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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

An assessment of production capacity, constraints and future perspectives of mussel (*Mytilus galloprovincialis* Lamarck, 1819) farming in Türkiye

Türkiye'de midye (*Mytilus galloprovincialis* Lamarck, 1819) yetiştiriciliğinin üretim kapasitesi, kısıtlar ve gelecek perspektifleri açısından değerlendirilmesi

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Abstract: The Mediterranean mussel (*Mytilus galloprovincialis*), the only bivalve species whose production has steadily increased through aquaculture and capture in recent years, holds significant importance in Türkiye due to its high nutritional value, economic potential, and consumer popularity. This study aims to evaluate the current status of Mediterranean mussel farming in Türkiye. The primary data were obtained from surveys conducted between January and March 2023 with 47 certified mussel farming enterprises. The study examined farm capacities, production areas, cultivation techniques, workforce structures, marketing strategies, and challenges encountered during production. The findings indicated that mussel farming has strong development potential; however, production levels remain below capacity due to difficulties in material supply, economic fluctuations, and environmental factors such as mucilage outbreaks. In addition, deficiencies in transport and logistics infrastructure, along with insufficient technical knowledge and a lack of skilled personnel, were identified as major constraints. The results are expected to provide valuable insights for planning and policymaking to improve production design and ensure sustainability in both existing and future mussel farming facilities in Türkiye, as well as for countries seeking to enter this emerging sector.

Keywords: Mussel farming, *Mytilus galloprovincialis*, production capacity, sustainability, aquaculture challenges

Öz: Akdeniz midyesi (*Mytilus galloprovincialis*), son yıllarda yetiştiricilik ve avcılık yoluyla üretimi istikrarlı şekilde artan tek çift kabuklu tür olup, yüksek besin değeri, ekonomik potansiyeli ve tüketici talebi nedeniyle Türkiye'de önemli bir yere sahiptir. Bu çalışma, Türkiye'de Akdeniz midyesi yetiştiriciliğinin mevcut durumunu değerlendirmeyi amaçlamaktadır. Araştırmanın temel verileri, Ocak–Mart 2023 tarihleri arasında sertifikalı 47 midye yetiştiriciliği işletmesi ile yapılan anketlerden elde edilmiştir. Çalışmada işletmelerin kapasite durumu, üretim alanları, yetiştiricilik teknikleri, iş gücü yapısı, pazarlama stratejileri ve üretim sürecinde karşılaşılan sorunlar incelenmiştir. Bulgular, midye yetiştiriciliğinin önemli bir gelişim potansiyeline sahip olduğunu, ancak üretimin; materyal teminindeki zorluklar, ekonomik dalgalanmalar ve müsilaj gibi çevresel faktörler nedeniyle kapasitenin altında kaldığını göstermiştir. Ayrıca, taşıma ve lojistik altyapısındaki yetersizlikler ile teknik bilgi eksikliği ve nitelikli personel yetersizliği başlıca kısıtlar olarak belirlenmiştir. Elde edilen sonuçların, Türkiye'de mevcut ve gelecekte kurulacak midye yetiştiriciliği işletmelerinde üretim planlamasının geliştirilmesine ve sürdürülebilirliğin sağlanmasına yönelik politika oluşturma süreçlerine katkı sağlaması beklenmektedir.

Anahtar kelimeler: Midye yetiştiriciliği, *Mytilus galloprovincialis*, üretim kapasitesi, sürdürülebilirlik, akuakültür sorunları

INTRODUCTION

Widely available and easily harvestable in coastal ecosystems, bivalve species have been recovered and consumed as one of the significant sources of protein at global scale since prehistorically times (Erlandson, 1988; Mannino and Thomas, 2001; Verdún-Castelló et al., 2020). Archeologic and paleoecologic findings present strong evidence that marine shellfish organisms were systematically harvested and consumed across coastal regions where natural bivalve beds existed (Román et al., 2022). Mussels, which are rich in proteins, lipids, and other bioactive compounds, have been an indispensable and widely preferred food throughout human history (Yıldız and Lök, 2005; Verdún-Castelló et al., 2020; Acarli et al., 2024). For this reason, mussel production has been of commercial importance in France and other European countries since the middle of 19th century. Commercial mussel farming has been sustained in nations such as France, Holland, Italy and Spain for centuries. Over one thirds of total aquacultural processes constitutes mussel output in European Community members with *Mytilus edulis* and *Mytilus galloprovincialis* being the two main species in the production (EUMOFA, 2024). Spain is the leading Mediterranean mussel producer in Europe, with a production of 255200 tons and a revenue of €159 million in 2022 (EUMOFA, 2024). Other mussel producers in Europe were Italy, Greece and France with the output of 61921 tons, 113508 tons and 62106 tons, respectively (FAO, 2023). Global mussel importation was recorded to be approximately 300000 tons in 2022. Although France and Italy have the capacity to produce 51000 tons in total, they are also the significant importers of mussel. On the other hand, the USA has recently shown to be a significant

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importer with some 38000 tons (FAO GLOBEFISH, 2024). Mean sales prices of Mediterranean mussel were determined as 0.81 EUR/kg and 1.02 EUR/kg in Spain and Italy, respectively (EUMOFA, 2024). Mussel farming businesses employ only a few aquacultural techniques, such as raft, long line, deep/depth, and 'bouchot', considering the depth of the output areas (Ramšak et al., 2024; EUMOFA, 2022). Avdelas et al. (2021) reported that the most common production techniques used in the EU in 2016, based on weight, were 48% raft, 25% longline, 18% bottom, and 9% bouchot systems.

Data from Republic of Türkiye Ministry of Agriculture and Forestry demonstrated that a Mediterranean mussel farming was initiated by Dardanel Kültür Balıkçılığı AŞ in a marine area of 26 ha in Eceabat Poyraz inlet Çanakkale in 1991. In addition, various attempts were made to produce Mediterranean mussel even before 1991 but the firms failed to maintain sustainable output processes at all. Some development has been observed since 2014 with gradual increases in the number of farms until recently (Yıldız et al., 2023). Hence, mussel output varied from 8738 tons in 2023 to 11320 tons in 2024 (TÜİK, 2024). It is of great importance that the current situation should be comprehensively explored in order to obtain a sustainable production from the sector of significant potential. The study thus seeks to determine the problems encountered in organizational structures of Mediterranean mussel farms which maintain their production activities. The data of the study is expected to contribute to actively restructuring organizational infrastructure and output of mussel farming businesses as well as developing sustainable production models.

MATERIALS AND METHODS

To determine the mussel farm installations in the research area, it was necessary that the results/ archive of Provincial Directorates of Agriculture and Forestry and Animal Information System (AIS/ HBS) should be used for the farms in the area, according to which the number of farms engaged in Mediterranean mussel business with farming certification was found to be 47. In addition, the classification of mussel farming areas (Class A, Class B and Class C) was based on the criteria established by the European Union for *Escherichia coli* levels in shellfish from monitored harvesting areas (Ciccarelli et al., 2022). Regarding the sampling approach, it is essential to examine the population or part of that population as a sample so as to achieve the information needed for the population present in the study. Accordingly, inclusion of the entire population in the scope of the study is referred to as integer method analysis. The dimension/ size of the population should be compatible with the constraints such as the determined time and financial/ substantial means in order to use the integer method (Karagölge and Peker, 2002; Karasar, 2011). Considering this and the number of the facilities being 47, the study employed the integer method due to ability to reach all of them with the time and financial means cited within the study (Figure 1).

Figure 1. Geographical distribution of mussel farming facilities in Türkiye

Preparation of the survey forms based on the previous scientific studies for the matter involved by Buruç and Kızak (2018), Çımat and Duran (2018), Demirci et al. (2019), Emiroğlu et al. (2019) and Özsayın et al. (2024). The questionnaire was originally developed in Turkish, and included both closed-ended and open-ended questions. The

prepared surveys were face-to-face/ directly applied to the facilities where Mediterranean mussel was produced as the mussel farming process between January and March in 2023. The prepared survey form covered general information on facility engineers/managers, facility characteristics, infrastructure and financial resources, product marketing and harvesting processes, technical practices and stabilization methods, financing and subsidies, product development and planning, as well as problems encountered and demand-related issues. The data obtained from the surveys were analysed using Microsoft Excel and SPSS software.

RESULTS

All those 47 facilities geographically assessed within the study are seen to range/distribute in the provinces of Balıkesir, Bursa, Çanakkale and Yalova in Marmara, İzmir and Muğla in Aegean and Sinop in the Black Sea regions. Of these, 39 facilities provided complete responses to all survey questions, while the remaining 8 facilities provided only partial data due to confidentiality concerns; therefore, only their general information (e.g., capacity, area, leasing status, and production methods) was included in the analysis.

Data of surveyed businessmen

Based on the positions of 39 respondents in the facilities, 19 were facility owners (49%), 8 were production managers (20%), and 12 were responsible engineers (31%) (Figure 2A). Among the facility owners, 13 had a university degree (68%), while 3 had completed high school (16%) and 3 had primary school education (16%). Of the facility managers, 9 had overseas experience in the sector 23% whereas 30 did not go abroad for vocational training (77%) (Figure 2B). Regarding ownership or partnership in other mussel farming facilities, 26 respondents (67%) reported that they had no ownership or partnership other than their current facility, whereas 13 respondents (33%) stated that they owned or were partners in other mussel farming facilities (Figure 2C). Most of those in the position of management in the facility were observed to have experiences of 2-5 years. There were not facility managers with experiences of 20 years, 6 owned no other facilities than their current farms (67%) and 13 had other farms in their ownership or partnerships related to the mussel farming sector in addition to their current facilities (33%) (Figure 3).

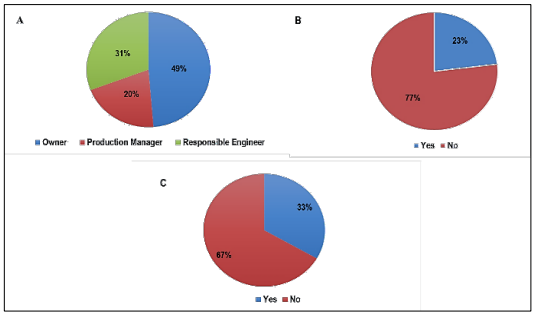

Figure 2. Competencies of facility managers (%) (A), overseas experience of facility managers (%) (B), and ownership or partnership in other mussel farms (%) (C)

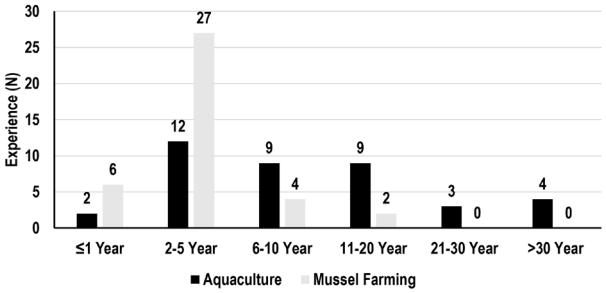

Figure 3. Experience levels of facility managers in the mussel farming sector (number of respondents)

Data of output capacities, areas and area renting of facilities

Assessment of the total production capacity by geographical regions indicates that mussel farming is predominantly concentrated in the Aegean and Marmara Seas. The Aegean Sea has the highest capacity, reaching approximately 15591 tons/year, followed by the Marmara Sea with about 19350 tons/year. The Çanakkale Strait contributes a moderate capacity of around 9790 tons/year, whereas the Black Sea shows a considerably lower production capacity of approximately 1980 tons/year. Overall, these results highlight the regional dominance of the Aegean and Marmara coasts in mussel production in Türkiye (Figure 4).

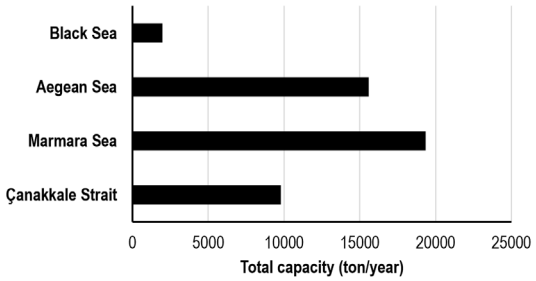

Figure 4. Total production capacities of mussel farming facilities by province (tons per year)

The amounts of marine areas rented on a provincial basis were found to be 143.9 ha, 124.83 ha, 91.28 ha, 79.1 ha, 20 ha, and 10 ha for Balıkesir, Çanakkale, Yalova, İzmir, Sinop, and Muğla, respectively. As for the number and total amounts of areas rented by the facilities according to their geographic regions, those in the Aegean region are mostly in the range of 1–2 ha. Two facilities have rented areas totalling 31 ha. Additionally, two facilities have marine areas located in the Black Sea region. In terms of the durations of their leases, it was observed that 96% of the facility areas were rented for a period of 15 years. Considering the regional distribution of mussel farms, Class B sites dominated, particularly in the Aegean Sea (17) and Marmara Sea (11), while Class A farms were limited (3 in Çanakkale Strait, 2 in the Aegean Sea, and 1 in the Marmara Sea). Class C farms were only recorded in the Aegean Sea (2), whereas some mussel farms remained unclassified due to the classification protocol not yet being implemented during the study period (Figure 5).

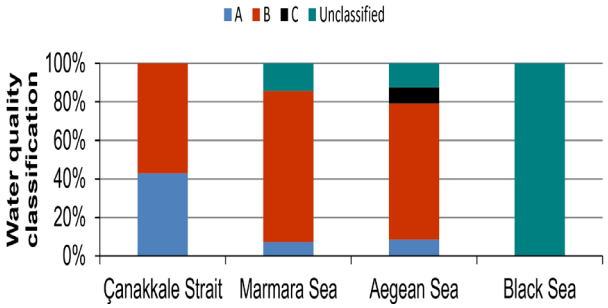

Figure 5. Distribution (%) of mussel farming facilities and corresponding water quality classification regions (Class A, B, and C) in Türkiye

The process of renting areas for Mediterranean mussel farming in Türkiye was found to be based on the year 2014, with only 3 facilities starting their activities. However, 7, 13, and 14 farms/facilities were found to have rented marine areas in 2020, 2021, and 2022, respectively (Figure 6).

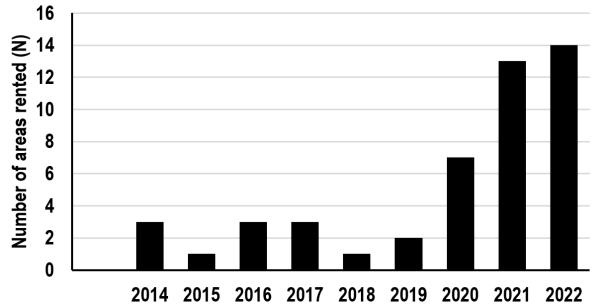

Figure 6. Number of mussel farming facilities by year

Data of production systems, infrastructures and Technical Personnel

The survey conducted in the present study indicated that 89% of mussel farming facilities in Türkiye use the longline system, in which buoys or pontoons are utilized as floaters. The results also showed that mussel farming is predominantly carried out using ropes arranged as longlines on HDPE pipes serving as floats. This method, referred to as the "pipe system" by facility managers, is employed by five facilities (9%), all located in the province of İzmir. In addition, one facility operates a pipe-raft system in the Çanakkale Strait (Figure 7A). To the question of how the production systems were fixed/stabilized on the sea bottom, 19 of 39 farms used concrete blocks (49%), 3 screwing method (8%), and 10 anchoring technique (25%). Other facilities reported that they fixed their systems on the sea bottom using two different methods simultaneously. Of those, 5 used both concrete block and screwing methods, and 2 chose both concrete block and anchoring techniques (Figure 7B).

It is reported that 3 of the facilities own their purification ponds (6%), 5 their processing/handling units, 8 refrigerating/cooling systems in their buildings (17%), 11 transportation networks (23%), and 6 sales outlet(s) (12%) (Figure 8).

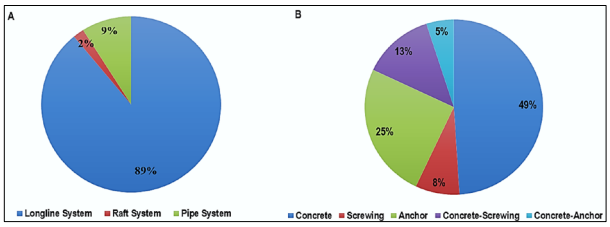

Figure 7. Production systems used in mussel farming (%) (A) and methods of securing production systems to the seabed (%) (B)

To the question of whether the respondents had harvesting boats on their farms/facilities or not, 31 replied that they had their own boats in their possession (79%), 2 had partnerships for harvesting vessels with others (5%), 1 rented boats for facility activities, and 5 did not have any harvesting vessels available in the facility processes (13%). The facilities possessed equipment such as ropes and buoys, some of which were self-manufactured on-site. However, 31 facilities (79%) reported procuring all necessary equipment such as mussel spat attachment ropes, mussel ropes from external markets. Specifically, one facility (3%) produced buoys and ropes internally, while two facilities (5%) fabricated ropes, buoys, and concrete blocks (Figure 9). When they were asked whether they possessed a port, dock, or wharf for vessels to pull into for loading and unloading material or products, 17 of the facilities (44%) answered positively and 56% negatively. The study demonstrated that at least one technical staff member was employed in 26 (55%) of the facilities, while 15 facilities (38%) experienced a shortage of personnel and 24 facilities (62%) reported no such deficiency.

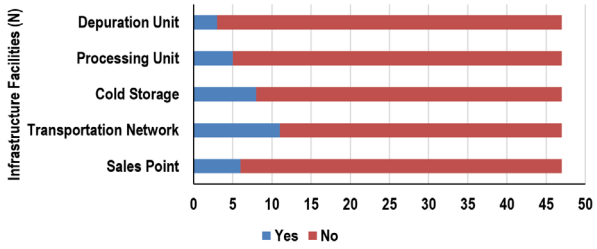

Figure 8. Infrastructure components and available equipment of mussel farming facilities (number)

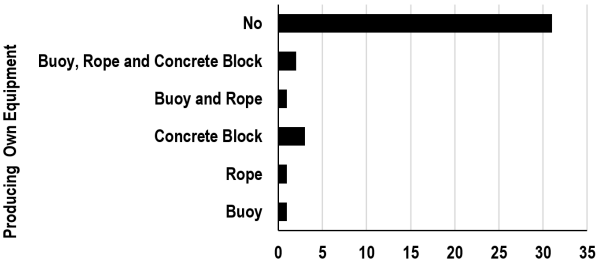

Figure 9. Number of facilities to produce their own equipment

Assessment of facilities for structure of partnership and economic issues

The study concluded that 14 (36%) were partners of their farms, 27 (69%) used only their present equities during the facility installation, and 12 (31%) used loans for creating

additional finance as well as their current equity capital. The facilities were reported to make use of government supports/subsidies, with 19 respondents (49%) finding the supports/subsidies sufficient and 20 (51%) insufficient, ultimately suggesting an increase in the amount of subsidies.

Rates of production, targets and product markets of facilities

When the facilities were asked up to what percentage of their capacity they could produce mussels, 15 replied that they had not yet started harvesting, although they were provided with farming certifications. It was found that 10 facilities (26%) were operating at 1–10% of their production capacity, 4 facilities (10%) at 11–20%, none at 21–30%, 4 facilities (10%) at 31–40%, and 3 facilities (8%) at 41–50%. Only 2 facilities (5%) were found to be operating at over 60% of their production capacity (Figure 10).

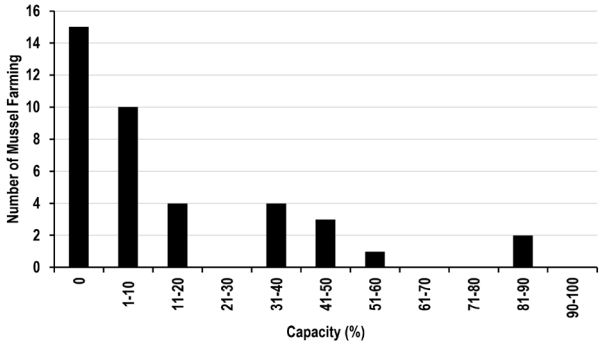

Figure 10. Number of mussel farming facilities producing at partial capacity levels (%)

The number of facilities who meant to produce any bivalve species other than Mediterranean mussel was 15, whereas 24 replied that they had no such intentions. It was determined that 35 facilities planned to increase their capacities in the future (90%), while 36 were to expand their production areas prospectively (92%). When the facilities were asked about their target markets, 10 (26%) stated that they aimed to supply domestic markets, 2 (5%) targeted foreign markets, and 27 (69%) planned to supply both domestic and foreign markets. Of the facilities, 16 supplied products to domestic markets (41%) and 7 to both domestic and foreign markets (18%). Considering the marketing forms of the products, 16 facilities (69%) marketed their products exclusively in live form directly from the facilities, while 2 facilities (9%) marketed their products only in processed (plain) form. No facilities were found to supply their products in both live and processed (plain) forms. The number of facilities supplying products in both live and processed (stuffed) forms was 3 (13%), whereas no facilities marketed only processed (stuffed) products. Additionally, 2 facilities (9%) were observed to market their products in live, processed (plain), and processed (stuffed) forms (Figure 11).

Problems experienced during and after installation of facilities

12 facilities experienced problems with the provision of material during the installation (31%), 27 reported financial damages related to the exchange rates between national and foreign currencies (69%), and 9 encountered bureaucratic obstacles during the farm installation (39%). They generally reported that 46% of facilities were negatively influenced by winds, 36% by currents, and 23% by mucilage. In addition to such environmental adversities, 26% reported encountering thefts, robberies, or intentional human damage to their facilities. During and after facility installation, 6 (15%) experienced negative reactions from local people, whereas 33 (85%) reported having no negative local problems.

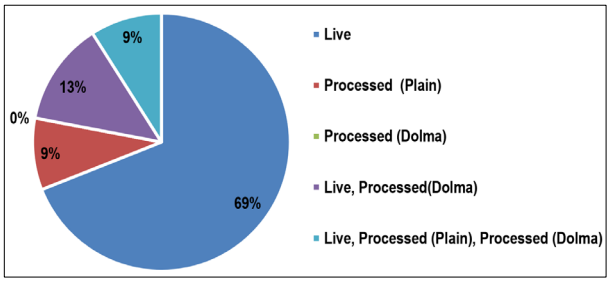

Figure 11. Product forms marketed by mussel farming facilities (%)

DISCUSSION

In Türkiye, mussel farming has expanded considerably in recent years; however, the sector remains in a developmental phase and has yet to achieve its full production capacity. Despite ongoing progress, data from the present study indicate that 15 of 39 facilities (39%) have not yet started production, with only 3 (8%) producing more than 50% of their capacities. Based on the related infrastructure and product recognition, output performance of the species varies from region to region in Europe. Italy had 240 mussel farms in 2019 (EUMOFA, 2022). Greece has licensed about 523 farms since 1976, but only 218 of them have a nominal output capacity of approximately 100 t/ha, employing a long single floating technique for farming areas of roughly 1–2 ha. Total annual output was reported to be more than 22000 tons in 2008 (Theodorou et al., 2011) and 23,500 tons (100 t/ha) in 2019 (Theodorou and Tzovenis, 2024). From the comparison of the two nations, it follows that the study included a limited number of facilities, and thus, it takes time for them to reach their full capacities.

Amounts of output/production obtained from farming systems vary across regions and years due to seasonal environmental fluctuations and regional characteristics that influence availability, reproduction, and growth patterns (Fuentes and Morales, 1994; Martinez and Figueras, 1998; Okumuş and Stirling, 1998). Moreover, climate change, diseases, issues related to mussel spat attachment, algal blooms, and poor profitability have significantly contributed to the decreases and fluctuations in mussel production in Europe (Avdelas et al., 2021; Soliño and Figueras, 2025; Calabrese et al., 2025). It is generally necessary to determine the production, considering the ground structure and environmental factors, in establishing capacity and location choice for installing mussel farming processes (Gatti et al.,

2023). The mere purpose of aquacultural farming is to obtain maximum yield per unit area (Vural et al., 2015), and what is to be aimed first in mussel farming is to determine the most suitable area and thus constitute the output capacity proportional to the area to be chosen. Output/production capacity varies according to regions, with Puck Bay producing mussels at 22.4 t/ha (Sokolowski et al., 2022), Baltic Sea Limfjorden at 41–90.4 t/ha (Taylor et al., 2019), and Greece at 100 t/ha (Theodorou and Tzovenis, 2024). The study on output capacities of the facilities in Türkiye indicates that the lowest and highest capacities were 0.75 ton/yr and 3000 ton/yr, respectively. Assessment of facility areas showed that the smallest and the largest rented areas were 0.5 ha and 40.3 ha, respectively. The facility projects approved by the Ministry of Agriculture and Forestry were found to have a capacity proportioned to 1000 tons/yr per 10 ha. However, many facilities have not yet achieved their full production capacity. We know that it takes time to achieve the determined capacity targets, and therefore, it is necessary to restructure and reregulate these target capacities over time. Each capacity area is considered a unique, self-contained system, and its specific requirements are identified through experience accordingly. We can consequently conclude that a revision needs to be made considering their output/production capacities. It is an obvious risk for investors in farming facilities to encounter uncertain and lengthy bureaucratic procedures from the very beginning of the facility installation process. For the solution to such problems observed in this connection, Suplicy (2020) pointed out that policies—most of which are implemented at the national level—are important for the industry to thrive. Moreover, Van Houtte (2001) emphasized the necessity of improving aquacultural farming management at both local and national levels, as well as establishing a legal and institutional framework to plan and operate sustainable development of the concerned process. Ozolina and Kokaine (2019) reported that the Latvian government applies the same procedures for approving the installation of mussel farms and wind parks. Consequently, it is difficult, costly, and time-consuming to establish such facilities at sea. These authors further noted that additional regulations are needed because the farming procedures and regulations for mussel farms are not on the same level as those for fish farming (due to over contamination) or wind park installations (associated with over construction and potential negative impacts). The present study indicates that mussel farmers complained about long and complicated bureaucratic procedures encountered during the processes of location selection, facility installation, and product marketing. The results of this and other studies emphasize several key issues: the need to improve current practices to avoid slow and time-consuming bureaucracy, expedite the licensing process, and separate these procedures from general aquacultural regulations by incorporating them into a specific mussel farming statute. Mussels are capable of directly turning primary seawater activity into meat (Gosling, 1992; Fry, 2012). Mussels can be easily contaminated with pollutants, as they are filter feeders that catch organic matter through seawater, which is, however, assumed to include organic and inorganic substances and pollutants as well (Acarli et al., 2023). Risk assessment for contamination with pathogens and sources of pollution in fisheries or aquacultural farming areas consists in public health precautions (Jones et al., 2009; EC, 2014). It is up to the EU authorized organs to develop and conduct the programs of bivalve classification and surveillance (EC, 2004). Considering the regional differences in classification status, the dominance of Class B mussel farming areas and the limited number of Class A sites may be associated with variations in environmental conditions, anthropogenic pressures, and water quality characteristics among regions. In semi-enclosed systems such as the Marmara Sea, factors such as limited water exchange, nutrient inputs, and pollution loads may restrict the occurrence of higher quality (Class A) areas. In contrast, relatively more open systems like the Aegean Sea may provide more favorable conditions, although local pressures still influence classification outcomes. Therefore, it is vital to carefully inspect both the product and the production areas to ensure that the mussels brought to consumers are sound and safe. For this purpose, supervisory bodies are expected to oversee the inspection process from harvesting to consumption. However, Ramšak et al. (2024) reported that businesses involved in Mediterranean mussel farming in Slovenia complained that bureaucratic procedures were too complex and time-consuming for effectively inspecting output areas. Ramšak et al. (2024) and Villalobos et al. (2025) emphasized the requirement for progressive devices of inspection, rapid acquirement of inspection results, the quickest interception of mussel harvesting, and, therefore, prevention of unnecessary costs from rising. Proximity of the facilities to the laboratory is of importance, considering rapid application of results from the analysis of samples, which is necessary for bivalve inspection procedures in the study, with the results indicating experience of substantial difficulties and waste of time in forwarding samples to the authorized laboratories. Among all other disastrous environmental experiences across Türkiye, the phenomenon called mucilage has recently been significant, severely emerging across the Marmara Sea and Dardanelles, especially after October in 2020 (Acarli et al., 2021). Yıldız et al. (2023) mentioned negative impacts of mucilage, occasionally seen in the Marmara Sea and Dardanelles, on the production of mussel farms. Yıldırım et al. (2024) determined the differences in output/systems, Mediterranean mussel spat attachment, and meat yields of the produced mussels before, during, and after the occurrence of mucilage aggregate visible in the Marmara Sea. We can suggest, within the frame of our personal interviews and observation, that the mucilage reappeared in the 2024–2025 period, which was, however, more limited in a shorter time than that in 2020 in terms of its prevalence and negative impacts. Among policy recommendations for such environmental problems encountered by mussel farms are increases in acquisition of financial and technical resources for small-scale farmers, formation of an emergency fund to alleviate losses of farmers during long-term harvesting

closures, and market diversification, considering various species to be produced for the problem-resistance to be increased (Avdelas et al., 2021; Villalobos et al., 2025). One of the main problems encountered in this and other studies is the substantial/financial adversities and bureaucratic procedures related to the recovery of samples for *E. coli* and HABs. It is recommended, especially in Türkiye, that recovery of samples for *E. coli* should be financially met by the related ministry through governmental subsidies for the first five years, and other financial costs, such as suitable loaning and governmental supports based on the dimension of damages caused by environmental catastrophes, should also be subsidized by direct government funds for the Mediterranean mussel facilities which have just been installed in Türkiye. It is compulsory that bivalve products harvested and excluded from Class A should be transferred to depuration systems in terms of final product safety (Ciccarelli et al., 2022). There are critical roles in the value chain in terms of depuration and distribution centers (Tudini and Forgione, 2024). Girard and Mariojouls (2003) stated that most EU nations present comparatively low and stable prices in aquaculturally produced mussels, which is caused by the fact that small-scale farmers remain outside purification and marketing processes and therefore they lose their market shares/powers to the facilities well equipped with infrastructure for processing, handling, and purification. Ramšak et al. (2024) reported that one of the mussel farmers said that his purification system is constantly in the position of working and ready to purify products of other farmers as well. STECF (2021) reported that Britain has limited purification facilities/ponds, and these shellfish products are sold to be processed by big purification facilities across the Channel in Europe. The study shows Türkiye has a limited number of facilities with an infrastructure composed of purification, processing/handling, warehousing, and logistics, which is assumed to create undesirable consequences in their market shares in the future. The facilities are, therefore, recommended to get together in collaborations associated with finding solutions to the problems or adversities likely to emerge later, thanks to cooperatives and unions.

Ability to establish the area for installation of Mediterranean mussel facility is the determinant factor, such as distance to the port and natural productivity (Mongruel and Thébaud, 2006). According to the present research, 56% of the respondents said that they had no landing point in their farms and tried to edge in with the land docking where they could ever find any available point or attempted to have special permission, all of which inevitably influence production processes directly. There is a general influence of fuel and power needed by boats and auxiliary equipment on consumer inflation included in mussel output costs (Muir, 2015; EUMOFA, 2022). Ramšak et al. (2024) concluded from their survey work in Slovenia that operation vessels of mussel farming could come across problems with any available landing activities for loading and unloading due to lack of any dock or wharfs, as well as other major obstacles in the related process. It is, thereby, crucial in the solution to the encountered problem that the concerned ministries should prioritize landing points in available docks and wharfs for mussel facilities or create new vessel landing points for mussel facilities. Costs of mussel farms are generally categorized into three main groups: investment costs (synthetic ropes, mussel farming nets, buoys, anchors, chains, clips, concrete blocks, and underwater buoys, working vessels, etc.), operational/maintenance costs (labour, energy, depreciation, sea rental, consumables), and post-harvesting costs (salaries and taxes, transportation, packaging) (Theodorou et al., 2011; Theodorou et al., 2014; Sokolowski et al., 2022). The amounts needed for the above costs in installation and operation of mussel farms can directly determine the value of the product as well. Provision of imported materials and equipment required for aquacultural farming activities is an inevitable foreign-based process in countries, especially in Türkiye, where production of Mediterranean mussel and its related infrastructure are being newly established.

For example, Ramšak et al. (2024) reported that much of the equipment required for mussel farming businesses was imported from Italy, and these facilities bought spat from Italy for a given period, but its high prices made the mussel output unsustainable. Theodorou et al. (2014) suggested that most mussel farms in Greece produced much less than their capacities; thus, they were supposed to share equipment with each other in cooperation to earn more and lose less. The present study stated that the facilities import their system equipment from abroad and encounter financial damages due to occasional changes between national and foreign currencies, which is directly associated with the national economy and supposed to be solved with short-term subsidies from the central government. However, we assume that the long-term process will hopefully help produce the needed material and equipment under market conditions of the domestic markets over time. For instance, some businesses have chosen to produce their own floaters rather than purchasing them from domestic or foreign markets.

Ramšak et al. (2024) found in a survey process that mussel farmers were freelancers who trained themselves through trial and error in their own business; therefore, they had no sufficient choices for an information hub to incentivize official support or innovations. Theodoridis et al. (2017) cited that socio-demographic variables, farmers' ages, their aquacultural experiences, vocational training, and educational degrees could influence yielding/productivity of farms/facilities, as cited by the results of the Tobit regression model, which can somewhat explain yielding differences. The researchers found from the survey in Greece that farmers with longer experience are more productive than those with shorter experience in aquacultural farming activities (66 mussel aquaculture farms were used for the estimation of the level of technical efficiency). The related study showed that mussel farms short of technical personnel/staff were negatively affected in their output performance, which is mainly accounted for by the fact that the mussel farming business has been initiated and developed in relatively recent years. Accordingly, aquaculture engineers are expected to gain the required experience and expertise thanks

to fieldwork over time in the future, which has been specifically observed in Türkiye through the historical process of development in marine/sea fish aquacultural farming for marine/sea fish and trout. Moreover, the employees, farmers, and businessmen who have not specifically been trained in aquacultural farming activities could participate in and complete training programs to be organized by the related ministry and universities.

The survey conducted in the present study pointed out that 89% of facilities in Türkiye use the longline system, in which buoys or pontoons are utilized as system floaters. The results of the study also indicated that mussel farming in Türkiye is mainly sustained using ropes arranged as longlines on HDPE pipes serving as floats. This method, referred to as the "pipe system" by facility managers, is employed by five mussel farming businesses (9%), all of which are located in the province of İzmir. In addition, one farming business operates this pipe-raft system in the Çanakkale Strait, Türkiye. The pipe and raft systems prefer HDPE (high-density polyethylene) as the system floaters in Türkiye, which are also used for aquacultural marine fish farming (Cardia and Lovatelli, 2015). The properties of HDPE make it a suitable option considering its material-carrying ability in water and its durability under solar radiation (Soriano and Pancorbo, 2012). Some firms in Spain that design mussel farming systems have manufactured HDPE raft systems, which they found to be 20% more efficient in output than wooden systems due to their elasticity in water, by modifying the conventional wooden raft process locally called "Baeda." The modified systems are more durable and suitable for offshore activities (Lado-Insua et al., 2009). No system can thus be said to be more perfect than or superior to another, as every marine area has its most suitable mussel farming technique according to the means and requirements for collecting spat (Avdelas et al., 2021). The present study indicates that the longline system has been widely used, whereas the techniques used for fixing the system vary. The options are determined by the bottom/ground structure and costs, with the result that 49% of the farms employed concrete blocks for bottom fixing.

CONCLUSION

This study demonstrated that mussel farming in Türkiye is still in a developing stage, with most facilities operating below their production capacity. The longline system was identified as the dominant culture method, while major constraints included dependence on imported materials, financial instability related to exchange rates, limited infrastructure, and bureaucratic challenges. In addition, environmental factors such as mucilage events continue to pose risks to production sustainability.

To ensure the future development of the sector, improvements in regulatory frameworks, infrastructure, and technical capacity are required. Supporting local production of farming equipment, strengthening logistics and depuration systems, and providing targeted financial incentives are essential steps toward sustainable mussel aquaculture in Türkiye.

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AUTHORSHIP CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection, analysis, and interpretation were performed by the authors. All authors contributed to the writing of the manuscript and approved the final version.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL APPROVAL

The data were collected through voluntary survey-based questionnaires conducted in accordance with ethical standards. The studies have been approved by Çanakkale Onsekiz Mart University on 14.02.2022 with the number of 22-YÖNP -0298 (E-84026528-050.0104.-2200083240) and have been performed in accordance with the ethical standards.

DECLARATION OF AI USE

During the preparation of this manuscript, AI-assisted tools were used solely for language editing and proofreading purposes. All scientific content, analyses, and interpretations are the responsibility of the authors.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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