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# An Assessment of the Cultivation Potential and Suitability for Human Consumption of Mediterranean Mussels (*Mytilus galloprovincialis* Lamarck, 1819) from the Yalova Coast of the Marmara Sea

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**Abstract**

This study aimed to determine into potential suitability of juvenile Mediterranean mussel (*Mytilus galloprovincialis*) for cultivation and human consumption collected from various stations (Kapaklı, Çınarcık, Koru, and Deveboynu) along the Yalova coast of the South Marmara Sea during the spring season. Specifically, meat yield, condition index, moisture content, density of fouling organisms on the shells, and heavy metal concentrations (copper, zinc, mercury, cadmium, lead, and arsenic) were analysed. The average meat yields for Çınarcık, Deveboynu, Kapaklı, and Koru were found to be 24.51±2.96, 21.72±3.92, 23.75±2.31, and 21.54±4.01, respectively. Similarly, the average condition index were found to be 7.29±1.16, 6.02±0.97, 7.30±0.77, and 5.94±1.39 for Çınarcık, Deveboynu, Kapaklı, and Koru, respectively. The average shell component index for Çınarcık, Deveboynu, Kapaklı, and Koru were detected that 72.06±2.75, 74.39±4.13, 69.99±2.55, and 74.68±4.54, respectively. Additionally, the average moisture contents were found to be 82.63±1.95, 83.34±3.23, 84.02±1.82, and 83.40±4.17 for Çınarcık, Deveboynu, Kapaklı, and Koru, respectively. The statistical analysis revealed significant differences ($p<0.05$) in these parameters among the stations. Moreover, the quantities of competitive and fouling organisms, such as polychaetes and barnacles, were found to be highest in the Deveboynu and Koru stations. It has been determined that copper, zinc, mercury, and lead levels of the mussels are suitable for human consumption in all stations. However, arsenic values exceeded legal limits in Çınarcık, Koru, and Deveboynu, and cadmium values exceeded legal limits in all stations.

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## INTRODUCTION

Food and Agriculture Organization of the United Nations report that aquaculture will play a crucial role in meeting the food needs of the world's population, which is expected to reach 9 billion by 2050 (FAO, 2015). Therefore, it is predicted that the growth in the world's aquaculture industry will continue to increase at an accelerated pace (FAO, 2015). While there are many economically valuable bivalve species such as mussels, oysters, scallops, and cockles that are rich in essential amino acids, unsaturated fatty acids, vitamins, minerals, and antioxidant substances along the coasts of Turkey, country's aquaculture production is focused on fish farming. Therefore the production of bivalve species is well below their potential (Yildiz et al., 2011). Additionally, there are no other species grown besides Mediterranean mussels. The production of Mediterranean mussels, which was 3 tons in 2015, rose to 907 tons in 2018 and 4.585 tons in 2021 (TUIK, 2022). The production potential of Mediterranean mussels along the coasts of Turkey is much higher than these amounts. There are many mussel farms that have recently been established and have received preliminary permits in the Marmara Sea, Çanakkale Strait, and around Izmir (Yildiz et al., 2023). In particular, in newly established mussel farms, a large number of juveniles are required, and initially, they are collected from natural beds rather than using collectors. The quality of the juvenile mussels collected from nature directly affects the quality of the product that will be sold in the market. Therefore, it is essential to establish specific criteria to determine the quality of the juvenile mussels. Meat yield and condition index are important criteria that determine the quality and marketing characteristics of mussels (Yildiz et al., 2021). The density of fouling organisms attached to the mussels is another factor that determines their commercial quality (Sievers et al., 2014; Forrest & Atalah, 2017).

Heavy metals can be formed from discharge or leakage from various anthropogenic activities in aquatic environments (Freije, 2015). The concentration of heavy metals in aquatic organisms is higher than in water, and they can accumulate biologically in aquatic organisms up to levels that can cause physiological damage in humans through the food chain (Raposo et al., 2009; Stanković et al., 2011). Since mussels feed by filtering seawater, this accumulation can be even higher. According to the Republic of Turkey Ministry of Agriculture and Rural Affairs Aquaculture Regulation (Republic of Turkey Ministry of Agriculture and Forestry, 2002), which is in line with internationally accepted criteria, the chemical acceptable values for bivalves, including mussels, are 0.5 mg/kg for mercury, 0.1 mg/kg for cadmium, 1.5 mg/kg for lead, 20.0 mg/kg for copper, 50.0 mg/kg for zinc, and 1.0 mg/kg for arsenic.

The overall aim of this study is to determine and evaluate the criteria for the usability of mussels collected from different stations for consumption and aquaculture systems. In this scope, in the Yalova coast of the Marmara Sea in different stations the meat yields, condition index, heavy metal contents (Cu, Zn, Hg, Cd, Pb, and As of juvenile mussels, and densities of organisms attached to the mussels were compared.

## MATERIALS AND METHODS

### Sampling Area

Mediterranean mussel samples were collected by hand from four stations (Kapaklı, Çınarcık, Koru and Deveboynu) in Yalova, Marmara Sea, Turkey in April 2021 (40° 27' 612"N, 28° 58' 061" E, 40° 38' 794"N, 29° 07' 049" E, 40° 39' 444"N, 29° 09' 271" E, 40° 39' 294"N, 29° 02' 707" E, respectively) (Figure 1). Three kilograms of mussels were collected from 1 to 2 m depth and rocky area each station and bring to the laboratory for analysis. The shells of all mussels were macroscopically examined. The area covered by fouling organisms on the surface of the mussel shells was determined (0 = no occurrence, 1 = 20% coverage, 2 = 40% coverage, 3 = 60% coverage, 4 = 80% coverage, and 5 = full coverage), and the type of fouling organism was recorded (Lök & Acarli, 2006). The fouling organisms adhering to the mussels were then removed using a knife, and the meat of the mussels was separated from the shells and stored in deep freeze.


**Figure 1.** Map showing the sampling area Marmara Sea

### Condition index, meat yield, moisture and shell component index

To assess the condition index (CI), meat yield (MY), moisture content, and shell component index (SCI) of *M. galloprovincialis*, 30 mussel samples were weighed from each station and their meats were removed. The meats were washed with distilled water to eliminate extraneous salt and sand particles and were then placed on an absorbent surface until they were as dry as possible. The shells were dried in an oven at 60 °C until they reached a constant weight (42-72 h), while the soft tissues were freeze-dried. These methods were adapted from previous studies (Freeman 1974; Pekkarinen, 1983; Crosby & Gale 1990; AOAC 2000).

$$MY = \frac{Wet\ meat\ weight\ (g)}{Total\ weight\ (g)} \times 100 \quad (1)$$

$$CI = \frac{Dry\ meat\ weight\ (g)}{Dry\ shell\ weight\ (g)} \times 100 \quad (2)$$

$$SCI = \frac{Wet\ shell\ weight\ (g)}{Wet\ shell\ weight\ (g) + Wet\ meat\ weight\ (g)} \times 100 \quad (3)$$

$$Moisture(\%) = \frac{Wet\ meat\ weight(g) - Dry\ meat\ weight(g)}{Wet\ meat\ weight(g)} \times 100 \quad (4)$$

To analyse the heavy metal composition, a 0.5 g of mussel meats (wet weight,ww) were taken from each station and mixed with 10 ml of $HNO_3$. The mixture was then incinerated using a microwave incinerator. The concentration of heavy metals in the mussel meat was detected according to reference method the NMKL 161 (1998) and NMKL 186 (2007) using inductively coupled plasma optical emission spectrometry (ICP-MS).

**Statistical analyses**

Statistical analyses were performed using SPSS 19.0 software for Windows. The data was analysed for normality and variance homogeneity using the Kolmogorov-Smirnov and Levene's tests, respectively. As the data showed a normal distribution, the relationship between morphometric components was determined using Pearson correlation. Differences between CI, MY, and SCI of different stations were determined using the one-way analysis of variance (ANOVA) test. Incase the necessary conditions for parametric analyses were not met, the non-parametric Kruskal-Wallis H test was used to compared the differences sampling stations for concentrations of heavy metals.

**RESULTS**

The results showed that the length of the Mediterranean mussels was 32.19±2.43 mm at Kapaklı station, 30.10±4.05 mm at Çınarcık station, 28.02±4.63 mm at Koru station, and 31.67±2.71 mm at Deveboynu station (Table 1).

**Table 1**. Morphometric characteristics and meat yield (MY), condition index (CI), moisture and shell component index (SCI) of *M. galloprovincialis* from Kapaklı, Çınarcık, Koru, Deveboynu station (mean±standard deviation)

| **Station** | **Length** | **Width** | **Height** | **Weight** | **MY (%)** | **CI** | **Moisture (%)** | **SCI** |
|---|---|---|---|---|---|---|---|---|
| **Kapaklı** | 32.19±2.43 | 18.07±2.21 | 11.07±1.25 | 2.40±0.46 | 23.75±2.31 | 7.30±0.77 | 84.02±1.82 | 69.99±2.55 |
| **Çınarcık** | 30.10±4.05 | 17.38±2.60 | 11.23±1.71 | 1.99±0.61 | 24.51±2.96 | 7.29±1.16 | 82.63±1.95 | 72.06±2.75 |
| **Koru** | 28.02±4.63 | 16.41±2.80 | 10.11±1.85 | 1.58±0.63 | 21.54±4.01 | 5.94±1.39 | 83.40±4.17 | 74.68±4.54 |
| **Deveboynu** | 31.67±2.71 | 18.36±1.37 | 12.12±1.33 | 2.18±0.54 | 21.72±3.92 | 6.02±0.97 | 83.34±3.23 | 74.39±4.13 |

**Fouling organism density**

Mussels collected from Deveboynu and Koru stations were grouped as "0" due to the absence of any adhesion in terms of cleanliness, brightness, and fouling organism attachment and density. Mussels collected from Çınarcık station were found to have polychaetes and *Balanus sp.* adhesion on their shells and were categorized as "3" in terms of adhesion density. Mussels collected from Kapaklı station were found to have adhesion of polychaetes, *Balanus sp.* and bryozoans on their shells and were categorized as "4" in terms of adhesion density.

**Meat yield, condition index, shell component index and moisture**

The results show that there were significant differences ($p<0.05$) in the meat yield (MY), condition index (CI), and shell component index (SCI) values among the stations. The MY, values were 21.54±4.01 %, 21.72±3.92 %, 23.75±2.31 %, and 24.51±2.96 %, CI 5.94±1.39, 6.02±0.97, 7.30±0.77, and 7.29±1.16; and SCI 74.68±4.54, 74.39±4.13, 69.99±2.55, and 72.06±2.75 for Koru, Deveboynu, Kapaklı, and Çınarcık stations, respectively. The moisture content of the mussel meat was detected also 82.63±1.95 %, 83.34±3.23 %, 84.02±1.82 %, and 83.40±4.17 % for Çınarcık, Deveboynu, Kapaklı, and Koru stations, respectively (Table 1).

**Heavy metal concentration**

Cu, Zn, Hg, Cd, Pb, and As concentrations were measured and presented in Table 2. Among all stations, Zn was the most abundant heavy metal. The highest concentration of Zn was found in the Çınarcık station, while the values for Koru, Deveboynu, and Kapaklı stations were similar. The highest amount of Cu was detected in the Çınarcık station, followed by Deveboynu, Koru, and Kapaklı stations. On the other hand, the As concentration was found to be the lowest in the Kapaklı station, while it was significantly higher in the other stations (Table 6).

**Table 2.** Pearson correlation of length, width, height, weight, MY, CI, moisture, SCI of *M. galloprovincialis* from Kapaklı station

| | **Length** | **Width** | **Height** | **Weight** | **MY** | **CI** | **Moisture** | **SCI** |
|---|---|---|---|---|---|---|---|---|
| Length | 0.1 | | | | | | | |
| Width | 0.533 | 1 | | | | | | |
| Height | 0.581 | 0.877* | 1 | | | | | |
| Weight | 0.887* | 0.295 | 0.420 | 1 | | | | |
| MY | -0.587 | -0.664 | -0.560 | -0.552 | 1 | | | |
| CI | -0.017 | -0.517 | -0.558 | -0.209 | 0.529 | 1 | | |
| Moisture | -0.388 | -0.231 | -0.111 | -0.061 | 0.442 | -0.442 | 1 | |
| SCI | 0.273 | 0.705 | 0.582 | 0.147 | -0.892* | -0.562 | -0.483 | 1 |

**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level

**Statistical analyses**

At Kapaklı station, there was a positive correlation between length, width, thickness, and weight, and a negative correlation between MY and SCI (Table 2). At Çınarcık station, there was a positive correlation between length, width, thickness, and weight, and between CI and MY, and a negative correlation between CI and moisture and SCI (Table 3). At Koru station, there was a positive correlation between length, width, thickness, and weight, and between MY and moisture, and a negative correlation between SCI and MY and moisture (Table 4). At Deveboynu station, there was a positive correlation between length, width, thickness, and weight, and between MY and moisture and CI, and a negative correlation between SCI and MY, CI, and moisture (Table 5). Among all stations of heavy metal composition, MY, CI, and SCI were found statistically significant ($p<0.05$).

**Table 3.** Pearson correlation of length, width, height, weight, MY, CI, moisture, SCI of *M. galloprovincialis* from Çınarcık station

| | **Length** | **Width** | **Height** | **Weight** | **MY** | **CI** | **Moisture** | **SCI** |
|---|---|---|---|---|---|---|---|---|
| Length | 1 | | | | | | | |
| Width | 0.811** | 1 | | | | | | |
| Height | 0.865** | 0.804** | 1 | | | | | |
| Weight | 0.894** | 0.920** | 0.896** | 1 | | | | |
| MY | 0.230 | 0.091 | 0.098 | 0.099 | 1 | | | |
| CI | -0.185 | -0.339 | -0.311 | -0.246 | 0.475* | 1 | | |
| Moisture | 0.126 | 0.168 | 0.108 | 0.088 | 0.264 | -0.577** | 1 | |
| SCI | 0.037 | 0.184 | 0.194 | 0.139 | -0.881** | -0.678** | -0.188 | 1 |

**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level

**Table 4.** Pearson correlation of length, width, height, weight, MY, CI, moisture, SCI of *M. galloprovincialis* from Koru station

| | **Length** | **Width** | **Height** | **Weight** | **MY** | **CI** | **Moisture** | **SCI** |
|---|---|---|---|---|---|---|---|---|
| Length | 1 | | | | | | | |
| Width | 0.897** | 1 | | | | | | |
| Height | 0.879** | 0.848** | 1 | | | | | |
| Weight | 0.954** | 0.889** | 0.913** | 1 | | | | |
| MY | 0.245 | 0.114 | 0.169 | 0.193 | 1 | | | |
| CI | -0.127 | -0.073 | -0.130 | -0.090 | 0.113 | 1 | | |
| Moisture | 0.298 | 0.195 | 0.241 | 0.237 | 0.575** | -0.692** | 1 | |
| SCI | -0.277 | -0.148 | -0.175 | -0.241 | -0.973** | -0.114 | -0.591** | 1 |

**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level

**Table 5.** Pearson correlation of length, width, height, weight, MY, CI, moisture, SCI of *M. galloprovincialis* from Deveboynu station

| | **Length** | **Width** | **Height** | **Weight** | **MY** | **CI** | **Moisture** | **SCI** |
|---|---|---|---|---|---|---|---|---|
| Length | 1 | | | | | | | |
| Width | 0.634** | 1 | | | | | | |
| Height | 0.819** | 0.504* | 1 | | | | | |
| Weight | 0.853** | 0.656** | 0.895** | 1 | | | | |
| MY | 0.181 | 0.082 | 0.380 | 0.300 | 1 | | | |
| CI | 0.084 | 0.346 | 0.176 | 0.212 | 0.689** | 1 | | |
| Moisture | 0.314 | -0.144 | 0.446 | 0.348 | 0.611* | -0.108 | 1 | |
| SCI | -0.265 | -0.081 | -0.492 | -0.406 | -0.975** | -0.605* | -0.709** | 1 |

**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level

**Table 6**. Heavy metal composition (Cu, Zn, Hg, Cd, Pb, As) of *M. galloprovincialis* (mg/kg ww)[l] from Kapaklı, Çınarcık, Koru, Deveboynu station (mean±standard deviation) and limitations of Republic of Turkey Ministry of Agriculture and Forestry (2002)

| Heavy metal | Kapaklı | Çınarcık | Koru | Deveboynu | The limitations of Republic of Turkey Ministry of Agriculture and Forestry (2002) |
|---|---|---|---|---|---|
| Cu | 0.21±0.00 | 0.99±0.05 | 0.60±0.05 | 0.61±0.04 | 20.0 |
| Zn | 15.93±0.04 | 39.66±0.63 | 39.03±0.56 | 37.29±0.64 | 50.0 |
| Hg | N.D. | N.D. | N.D. | N.D. | 0.5 |
| Cd | 0.11±0.02 | 0.19±0,03 | 0.15±0.02 | 0.13±0.00 | 0.1 |
| Pb | 0.11±0.03 | 0.72±0,05 | 0.57±0.04 | 0.31±0.05 | 1.5 |
| As | 0.61±0.05 | 2.59±0.04 | 2.29±0.04 | 1.92±0.05 | 1.0 |

ND: Not detected.

## DISCUSSION

Various factors such as environmental factors (Yıldız et al., 2006; Yildiz & Berber, 2010; Yıldız et al., 2013a, b; Vural et al., 2015; Acarlı et al., 2018), interspecific competition (Bertness and Grosholz, 1985; Okamura, 1986), and epibionts on shells (Arakawa, 1990; Dittman & Robles, 1991; Buschbaum & Saier, 2001) are influential in the growth of bivalves. Biofouling is a significant concern in aquaculture (LeBlanc et al., 2002). Therefore, seed collected from natural beds or spat collectors is thoroughly cleaned to eliminate epifauna and other organisms (Velayudhan et al., 2007). In this study, mussels collected from the Deveboynu and Koru stations were found to be clean in terms of cleanliness, brightness, and fouling organisms; meaning that no biofouling organisms or mud were detected on them. Mussels collected from the Çınarcık station were evaluated as '3' for polychaetes and barnacles, and those collected from the Kapaklı station were evaluated as '4' for polychaetes, barnacles, and *Bugula sp*. Polychaetes and barnacles can potentially compete with mussels by weighing down on the mussel shells and restricting water circulation (LeBlanc et al., 2002). This competition can lead to a decrease in yield because it makes it difficult for mussels to find food. Considering that biofouling organisms on young individuals to be transported to the cultivation area are unwanted despite the possibility of transportation to this area, the preferred stations to be placed in the cultivation system are Koru and Deveboynu.

In general, MY, CI, and SCI are often used as indicators of the feeding status of bivalves (Crosby & Gale, 1990; Yildiz et al., 2011), it's ability to tolerate stress (Mann, 1979), harvest time (Galvao et al., 2015), and reproductive status. MY is also an indicator of meat-to-shell ratio and is therefore an indicator of quality, with higher values generally indicating better quality. It is particularly important for seed collection, a critical step in the mussel production cycle (Macneill et al., 2000). In this study, the lowest MY was observed at Koru station (21.54±4.01%), and the highest at Çınarcık station (24.51±2.96%). Yıldız et al. (2021) found that the MY and CI of *M. galloprovincialis* (83.69 mm in length) in the Çanakkale Strait was 17.79% and 9.33 in April, respectively. Lök et al. (2011) was determined that MY and CI of *M. galloprovincialis* was 27.05% and 11.53 (51.22 mm in length) in the Sinop- Içliman (Black Sea), and 22.63% and 10.47 (62.56 mm in length) in Edincikaltı (Marmara), 18.26% and 9.93 (50.44 mm in length) in Mersin Bay (Aegean Sea), respectively. In this study, Koru and Deveboynu stations were found to have lower MY and CI compared to Çınarcık and Kapaklı stations. Environmental parameters, size, and reproductive period are directly related to CI, MY, and SCI (Acarli et al., 2015; Vural et al., 2015; Acarlı et al., 2018; Kızılkaya et al., 2019; Biandolino et al., 2020; Yıldız et al., 2021). In this study, differences were found between stations ($p<0.05$). Even between neighboring stations, the differences in CI and MY may be attributed to the biological status of the organisms, including their feeding status.

As a result of natural processes and various anthropogenic activities, discharge or leakage can lead to the formation of heavy metals in aquatic environments (Freije, 2015). Concentrations of heavy metals in aquatic organisms are higher than in water and they can biologically accumulate to levels that can cause physiological disturbances in humans through the food chain (Raposo et al., 2009; Stanković et al., 2011). The accumulation rate depends not only on the metal loads present in the environment but also on factors such as temperature, pH, salinity, age, sex, size, and sexual maturity of mussels (Bartolomé et al., 2010; Besada et al., 2014; Richir & Gobert, 2014; Mandich, 2018).

Excessive Cu has a toxic effect on the body and can inhibit the functions of some enzymes (Bajgas, 2000). Cu levels decrease when industrial and urban emissions, fertilizers, algaecides, fungicides, molluscicides, and cyanobacteria in the region decrease (Moffett et al., 1997; Besada et al., 2002; Cheriyan et al., 2015). Cu is found in the greenish-blue pigment (hemocyanin) that carries oxygen in mollusks and crustaceans (Clark, 1992). The influx and efflux of Cu in bivalves vary among species (Cai & Wang, 2019). Republic of Turkey Ministry of Agriculture and Forestry (2002) has specified the maximum value for Cu as 20 mg/kg. Erkan et al. (2011) reported Cu levels in *Ostrea edulis* as 1.075 mg/kg ww in April in the Marmara Sea, while Türk Çulha et al. (2011) found the highest Cu levels in *M. galloprovincialis* as 0.93 mg/kg ww in the spring season (49.62 mm and 9.87 g) in the Marmara Sea. Lök et al. (2010) indicated that Cu concentration of *M. galloprovincialis* in the Çanakkale Strait was determined as between 0.54 mg/kg ww and 0.66 mg/kg ww whereas, Topçuoğlu et al. (2004) reported that Cu levels of *M. galloprovincialis* varied between 94 mg/kg ww and 1.33 mg/kg ww (70-80 mm) among regions in the Marmara Sea. In this study, Cu levels were measured as 0.21 mg/kg ww, 0.99 mg/kg ww, 0.60 mg/kg ww, and 0.61 mg/kg ww in Kapaklı, Çınarcık, Koru, and Deveboynu stations, respectively. These values were well below the limits set by Republic of Turkey Ministry of Agriculture and Forestry (2002).

Zinc (Zn) is involved in the synthesis of several enzymes that influence the uptake of $CO_2$ and P, photosynthesis, phytoplankton and microalgal growth, and the catabolism of carbohydrates, fats, proteins, and nucleic acids. Zn found in the cell wall of bacteria and diatoms, and the death or decay of these microorganisms can increase the amount of Zn in the upwelling zone where coastal water and seawater mix. Higher amounts of Zn have been reported in mollusks than in fish (Storelli et al., 2000). In the Marmara Sea, the Zn levels in *O. edulis* ranged from 290.114 to 147.62 mg/kg ww throughout the year, with the highest values found in April (Erkan et al., 2011; Özden et al., 2010; Türk Çulha et al., 2011). Topçuoğlu et al. (2004) found that the Zn content in Marmara Sea ranged from 29.16 to 44.79 mg/kg ww in *M. galloprovincialis* (70-80 mm), while Lök et al. (2010) declared that Zn concentration of *M. galloprovincialis* in the Çanakkale Strait was from 32.55 mg/kg ww to 65.61 mg/kg ww. However, Periyasamy et al. (2014) reported 0.34 mg/g dw in *D. incarnatus* and Orban et al. (2007) reported 0.91-1.48 mg/100g ww in *Chamelea gallina*. In the current study, Zn levels in mussels ranged from 15.93 to 39.66 mg/kg ww across all sampling stations, which was within the limits set by Republic of Turkey Ministry of Agriculture and Forestry (2002) of 50 mg/kg. These results suggest that the Zn content in mussels from all sampling stations is suitable for cultivation.

When the limit of Cd in the body is exceeded, it can damage the kidneys and cause chronic toxicity (Abou-Arab et al., 1996; Mol, 2011). Azizi et al. (2018) found a Cd concentration of 0.89 mg/kg in *M. galloprovincialis* in Cala Iris offshore (Northern Morocco) during the winter season. According to Wallace and Luoma (2003), biological detoxification of Cd in bivalves increases Cd concentration depending on the color and age of the organism. Erkan et al. (2011) found Cd concentrations in *O. edulis* to be 0.120 mg/kg ww in April in the Marmara Sea. Cd of *M. galloprovincialis* in the Marmara Sea varied from 0.18 to 0.40 mg/kg ww (70-80 mm) (Topçuoğlu et al. 2004). In addition Lök et al. (2010) found that Cd content of *M. galloprovincialis* in the Çanakkale Strait changed between 0.10 mg/kg and 0.52 mg/kg. Kayhan (2006) reported Cd levels in unpolluted water to range from 0.01-5 µg/L. Industrial and agricultural activities are the main sources of cadmium (Jarup & Akesson, 2009; Obaiah et al., 2020). Sources of cadmium in freshwater and sea water environments include atmospheric deposition, runoff, and direct discharges into water or watersheds (Wright & Welbourn, 1994). In this study, Cd concentrations were measured in Kapaklı, Çınarcık, Koru, and Deveboynu stations as 0.11 mg/kg ww, 0.19 mg/kg ww, 0.15 mg/kg ww, and 0.13 mg/kg ww, respectively. The permissible limit for Cd is 0.1 mg/kg (Republic of Turkey Ministry of Agriculture and Forestry, 2002). The results from all stations in this study were found to exceed the permissible limits. The source of the detected cadmium in the study may have been due to agricultural activities in the areas where the stations were located, or in other words, the rainwater that carried the cadmium to the areas where the mussels were collected.

El Shenawy et al. (2016) stated that high levels of Pb in sediment could be attributed to human activities such as shipbuilding and maintenance, industrial and agricultural discharges, as well as leaded gasoline spills from fishing boats. Excessive amounts of Pb are known to exhibit mutagenic, teratogenic, and carcinogenic effects (Castoldi Anna et al., 2003; Lidsky & Schneider, 2003; García-Lestón et al., 2010; Sharma et al., 2014). Erkan et al. (2011) found Pb levels in *O. edulis* as 0.165 mg/kg ww in April, while Türk Çulha et al. (2011) measured the highest Pb levels in *M. galloprovincialis* (49.62 mm and 9.87 g) in the spring season, with 0.35 mg/kg ww. Topçuoğlu et al. (2004) reported that Pb levels of *M. galloprovincialis* in the Marmara Sea ranged from <0.014 to 0.73 mg/kg ww (70-80 mm). However, Lök et al. (2010) reported that Pb content of *M. galloprovincialis* in the Çanakkale Strait was between 0.22 mg/kg ww and 18.47 mg/kg ww in the Çanakkale Strait. Özden et al. (2009) examined Pb concentrations in *C. gallina* and *Donax trunculus*, which yielded 1.34 mg/kg and 1.32 mg/kg ww, respectively. Prato et al. (2019) measured Pb in *F. glaber* at 0.55 mg/kg ww. The amount of Cd accumulated in the body varies depending on species, age, size, etc. In this study, Pb levels were measured at Kapaklı, Çınarcık, Koru, and Deveboynu stations at 0.11 mg/kg ww, 0.72 mg/kg ww, 0.57 mg/kg ww, and 0.31 mg/kg ww, respectively. The limit value for Pb in this study was determined to be 1.0 mg/kg (Republic Turkey Ministry of Agriculture and Forestry, 2002), and all stations in this study had Pb values below this limit.

Seafood is known to contain high levels of organic arsenic (As) (Han et al., 1998). Inorganic forms of As are carcinogenic and chronic exposure to inorganic As can lead to various health problems by affecting the gastrointestinal, respiratory, skin, liver, cardiovascular, and nervous systems (Mandal & Suzuki, 2002); in addition, it can cause vomiting, diarrhea, anemia, liver damage, and death (Centeno et al., 2002). Özden et al. (2010) reported that the As content in *M. galloprovincialis* varied between 0.070 mg/kg ww (in September) and 1.183 mg/kg ww (in February) in the Marmara Sea (Istanbul) and was 0.150 mg/kg ww (in April). Lök et al. (2010) informed that As content of *M. galloprovincialis* in the Çanakkale Strait changed between 0.03 mg/kg ww and 0.05 mg/kg ww. As values in *C. gallina* and *D. trunculus* varied between 2.64-2.91 mg/kg ww and 1.74-3.45 mg/kg ww, respectively, in winter and summer seasons (Özden & Erkan, 2011). Prato et al. (2019) measured the As content in *F. glaber* to be 6.10 mg/kg ww. Republic of Turkey Ministry of Agriculture and Forestry (2002) reported that the maximum limit for As is 1 mg/kg. In this study, the As content was measured as 0.61 mg/kg ww in Kapaklı, 2.59 mg/kg ww in Çınarcık, 2.29 mg/kg ww in Koru, and 1.92 mg/kg ww in Deveboynu stations, respectively. Generally, As values obtained in studies conducted in the Marmara Sea are above the limit values, including those found in this study, except for the Kapaklı station. The entry of anthropogenic arsenic is mainly from agricultural, forestry, industrial, and mining activities, which contaminate the soil and water (Smith et al., 2003). We believe that the study area is located in regions affected by agricultural activities, and waste resulting from pesticide spraying and mixing with the soil is carried to the natural habitat of mussels through freshwater sources. Mussels are filter-feeding organisms, meaning that they take in organic and inorganic substances present in the environment, and As may accumulate in their bodies as a result.

## CONCLUSION

In recent years, there has been a significant increase in commercial activities for the production of mussels through aquaculture in Turkey. However, due to the new structuring of the sector, many problems have been encountered in the production facilities such as facility installation and qualified personnel. Especially during the initial establishment phase of the system, the lack of juvenile mussels is known as the most common problem. Procuring juveniles from other businesses is a widely used method, but currently, it is not considered a sufficient solution for the needs of newly established businesses. Therefore, it is important to determine the conditions of stations in the Marmara Sea for collecting *M. galloprovincialis* juvenile. Therefore, determining the meat quality and heavy metal concentration of *M. galloprovincialis* in the Sea of Marmara in the different stations is important for its aquaculture facilities.

Although it was possible to say that the mussels at all stations are suitable for use in a production system in terms of their condition index, meat yield, fouling organism attachment, and Cu, Zn, Hg, and Pb values, it had been concluded that Çınarcık, Koru, and Deveboynu stations were risky due to the As level found in these stations and the Cd level detected in all stations exceeding the limit value according to Republic of Turkey Ministry of Agriculture and Forestry (2002). Although other parameters was appropriate, the study has concluded that the quality of the products from these stations was not safe for both the juvenile collection and human consumption due to the toxicity of As and Cd.

## COMPLIANCE WITH ETHICAL STANDARDS

### a) Authors' Contributions

1. S.A.: She designed the study and interpreted the data.

2. P.V.: She carried out the laboratory work.

3. H.Y.: He designed the study and prepared the article.

### b) Conflict of Interest

The author(s) declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper

### c) Statement on the Welfare of Animals

Not applicable

### d) Statement of Human Rights

Not applicable

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