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HEALTH RISK ASSESSMENT OF ARSENIC CONTAMINATION FROM THE CONSUMPTION OF COMMERCIALLY IMPORTANT EUROPEAN SEA BASS (*Dicentrarchus labrax* L., 1758)

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Abstract

Sea bass (Dicentrarchus labrax L., 1758) production in Turkey has increased significantly in recent years, especially for export to EU countries. This study determined inorganic arsenic (iAs) levels by measuring total arsenic levels (AsT) in muscle tissues sampled from sea bass fished and farmed (both in earthen ponds and sea cages) in Güllük Bay within the borders of Muğla province. The study also conducted a risk assessment of sea bass consumption for consumer health. For this aim, fish muscle tissues were mineralized with microwave digestion before total arsenic concentrations were measured using inductively coupled plasma mass spectroscopy (ICP-MS). The highest mean arsenic levels were detected in sea bass cultured in earthen ponds (0.38 mg kg^{-1}) while levels in both sea bass cultured off-shore and wild sea bass were 0.26 mg kg^{-1}. According to the risk assessments based on estimated daily intake (EDI), target hazard quotient (THQ), carcinogenic risk (CR), and lifetime cancer risk (TR), it was revealed that eating sea bass did not damage human health.

Keywords: Arsenic, consumer health, *Dicentrarchus labrax*, risk assessment.

EKONOMİK OLARAK DEĞERLİ BİR TÜR OLAN LEVREK BALIĞININ (*Dicentrarchus labrax* L., 1758) TÜKETİMİ SONUCUNDA OLUŞABİLECEK ARSENİK KONTAMİNASYONUNUN HALK SAĞLIĞI RİSK DEĞERLENDİRMESİ

Özet

Ülkemizde son yıllarda levrek balığı (Dicentrarchus labrax L., 1758) üretim faaliyetleri, özellikle AB ülkelerine ihraç edildiği için önemli ölçüde artmıştır. Bu çalışmanın amacı, Muğla'da ili sınırları içerisindeki Güllük Körfezi'nde avcılığı ve yetiştiriciliği (hem toprak havuzlarda hem de denizdeki kafeslerde) yapılan levreklerin (Dicentrarchus labrax L., 1758) kas dokularındaki toplam arsenik miktarlarının (AsT) belirlenmesi yoluyla inorganik arsenik (iAs) düzeylerinin hesaplanmasıdır. Çalışmada ayrıca, levrek tüketiminin tüketici sağlığı açısından risk değerlendirmesini de yapılmıştır. Bu amaçla, balıkların kas dokuları mikrodalga sindirimi ile mineralize edilmiş ve endüktif eşleşmiş plazma kütle spektroskopisi (ICP-MS) yöntemi ile toplam arsenik konsantrasyonları tespit edilmiştir. En yüksek ortalama arsenik düzeyi toprak havuzlarda yetiştirilen levreklerde tespit edilmiş olup (0.38 mg kg^{-1}), avlama ve kafeste yetiştiricilik yöntemiyle alınan örneklerde ise en yüksek ortalama arsenik seviyesinin 0.26 mg kg^{-1} olduğu ortaya konmuştur. Tahmini günlük alım (EDI), hedef tehlike katsayısı (THQ), kanserojen risk (CR) ve yaşam boyu kanser riski (TR) bazında yapılan risk değerlendirmeleri sonucunda insan sağlığı açısından olumsuz bir sonucun olmadığı ortaya çıkmıştır.

Anahtar Kelimeler: Arsenik, tüketici sağlığı, *Dicentrarchus labrax*, risk değerlendirmesi.

Cite

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1. Introduction

Increasing world population, rising demand for protein, and falling natural fish stocks have combined to cause an increase in aquaculture investment [1]. Whereas the quantity of fish caught by fishing has not risen in the last 10 years, there has been a continuous increase in aquaculture and fisheries production [2]. Being surrounded by seas on three sides and with a coastline of 8,333 km, Turkey has approximately 25 million hectares suitable for aquaculture production. In addition, the country's watercourses, which are already used for aquaculture, have a total length of 177,714 km. Thus, there is clearly huge potential to expand aquaculture in Turkey [3]. Indeed, aquaculture has become a prominent component of its agriculture industry in recent years, moving the country's ranking from the 36nd in 2005 to the 22th in 2016 in terms of global aquaculture production [4].

Aquaculture in Turkey mostly depends on marine cage (offshore) farming whereas earthen pond fish farming constitutes only a little share of total production. Almost 92% of cages are located in the Aegean region that is particularly suitable for farmed species given its geographical and hydrographical conditions. In addition, the Aegean Sea has far more sheltered bays required for marine cage farming than Turkey's other coastal areas [5].

Regarding species, finfish production has become more prevalent in recent decades in the Aegean region than in northern Europe. In 1990s, finfish production concentrated on three species: European sea bass (*Dicentrarchus labrax* L., 1758), gilthead sea bream (*Sparus aurata* L., 1758), and rainbow trout (*Oncorhynchus mykiss* W., 1792). European sea bass is a white demersal fish species native to the Eastern Atlantic Ocean, the Mediterranean, and the Black Sea. The countries with the highest potential for its production are France, the United Kingdom, Italy, Turkey, and Egypt [6].

In line with recent technological developments experienced in recent years, Turkey's aquaculture production, especially from sea bream and sea bass farming, has gained an important place in the world market. In 2020, total aquaculture production was 421,411 tons, worth approximately € 1,351,871,278. Of this, sea bream, sea bass, and rainbow trout accounted for 258,656 tons and a large part of the total income (approximately € 829,759,112) [7]. Total sea bream and sea bass farming increased from 25,000 tons in the early 1990s to 78,000 tons in 2010. By 2020, sea bass production alone reached 148,907 tons [8]. In 2019, sea bass, rainbow trout, and sea bream accounted for 37%, 33%, and 27% of production, respectively. Sea bass production has grown steadily, doubling in 10 years. Production of these two species in Greece and Turkey may continue to dominate Mediterranean aquaculture in the future [9]. Most of Turkey's marine fish farms have been founded along its Aegean coasts, particularly in Mugla and Izmir provinces. In 2016, production in Mugla province was 41,000 tons, approximately 54% of Turkey's total European sea bass production [10].

Unfortunately, fish may pose a health risk to human consumers. Aquatic organisms, including fish, are regularly exposed to chemicals like heavy metals due to polluted and contaminated waters [11]. Since heavy metals can be transported to humans, the last link of the food chain, their sub-lethal effects have long been a concern [12]. The primary heavy metals threatening human health are arsenic, cadmium, mercury, and lead [13]. Arsenic occurs naturally in the lithosphere in hot springs, volcanic and non-volcanic rocks, sea water, and mineral sediments. It can then enter the environment through volcanic movements, rock erosion, and forest fires as well as from industrial and agricultural activities [14,15]. Arsenic acid is extensively used as a nutritional supplement, especially in animal husbandry (e.g., 3-nitro-4-hydroxy phenylarsonic acid, H_3AsO_4, and 4-nitrophenylarsonic acid) and the clothing industry as a cotton desiccant [16,17]. In addition, many arsenic derivatives are the most important components of agricultural pesticides (e.g., arsenic acid, dimethylarsinic acid (cacodylic acid), monosodium methylarsenate (MSMA), and disodium methylarsenate (DSMA)) [18].

Arsenic is defined as a Group 1 carcinogen because of its adverse effects on human health [19]. As a carcinogenic chemical, it not only causes cancer in many different tissues and organs (e.g., lung, bladder, kidney, and skin) [20] but also cardiovascular, metabolic, and developmental disorders [21-25].

Arsenic is found at higher levels in marine environments than terrestrial areas because of its high solubility in water, which enables it to permeate into marine environments from arsenic-containing rocks through wave action [26]. The Mediterranean Sea specifically has higher As levels than other seas or oceans [27]. The bioaccumulation of As in aquatic organisms, specifically in fish, threatens both these species and human health because fish consumption is an important source of toxic trace elements monitored in human systems [28]. European sea bass production is widespread because of its high commercial value in Europe [29].

Given the high production and consumption of fish, risk assessment methods are frequently applied [30-32]. The Environmental Protection Agency (EPA) defines human health risk assessment as the process of estimating the probability of adverse health effects in people exposed to chemicals in polluted or contaminated environments [34].

One standard risk assessment method used by the US Environmental Protection Agency (USEPA) is based on THQ. This enables assessment of risks from consumption of food contaminated with toxic matter, such as heavy metals [33]. Risk assessments for heavy metals can be conducted with various parameters, such as EDI, THQ, TR, and CR. These parameters depend on intake rate, exposure frequency and duration, the contaminant's oral reference dose (RfD_o), and the sampled people's mean body weight [35].

The aim of this study is to determine inorganic arsenic levels by measuring total arsenic levels in muscle tissues from sampled European sea bass farmed in marine cages and earthen ponds, and wild sea bass caught from the coast of Mugla province, Turkey. The study also provides a risk assessment of European sea bass consumption for consumer health.

2. Materials and Methods

2.1. Study area and sampling

The study was conducted in Gulluk district in Milas (Mugla, Turkey) during 2019 [Figure 1]. Fifteen adult fish of serving size were sampled from each of the three groups (cages, ponds, and sea), making 45 specimens in total. The bass cultured in earthen ponds were taken from ponds near Milas-Bodrum Airport (1) during January. Off-shore marine cage cultured bass (2) and wild (natural) sea bass (3) were obtained from Gulluk Bay (Eastern Aegean Sea) which is overflown by almost 1,000 planes per month landing or taking off from the regional airport. There is also a commercial port in Gulluk Bay, mainly used for shipping mining products and tourism, especially in summer. All samples were brought to the laboratory under cold chain conditions (4°C) and stored at −18°C for analysis of total As (AsT).

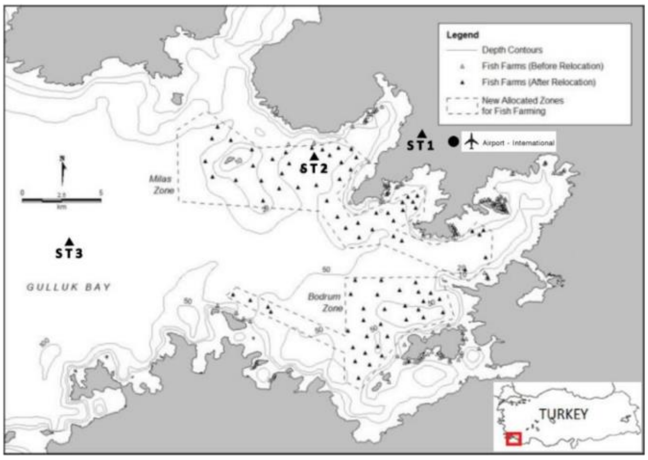

Figure 1. Map of Study Area (1: Earthen ponds, 2: Offshore marine cage systems, 3: Fishing area). (Figure was modified from [36]).

2.2. Analytical procedures

This study used wet digestion, one of the most commonly used methods for elemental analysis in muscle tissue samples. It is based on the use of different acids. Muscle tissue samples were taken by dissection after medicating the sampled fish with deionized water (resistivity: 18.0 MΩ cm). The muscle tissues were then homogenized completely in a laboratory blender (Waring trademark) with stainless steel cutters before the samples were digested using a high pressure closed microwave system.

For this process, nitric acid and hydrochloric acid (9:1 v/v) were used as solvents [37], with 0.5 g (w/w) of the homogenized tissue samples added to polytetrafluorethylene (PTFE) vessels along with 9 mL nitric acid (65 % suprapur, Merck) and 1 mL hydrochloric acid (30 % suprapur, Merck) solution. A Milestone ETHOS Easy® microwave digestion system was used to digest the fish samples for the heavy metal analysis. Digestion was completed with 2 % nitric acid (65 % suprapur, Merck), 0.5 % hydrochloric acid (30 % suprapur, Merck) solution to 30 mL in acid-washed standard flasks and then put in 50 mL polypropylene centrifuge tubes [38] [Table 1].

Table 1. Protocol for microwave digestion.

Step	1	2	3	4	5
T (temperature, °C)	150	175	220	50	50
P (pressure, psi)	35	35	35	35	35
Ta (rump time, min)	5	5	5	1	1
T (hold time, min)	5	5	17	1	1
Power	90	90	90	10	10

Total arsenic (AsT) concentrations within the samples were estimated using ICP-MS (Agilent 7700 with auto-sampler) at the Applied Science Research Center (ONCE I) at Celal Bayar University, Manisa, Turkey. A mixed element standard solution (AccuTrace© Mes-21-1) was used to prepare the calibration curve. Table 2 presents the ICP-MS operation conditions. The results are shown as mg kg^{-1} wet weight (w/w).

Table 2. Operating conditions of Agilent 7700X ICP-MS.

Radio frequency power	1550 W
RF matching	2.1 V
Sampling depth	8 mm
Carrier gas	0.95 L min^{-1}
S/C temperature	2°C
Nebulizer type	MicroMist

2.3. Analysis of reference material

The National Research Council Canada TORT-2 lobster hepatopancreas reference material for trace metals (NRCC TORT-2) was applied to test the reliability of the results of all analyses performed with ICP-MS. Recovery rates were found to be within acceptable limits (95.69 %). To calibrate the ICP-MS device, 10 mg L^{-1} mixed element standard solution (AccuTrace MES-21-1) was used. The analyses were repeated five times with concentrations of 0, 5, 10, 50, and 100 µg L^{-1} for the arsenic and the calibration curve was prepared.

The calibration curve revealed good linearity with values higher than the range of concentrations, and a determination coefficient higher than 0.999. The limit of quantitation (LOQ = standard deviation (SD) 10) and limit of detection (LOD = standard deviation (SD) 3) were calculated by analyzing five replicate sample blanks consisting of deionized water + 2% HNO_3. The detection limit (LOD) for As was calculated as 0.025 µg kg^{-1}.

2.4. Human Health Risk Assessments

The health risks assessments for heavy metal-contaminated seafood consumption were calculated according to the EDI of heavy metals, THQ and CR [39]. The daily intake rates used for all calculations in this study were evaluated with two different parameters: meal size (MS) and fish ingestion rate (FIR). The results were then compared. Daily intake rates used in the formulas of EDI, THQ, and TR are represented as daily consumption of fish per person (DC_{per} - kg $person^{-1}$ day^{-1}).

2.5. Estimated Daily Intake of inorganic arsenic

The arsenic concentrations obtained in this study were AsT although the As risk factors and consumption limits were only estimated for the potentially toxic, inorganic form, which varies between 1 and 10% of AsT [40,41]. Previous studies have reported varying shares of iAs in fish muscle: 5-12% of AsT [42]; 10% [43]; and only 3% in recent studies [30,44,45]. This suggests that 3% of AsT in the present study can be accepted as iAs. Accordingly, iAs concentrations that were calculated with this method were used in the risk assessments.

EDI provides an alternative approach for food risk assessments [33,46]. The EDI_m (mg kg BW^{-1} day^{-1}) values per meal size and EDI_T (mg kg^{-1} body $weight^{-1}$ day^{-1}) values based on annual consumption for the Turkish population were calculated using the formulas below suggested by Copat et al. (2012) [47]:

$$\mathrm{EDI} = \frac{\mathrm{DC_{per}\ x\ C}}{\mathrm{BW}} \qquad (1)$$

C is the average element concentration in fish muscle tissue (mg kg^{-1}); DC_{per} refers to meal size (kg $person^{-1}$ day^{-1}) and daily fish consumption rate (kg $person^{-1}$ day^{-1}); BW is mean body weight (kg). The reference body weight for risk assessments is generally specified as 16 kg for children and 70 kg for adults [48,49]. Ideal meal size is considered to be 0.114 kg $person^{-1}$ day^{-1} for children and 0.227 kg $person^{-1}$ day^{-1} for adults [47]. In Turkey, the five-year mean annual fish consumption per person is 6.08 kg $year^{-1}$ (2016–2019), so daily fish consumption per person is 16.6 gr day^{-1} (≅ 0.017 kg day^{-1}) [50]. This value was used as the FIR value.

2.6. Determination of target hazard quotient

THQ is one method used estimate non-cancer risk [51], based on the ratio of the determined dose of a pollutant to the dose level (RfD_o). A risk assessment based on THQ does not provide a quantitative approximation of the probability of an exposed population experiencing an unfavorable health effect; instead, it indicates the risk level associated with exposure to the pollutant [52]. In other words, THQ measures level of concern rather than risk [53,54]. If the THQ value obtained from a risk assessment based on THQ is <1, this indicates that there are no adverse effects. Conversely, if it is >1, there is a risk for human health [55].

The THQ value was calculated using the adapted formula below given by USEPA (1989) [56]:

$$\mathrm{THQ} = \frac{\mathrm{E_{fr}\ x\ ED_{tot}\ x\ DC_{per}\ x\ C}}{\mathrm{RfD_o\ x\ BW\ x\ AT}}\ \mathrm{x}\ 10^{-3} \qquad (2)$$

E_{fr} is the exposure frequency (365 days $year^{-1}$); ED_{tot} is the exposure period (mean life expectancy = 70 years approx.); DC_{per} refers to meal size (kg $person^{-1}$ day^{-1}) and daily fish consumption rate (kg $person^{-1}$ day^{-1}); C is the concentration of heavy metal in fish muscle tissue (mg kg^{-1}); RfD_o is the oral reference dose (mg kg^{-1} day^{-1}); BW is mean body weight(*); AT is mean length of exposure to non-carcinogens (365 days $year^{-1}$ × number of exposure years - 70 years for adults; 6 years for children).

As mentioned above, 70 kg body weight is usually applied for adults [48] and 16 kg of body weight for children [49].

2.7. Cancer slope factor and carcinogenic risk

Cancer slope factor (*CSF*) referring to the carcinogenic risk and the related weight-of-evidence specification is the toxicity data which is commonly used for the specification of potential human carcinogenic risks [57]. Generally, *CSF* is applied to risk assessments to determine the upper-limit lifetime likelihood of an individual developing a cancer attributable to exposure to a specific level of a potential carcinogen over a period of time [58,59]. In the present study, the lifetime probability to contract cancer attributable to exposure to site-related chemicals was estimated in accordance with Nkpaa et al. (2016), using the following formula [39]:

$$\text{Carcinogenic risk (CR) or lifetime probability of cancer} = \mathrm{EDI} \times CSF \qquad (3)$$

EDI= estimated daily intake of inorganic arsenic (mg^{-1} kg^{-1} day^{-1}); *CSF* = ingestion cancer slope factor (mg^{-1} kg^{-1} $day^{-1})^{-1}$. The EDI value refers to both EDI_m and EDI_T.

By comparing the daily intake (amount of fish consumed over a specified period) with the chronic oral reference dose (RfD_o), it is possible to determine whether an individual's exposure level exceeds tolerable health guidance levels [60].

We also used the target cancer risk (TR) model to estimate lifetime cancer risks. The TR value was calculated using the formula below given by [56,61,62]:

$$\mathrm{TR} = \frac{\mathrm{E_{fr}\ x\ ED_{tot}\ x\ DC_{per} x\ C\ x}\ CSF}{\mathrm{BW\ x\ AT}}\ \mathrm{x}\ 10^{-3} \qquad (4)$$

E_{fr} is the exposure frequency (365 days $year^{-1}$); ED_{tot} is the exposure duration (70 years); DC_{per} refers to both meal size (kg $person^{-1}$ day^{-1}) and daily fish consumption rate (kg $person^{-1}$ day^{-1}); C is the concentration of inorganic As in fish muscular tissue (mg kg^{-1} w/w); *CSF* is the oral carcinogenic potency slope of iAs (risk per mg

kg^{-1} body $weight^{-1}$ day^{-1}); BW is mean adult and child body weight (kg) The life-time exposure for calculating cancer risk was set as 365 days $year^{-1}$ for 70 years (AT = 70 years × 365 days $year^{-1}$).

By comparing the daily intake (of the amount in fish consumed over a certain time) with the chronic oral reference dose (RfD_o), it is possible to determine whether exposure level of a person exceeds acceptable health guidance levels [60]. All calculations were made according to USEPA risk analysis, FAO/WHO, and ATSDR standards, as indicated in Table 3.

Table 3. Variables and values used in the risk assessments

Variable	Value
E_{Fr} (frequency of exposure)	365 days $year^{-1}$
ED_{tot} (period of exposure)[a]	6 years for children
	70 years for adults
C (concentration of iAs in fish muscular tissue)	mg kg^{-1} w/w
FIR (daily ingestion rate of fish)[a]	0.017 kg $person^{-1}$ day^{-1}
MS (meal size)	0.114 kg $person^{-1}$ day^{-1} for children
	0.227 kg $person^{-1}$ day^{-1} for adults
BW (mean body weight)[a]	16 kg for children
	70 kg for adults
AT (period of mean exposure to carcinogens)	E_{fr} x ED_{tot}
CSF (cancer slope factor of iAs)[b]	1.5 mg kg^{-1} body $weight^{-1}$ day^{-1}
RfD_o (oral reference dose)[c]	3×10^{-4} mg kg^{-1} body $weight^{-1}$ day^{-1}

[[c]59, [a]63,64,[b]65,66].

2.8. Statistical analysis

To determine the relationships between groups, Kruskal Wallis and Mann-Whitney U nonparametric tests were applied. The threshold for a statistically significant difference was set at an alpha level of 0.05. All analyses were performed using IBM SPSS Statistics V.20.

3. Results and discussion

A total of 45 fish specimens were collected from three different aquaculture production environments. Table 4 presents the minimum, maximum, and mean concentrations of AsT and iAs detected in fish muscle tissues for each group. There were no statistically significant differences between the three groups in terms of length and weight ($p>0.05$). Regarding AsT and iAs levels, there were no statistically significant differences between offshore cultured sea bass and wild sea bass ($p>0.05$). However, there was a statistically significant difference between offshore cultured sea bass and wild sea bass plus sea bass cultured in earthen ponds ($p<0.01$).

The latter result can be explained in terms of the area's extensive use, before the development of aquaculture, for tobacco and cotton farming, which may have caused arsenic accumulation. As levels in decontaminated soil and rocks can vary between 0.2 and 40 mg kg^{-1} while inorganic arsenic is used as an agricultural insecticide [67]. During the first half of the 20th century, for example, arsenic-containing pesticides like lead, calcium, and sodium arsenate were applied intensively to apple, blueberry, and potato crops.

Excessive use of such compounds can raise arsenic contamination levels in the sediments of adjoining streams. Robinson and Ayuso (2004) reported arsenic residue levels of 0.3 to 93.0 mg kg^{-1} in 1,600 stream sediment samples [68]. Similarly, between 1920 and 1950, US cotton producers applied calcium arsenate, an arsenic insecticide, intensively to control boll weevils [69]. Between 1900 and 1980, 25 million kg of lead arsenate and 9 million kg of calcium arsenate were transmitted into the soil in the state of New Jersey along. Though mostly abandoned later, arsenical pesticides were widely used in orchards and cotton and rice fields in the USA, which resulted in critical soil contamination [70,71].

Thus, in the present study, the significantly higher inorganic arsenic concentrations in bass cultured in earthen ponds than the other two fish groups can be attributed both to the soil's natural structure and earlier agricultural activities (like cotton or tobacco production) in the areas where the earthen ponds have been built. In addition, it is possible that soil arsenic levels have been increased because of the local airport, which operates intensively during the summer. Previous studies have detected arsenic in jet fuel at levels of 0.006-0.02 mg L^{-1} [72] while air pollution from airports releases arsenic at concentrations of 1.0-1.1 ng m^{-3} [73].

Table 4. AsT concentrations detected in three fish groups (mg kg^{-1} w/w).

Fish groups	AsT			iAs
	Min	Max	Mean ± s.d.	
(1) Earthen pond	0.35	0.44	0.38 ± 0.03	0.011
(2) Offshore	0.22	0.28	0.26 ± 0.02	0.008
(3) Wild (Natural)	0.24	0.27	0.26 ± 0.02	0.008

Regarding previous studies of As levels in fish, Makedonski et al. (2015) detected fish muscle As concentrations of 1.6-1.8 mg kg^{-1} w/w in European sea bass (n=4) sampled from the Aegean Sea regions of intensive fishing in Greece. However, this range met Bulgarian food safety standards (maximum 5.0 mg kg^{-1} fresh weight) [74]. Another study, which measured essential and non-essential elements (including toxic elements) in both cultured and wild European sea bass muscle samples from the Adriatic Sea, reported mean As levels of 2.335 ± 0.975 mg kg^{-1} w/w in cultured fish and 2.114 ± 0.808 mg kg^{-1} w/w in wild fish. As accumulation in fish muscle sampled from the natural environment was 1.8 times higher than in the muscle tissues of cultured fish. However, this difference was not statistically significant [75].

Several studies have investigated Turkey specifically. The first reported that European sea bass muscle samples from the Black Sea had As concentrations less than 0.0006 ± 0.00 mg kg^{-1}, which indicated that the issue could be ignored, according to the researchers [76]. The second study measured heavy metal (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn) concentrations in muscle tissues from 11 species of cultured and wild fish purchased from fish markets in Kahramanmaraş. The mean iAs level in European sea bass muscle samples was 0.61 mg kg^{-1} w/w [77]. The third study investigated toxic element accumulation (Cd, Hg, Pb, As, Al, Cu, Fe, Zn) in both wild and cultured European sea bass muscle, sampled from fish markets in Sinop. The mean muscle As concentration was 0.11 ± 0.02 mg kg^{-1}. Furthermore, As accumulations were slightly higher in cultured European sea bass than wild European sea bass [78]. Finally, Yabanlı et al. (2016) investigated arsenic accumulation wild and cultured gilthead sea bream (*Sparus aurata* Linnaeus, 1758) muscle samples in fish from Güllük Bay. As in the present study, fish sampled from earthen ponds had the highest mean concentration (0.60 ± 0.03 mg kg^{-1}) while wild sea bass had the lowest mean concentration (0.35 ± 0.03 mg kg^{-1}). The researchers concluded that the isolated nature of the earthen ponds may have made them more affected by environmental factors, which in turn led to higher As accumulation in fish muscle tissue [79]. Table 5 presents mean AsT concentrations in muscular tissues of various fish species in different world regions, including the present study.

Table 5. Mean AsT concentrations of various marine fish species in different regions.

Species	Mean AsT$_{muscle}$ (mg kg^{-1})	Region	Reference
Mullus barbatus	1.47-18.62	South-Eastern Mediterranean Sea	[90]
Nemipterus randalli	2.05-152.64		
D. labrax	0.42-1.06	Aegean and Ionian Sea	[40]
D. labrax	1.6 - 1.8	Aegean Sea	[74]
D. labrax	2.34 - 2.11	Adriatic Sea	[75]
D. labrax	0.0006 ± 0.00	Black Sea	[76]
Sparus aurata	0.35 – 0.60	Eastern Aegean Sea, Western Anatolia	[79]
D. labrax	0.26-0.38	Eastern Aegean Sea, Western Anatolia	*Current study*
Sardina pilchardus	0.979-0.999	Atlantic Ocean	[91]
Scomber japonicus	0.81-1.06		
Trachurus trachurus	1.34-0.95		
Mullus barbatus	11.024	Catania	[30]
Engraulis encrasicolus	5.275		
Trachurus trachurus	5.409		
Triglia lucema	1.01	East Mediterranean Sea	[92]
Lophius budegassa	0.98		
Solea lascaris	1.74		
Istiophorus platypterus	5.1	Gulf of California	[93]
Tetrapturus audax	4.0		

Table 6 presents the results of the risk assessments for EDI, THQ, and TR for children and adults, and CR for adults only. The THQ levels calculated for children and adults regarding consumption of three fish groups were lower than 1, which is the critical value for THQ. Previous research has also reported THQ values for various seafood products sold in fish markets in Istanbul, Turkey, as lower than 1 [80]. Conversely, Copat et al. (2013) reported THQ values based on fish consumption (*Engraulis encrasicolus*, *Mullus barbatus* and *Trachurus trachurus*) 4 days a week that were more than 1 for both children and adults [30].

Estimated daily intake amounts (EDI) in adult and children were compared using the tolerable intake rates ($\mu g\ kg^{-1}$-daily) recommended by the Joint FAO/WHO Expert Committee on Food Additives [81] [Table 6]. To estimate potential limit excesses, the calculated EDI_m, EDI_T, and TDI values were compared with tolerable iAs exposure levels. According to the New York State Department of Health [82], an EDI ratio of a heavy metal to its RfD_o equal to or less than the RfD_o means that the risk will be minimal; > 1–5 times the RfD_o indicates that the risk will be low; > 5–10 times the RfD_o indicates moderate risk; >10 times the RfD_o indicates high risk [83].

In the present study, iAs rates were ≤ 1 for all fish groups and genders. The World Health Organization (WHO) has set the Provisional Maximum Tolerable Daily Intake (PMTDI) for arsenic (As^{+2}) as ** $\mu g\ kg^{-1}\ BW^{-1}\ day^{-1}$ [84]. The highest EDI value obtained in the present study for children was 0.08 $\mu g\ kg^{-1}\ BW^{-1}\ day^{-1}$, which is lower than PMTDI value. Similarly, EDI levels for two sea-cultured fish species (*Pagrus major* and *Lateolabrax japonicus*) wre also lower than the PMTDI level (0.009 and 0.014 $\mu g\ kg^{-1}\ BW^{-1}\ day^{-1}$, respectively) [85]. However, an extremely high maximum EDI value was reported from Cambodia (7.45 $\mu g\ kg^{-1}\ BW^{-1}\ day^{-1}$) [86].

Table 6. Target hazard quotient, cancer risk, and target cancer risk estimations for iAs, assumed as 3% of total iAs concentrations, at different levels of exposure.

Results from estimations using meal size (MS)	**Fish groups**	**Children**			
		EDI_m*	**THQ**	**TR**	**CR**
	(1) Earthen pond	0.08	2.6×10^{-4}	1.2×10^{-7}	1.2×10^{-4}
	(2) Offshore	0.06	1.9×10^{-4}	8.5×10^{-8}	8.5×10^{-5}
	(3) Wild (Natural)				
	Fish groups	**Adult**			
		EDI_m*	**THQ**	**TR**	**CR**
	(1) Earthen pond	0.004	1.2×10^{-5}	5.4×10^{-8}	5.4×10^{-5}
	(2) Offshore	0.003	8.7×10^{-5}	3.9×10^{-8}	3.9×10^{-5}
	(3) Wild (Natural)				
Results from estimations using food ingestion rates (FIR)	**Fish groups**	**Children**			
		EDI_T*	**THQ**	**TR**	**CR**
	(1) Earthen pond	0.010	3.9×10^{-5}	1.8×10^{-8}	1.8×10^{-5}
	(2) Offshore	0.009	2.8×10^{-5}	1.3×10^{-8}	1.3×10^{-5}
	(3) Wild (Natural)				
	Fish groups	**Adult**			
		EDI_T*	**THQ**	**TR**	**CR**
	(1) Earthen pond	0.003	8.9×10^{-6}	4.0×10^{-9}	4.0×10^{-6}
	(2) Offshore	0.002	6.5×10^{-6}	2.9×10^{-9}	2.9×10^{-6}
	(3) Wild (Natural)				
Legal limits	**TDI***	2.143			
	RfD_o*	0.3			

*$\mu g\ kg^{-1}\ BW^{-1}$ day

The USEPA considers CR values between 10^{-6} (1 in 1,000,000) and 10^{-4} (1 in 10,000) as acceptable predicted lifetime risks for carcinogens [49,87]. In this study, all iAs CR values were within these limits except for specimens from earthen ponds and calculated using MS for children.

As with CR, a TR value estimated using total iAs that exceeds 10^{-6} indicates a cancer risk [51]. The TR values in the present study were interpreted by comparing them with the EPA's suggested lifetime cancer risk benchmark value of × 10^{-6} [88]. The TR values obtained in the present study ranged from 4.0 x 10^{-9} to 1.2 x 10^{-7}, indicating an extremely low lifetime cancer risk [Table 6].

This contrasts with other studies reporting values exceeding 1 x 10^{-6}, which is the carcinogenic risk threshold value for iAs in food. For example, a lifetime cancer risk assessment study in Taiwan for consumption of various seafood products for inorganic arsenic found the highest risk was for oysters (5.1×10^{-4}) [88] while the carcinogenic risk value for fish consumption in Bangladesh was 1.6×10^{-5} [94].

In the present study, all TR values calculated from both meal size and daily fish consumption rate were within permissible limits both for adults and children. Although the CR values for specimens sampled from earthen ponds, calculated using MS for children, were very close to the permissible threshold, it should be noted that this would require an unrealistic level of consumption of eating European sea bass at least once a day for a lifetime (70 years for adults and 16 years for children) to represent almost 83 kg for adults and 42 kg for children annually.

While research assessing AsT concentrations in fish has been increasing, it is important that this should continue because of arsenic's carcinogenic implications for human health.

4. Conclusion

This study assessed inorganic arsenic levels by measuring total arsenic levels in muscle tissues from European sea bass cultured in cages at sea and earthen ponds, and wild sea bass caught from the coast of Mugla province. The results are important because Mugla is an important aquaculture region in Turkey, which itself is Europe's largest sea bass producer. The study also conducted a risk assessment of European sea bass consumption to determine if there is any threat to consumer health.

Both the AsT and iAs concentrations were higher in sea bass cultured in earthen ponds than those cultured in offshore cages or in wild fish. This may because previous agricultural practices in the area where the earthen ponds have been built increased arsenic levels in the soil.

The risk assessment showed no evidence of negative outcomes for human health for consumption of any of the three bass groups studied (soil ponds, offshore marine cages, and wild-caught) except for specimens from earthen ponds if the risk was calculated using MS for children. However, as this would require an unrealistic consumption level, it can be concluded that European sea bass consumption currently poses not human health risk. Nevertheless, as arsenic is a carcinogen and has biomagnification characteristics, it remains essential to conduct such studies regularly to ensure consumer health into the future.

5. References

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