through consumption of economically important fish species by Palestinian people in the Gaza Strip are illustrated in Table 5. Daily intake of heavy metals was estimated on the basis of the concentrations measured in fish muscle and daily fish consumption rate (11.66 g). Average Palestinian body weight was assumed to be 70 kg. Current metal intakes were compared with the respective permissible tolerable daily intake for a 70 kg person ($PTDI_{70}$) (μg/day).

As can be seen in Table 5, the values of estimated daily intakes (EDI) of Cu, Zn, Mn, Ni, Cd and Pb in muscles of fish in this study are well below their corresponding permissible tolerable daily intake for 70 kg person ($PTDI_{70}$) values.

The dose of a toxic metal that one obtains from fish however, not only depends on the concentration of specific metal in fish, but also on the quantity of fish (intake) consumed.

As high intakes of fish are traditional components of the diet of some Palestinian people, we also calculated the daily amount (in grams) of each fish species that should be consumed in order to attain the permissible tolerable daily intake of metal for 70 kg person, $PTDI_{70}$ (Table 5). Accordingly, Palestinian person will be at risk of the deleterious effects of a metal only if his/her daily intake of any fish species included in the study exceeded their respective $PTDI_{70}$. Considering normal consuming habits, we can firmly state that the calculated daily intake of fish is far away from the actual daily amount of fish consumed by most Palestinian people in general (Table 5) and therefore, no risk of normal fish consumption originating from the local market on Palestinian people's health. Although levels of heavy metals are not high, care must be taken considering some people regularly consume large quantities of fish. It is also recommended to conduct continuous monitoring for commercial fish in Gaza Strip markets to ensure that the concentrations of metals remain within the prescribed worldwide limits.

5. Conclusions

The result obtained in this study revealed that, the highest concentrations of metals in the muscles of the studied fish species were detected for zinc, and the lowest were for lead and cadmium. There was no single type of fish that was consistently high for all metals. The highest levels of metals were found in muscles of *Mugil cephalus* and *Micropogonias furnieri*. Except in a few cases, the heavy metal concentrations in most fishes were well below the limits proposed for fish by various international standards and guidelines such as EU (2001), FAO/WHO (1989), MAFF (2000), Turkish guidelines and Saudi guidelines. Regarding the daily intake and safety aspects, the examined fish were safe for human consumption at least with regard to residual levels of cadmium, copper, manganese, nickel, lead and zinc but a continuous monitoring of heavy metals in commercial fish in Gaza Strip markets is necessary to insure the prescribed worldwide limit.

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