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How do mussel provenance and spat size affect mussel aquaculture performance in the South-Western Mediterranean (Algeria)?

by

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Abstract

The objective of this research was to study the effects of size and spat origin of farmed *Mytilus galloprovinciallis* in mussel longlines in the east of Bou-Ismail Bay (central coastal Algeria, south-western Mediterranean). The study was conducted from October 2017 to July 2020 in the east of Bou-Ismail Bay. The mussel spat were obtained from four origin sites (Tlemcen, Tenes, Ain Tagourait and the study site) and were seeded on three spat sizes (10–30, 30–60 and >60 mm). The production performance of this species was analysed on 284 random mussel plots using average physical product (APP), gain and loss rates, condition index (CI), percentage of edibility (PE) and shell thickness index (STI). Apart from the CI and loss rate, the performance indicators showed significant differences according to spat size and source ($p < 0.05$). Overall, the highest APP (4.3) was recorded for the small seeded mussels (10–30) mm and for those originating from Tlemcen, near finfish cages (APP = 4.14). These individuals exhibited more efficient growth and physiology for commercial size and performed better than the spat collected at the study site. The results can be considered a valid contribution to best farming practice for optimising the production of this species in Algeria. It also contributes to the development of integrated multitrophic aquaculture (IMTA) methodology, which is suitable for use in the oligotrophic Western Mediterranean.

Key words: Mediterranean mussel, farming, production, recruitment, Algeria

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1. Introduction

In recent decades, aquaculture production has served as an essential source of protein for a large portion of the world's population. An ever-increasing demand for aquatic products suggests that aquaculture will continue to be one of the fastest-growing sectors for protein-based food production (FAO 2016). Therefore, the rapid development of aquaculture has increased the need for sustainable production strategies (Fuentes-Santos & Cubillo 2015). In this context, integrated multitrophic aquaculture (IMTA) has demonstrated a reduction in the environmental footprint and has increased the profitability of farming (Chatzivasileiou et al. 2022). This innovative mariculture methodology combines species cultivation from different trophic levels, simulating a natural food web (Chatzivasileiou et al. 2022). As commercial aquaculture is a profit-orientated activity, achieving control over the costs and returns is a key element in optimising production (Asche et al. 2008, 2012; Theodorou et al. 2014, 2020, 2021). It is therefore possible to analyse the performance of a given production process and to propose improvements to increase its efficiency.

According to the latest statistics from the Food and Agriculture Organization of the United Nations, mariculture and coastal aquaculture production reached 30.8 million tonnes (equivalent to 106.5 billion aquatic animals) in 2018 (FAO 2020). A significant part of its production is of bivalve origin (i.e. clams, oysters, mussels and other species) (FAO 2020). Their production has been increasing considerably with consumer demand (Prato et al. 2019). In the Mediterranean countries, they are considered a rich food source and a healthy balanced diet (Cherifi et al. 2018; Dridi et al. 2007). Their cultivation continues to play an important role in providing food for the growing world population (Landmann et al. 2019). For example, *Mytilus galloprovincialis* is the main species used in mussel farming on the French, Spanish, Italian, Greek, Tunisian and Algerian coasts (FAO 2016). In order to increase its production from less than 150 metric tonnes in 2013 to 7600 tonnes in 2025 (MPRH 2008), the Algerian Ministry of Fish and Fisheries Resources designed a strategic plan to sustainably develop marine aquaculture (MPRH 2008). This programme aims to establish 56 new farms of this species along the Algerian coast between 2015 and 2025.

Several scientific studies have been carried out to improve the production of mussels in offshore systems. Some authors were interested in comparing the farming production (Camacho et al. 1995; Okumus & Stirling 1998; Fuentes et al. 2009), taking into account response variables such as growth (Fernandez-Reiriz et al. 1996; Hatzonikolakis et al. 2017) and condition index (Okumus & Stirling 1998). Guillou et al. (2020) studied the commercial performance of the blue mussel in Canada. Theodorou et al. (2014) reported that the optimal farm size for mussel production of the Mediterranean mussel in Greece is a larger than 3 ha. Other researchers focussed on improving aspects of grow-out techniques in order to reduce losses, by minimising mussel thinning practices during the grow-out period (Pérez-Camacho et al. 2013), varying the seeding density (Cubillo, Peteiro, Fernández-Reiriz, et al. 2012b), grading mussels by size during the initial seeding (Lauzon-Guay et al. 2005; Supono et al. 2020), adjusting the spacing of mussel ropes (Drapeau et al. 2006) and providing a period of feeding and conditioning before transferring them to coastal farms (Sim-Smith 2006; Carton et al. 2007).

Several studies have demonstrated that PE and CI are the main tools for the commercialisation of bivalves, depending generally on endogenous and exogenous conditions (Lagade et al. 2015). They provide information about the physiological state and growth of the organisms (Andral et al. 2004), which is of great interest for harvesting purposes, e.g. to indicate the market value (Martinez et al. 2018). The physiological implications of mussel size on shell thickening or byssus attachment strength, together with the ecological implications driven by site-specific heterogeneity, will therefore play a key role in mussel performance in a widely exploited area.

In Algeria, mussel farming data are almost unavailable, apart from a study by Laama and Bachari (2018) on evaluating site suitability for the expansion of mussel farming and one by Lourguioui et al. (2017) on the environmental impacts of aquaculture. Offshore aquaculture remains a very recent activity with little research into the characterisation and improvement of farming production. Specifically, there is a lack of data on the results of mussel production optimisation due to a lack of scientific studies, monitoring and follow-up systems of mussel production in Algeria. Furthermore, there is a lack of knowledge about the effects of different spat sizes and origins on the growth of *M. galloprovincialis* and the biomass produced in a mussel culture system in Algeria. This work aims to acquire the information on mussel farming necessary for the management and optimisation of *M. galloprovincialis* in Algeria. It is the first study to develop best farming strategies for optimising the production of this species in the study area, and the only one that deals with optimally growing in a suspended culture system on a microgeographic scale. The objectives of this paper are 1) to study the main production processes governing mussel farming activity, 2) to estimate the variation of relative biomass production (RBP) in a mussel farming system and 3) to analyse biomass production gain and loss based on spat size and origin in order to understand their effect on productivity. For the analysis, we used data from Cultmare farm on three initial spat size classes and four different sources, over three years (2017–2020). The experiment was strictly conducted according to commercial culture methods to ensure that our findings from the study are applicable to improving mussel culture and contribute to the development of an IMTA methodology suitable for use in the oligotrophic Western Mediterranean.

2. Materials and methods

2.1. Study area

Bou-Ismail Bay is located on the central coast of Algeria (the south-western Mediterranean Sea); it extends for over 47 km and has a wide continental shelf of 11 km. It is bounded by the promontory of Ras Acrata in the east and by the Cape of Mount Chenoua in the west (Amarouche et al. 2018). It is characterised by a mobile bottom and strong hydrodynamic activity (Amarouche et al. 2018). This bay is an important economic zone that brings various investment in the tourism, industry, fishing and energy sectors (Houma 2009). The field experiments took place at Cultmare farm, located in the east of Bou-Ismail Bay. It is a mussel production farm that hosts a series of floats, or rafts, from which *M. galloprovincialis* mussels are suspended on 'droppers'. These droppers hang in the water column on 20 lines, each 300 m long and extending perpendicular to the shoreline (Fig. 1).

2.2. Sampling and laboratory procedures

The production performance of *M. galloprovincialis* was studied on 284 mussel plots from October 2017 to July 2020. The spats were sampled from different origins: Tlemcen, Tenes, Ain Tagourait and from the collectors at the study site. They were sorted into three size categories (10–30, 30–60 and >60 mm) and transplanted into socks suspended culture method

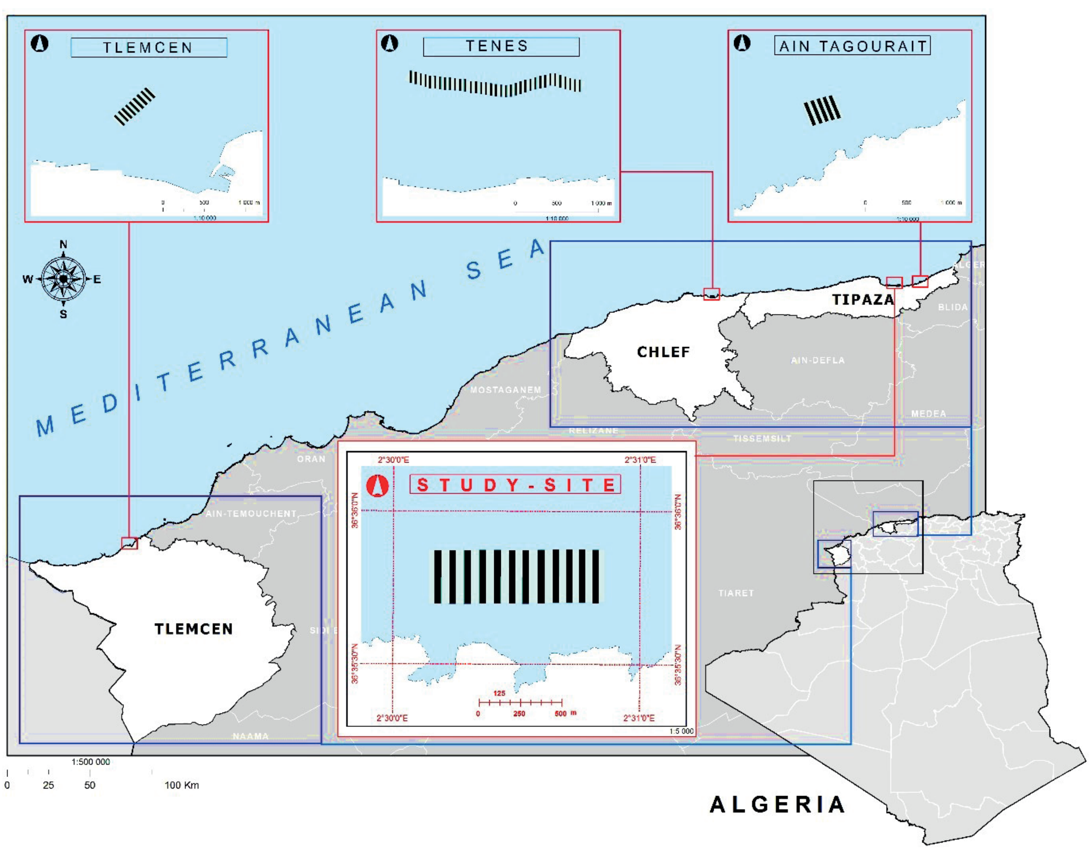

Figure 1

Study area location and sampling stations at the Cultmare farm in densities of 1200 ind m^{-1}, 600 ind m^{-1} and 300 ind m^{-1} (Fig. 2). The mussels from each sock were harvested after a traditional production cycle in one of three grow-out periods (16, 12 and 8 months, respectively). All socks were weighed before seeding and after harvesting, using a digital scale with a capacity of 50 kg and an accuracy rating of 0.05 kg.

Note that the Tlemcen and Tenes mussels reared at the study site were spawned near a finfish cage farm, while those from Ain Tagourait were obtained from mussel lines suspended on artificial collectors in the same way as the specimens collected for the study site (Fig. 2).

The physiology of *M. galloprovincialis* was investigated using biological data from 1180 commercial-sized individuals measuring between 35 and 85 mm. They were randomly sampled during grow-out from 21 socks (Fig. 3) from three sources (Tlemcen, Tenes and the study site) in two initial spat sizes (10–30 and 30–60 mm). These individuals were

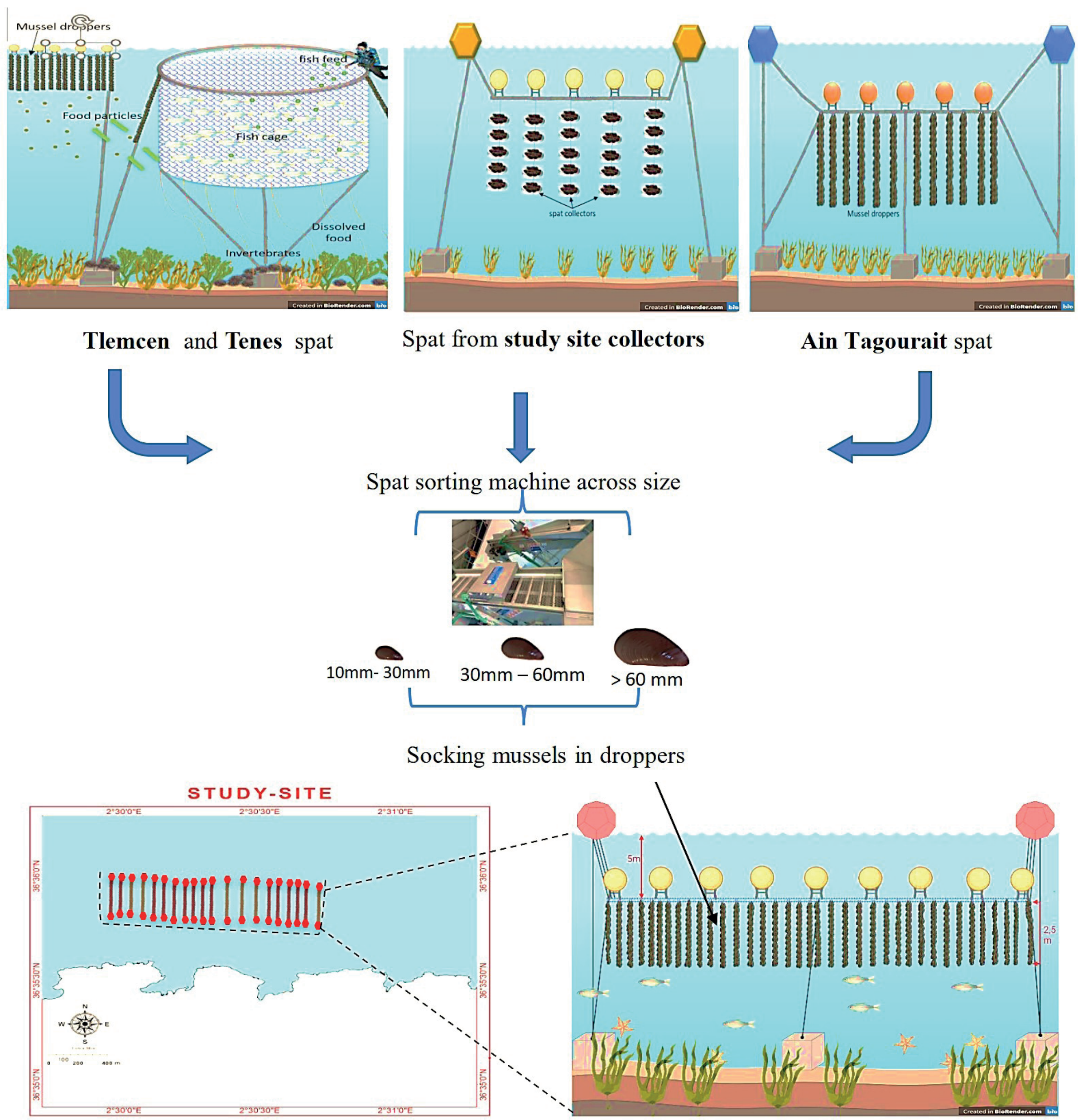

Figure 2

Transplantation of *M. galloprovincialis* from different origins (Tlemcen, Tenes, Ain Tagourait and the study site) and sorting three spat sizes

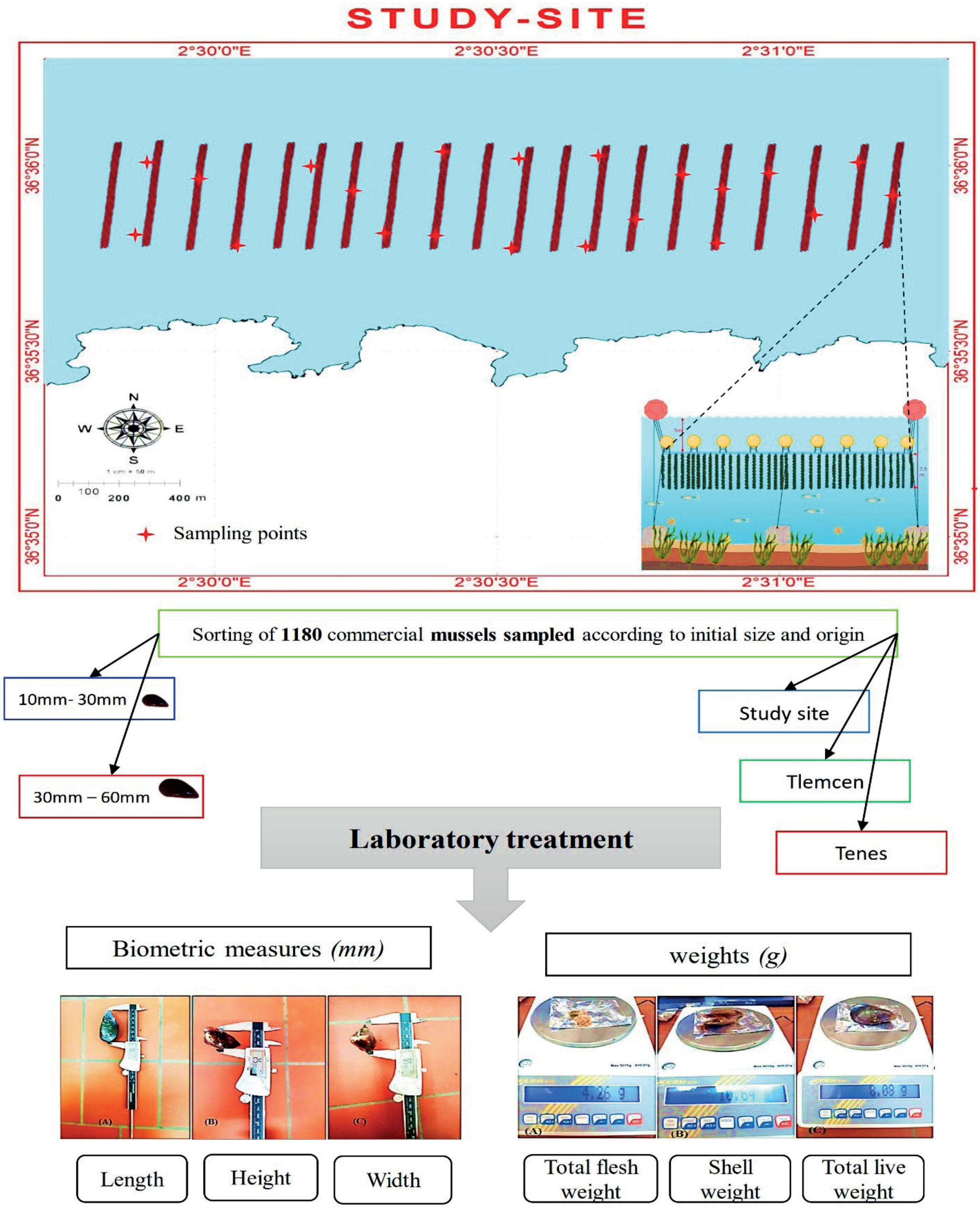

Figure 3

Random sampling points of *M. galloprovincialis* from 21 droppers at the study site and the laboratory processing of individuals transported in thermal bags to the laboratory and stored overnight in a refrigerator (4°C) to be analysed the next day. After the mussels were dislodged, the anterior-posterior (lengths), dorsoventral (heights) and lateral axis (widths) of the shells were measured using a Vernier calliper (± 0.1 mm). The total live weight (TLW) after the tissue was dissected from the shell, the total flesh weight (FW) and the shells (patted dry with paper towels) of each animal were weighed to the nearest 0.01 g (Fig. 3).

2.3. Data analysis

2.3.1. Production and stock performance

The index for culture efficiency is the average physical product (APP) (Ferreira et al. 2007b) or the relative biomass production (RBP) (Capelle et al. 2016). The overall production of the farm in each plot was calculated by the ratio between the initial mussel biomass (kg m^{-1}) before submersion (WBS) and the harvested mussel biomass (kg m^{-1}) after the growing cycle (WBH). The APP was defined as follows (Ferreira et al. 2007b):

$$APP = \frac{WBH}{WBS}$$

The mussel biomass gain ratio (in) represents all plots that gained biomass after one growing cycle and had an greater than , given by:

$$Gain\% = (APP - 1) \times 100$$

The loss ratio (in %) represents the amount of mussel biomass lost from initial weight, after one growing cycle, given by:

$$Loss = (1 - APP) \times 100$$

2.3.2. Marketability indices

The percentage of edibility (PE) and the condition index (CI) were derived after separating the meat from the shells, according to Mohite et al. (2008) and Okumus and Stirling (1998):

$$PE(\%) = \frac{total\ flesh\ weight}{total\ live\ weight} \times 100$$

$$CI(\%) = \frac{total\ flesh\ weight}{shell\ weight} \times 100$$

The values of shell thickness index (STI) were obtained according to the following formula (Freeman et al. 2009; Freeman & Byers 2006; Babarro et al. 2020):

$$STI = 1000 \times \frac{dry\ shell\ weight}{\left[L\left(H^2 + W^2\right)^{0.5} \times \frac{\pi}{2} \right]}$$

L, H and W are the length, height and width of the shell (in mm), respectively.

2.4. Statistical analysis

With the null hypothesis stating that there would be no effect of seed size or origin on the biomass produced in the mussel culture, the one-factor analysis of variance (ANOVA) was applied to the gain and loss ratios of the APP of all mussel stocks. The total weight (TW), CI, PE and STI of all mussel samples were also compared by ANOVA according to spat size and origin. Tukey's test was used when significant differences were detected (differences were considered significant when $p < 0.05$).

3. Results

3.1. Production and stock performance

The ANOVA results for APP ratio revealed a statistically significant difference in performance between the three seeding sizes (Table 1). Significant inverse relationships between seeding size and APP were indicated by Tukey's HSD test (Table 2). However, the mussel loss rate was statistically non-significant for all three seeded size classes (Tables 1 and 2).

In the total mussel production, no significant differences were observed between the four spat sources, whereas significant differences were noted in biomass gain and loss rates (Table 1), in favour of the Tlemcen mussels (Table 2).

The values of APP ratio between the seeded and harvested biomass in each mussel plot are presented in Figure 4. APP varies over a magnitude of 3.02, with a minimum of 0.95 and a maximum of 3.97. The highest APP values were observed in the small spat class (10–30 mm), according to their origin. Spat size is in a distinct inverse relationship with the amount of biomass produced (APP was 1.72 to 3.97 for spat sizes of 10 to 30 mm, 1.15 to 1.33 for spat sizes of 30 to 60 mm and 0.95 for sizes over 60 mm). Moreover, it was found that biomass production was greater when the spat source was closer to the rearing site (Ain Tagourait).

Table 1

Statistical analysis of variance of the average physical product of mussel plots according to the three initial seeding sizes and the four origins of the seeded spat stocks

		df	SS	MS	*F*	*P*
Spat Sources : Study site; Ain Tagourait; Tlemcen ; Tenes	Overall production (*APP*)	3	2.445	0.815	1.640	0.180
	Gain biomass (%)		13.278	4.426	10.581	**< 0.0001**
	Losses (%)		0.395	0.132	7.857	**< 0.0001**
Seed-size of spat (mm) 10 – 30; 30 – 60; >60	Overall production (*APP*)	2	54.522	27.261	87.960	**< 0.0001**
	Gain biomass (%)		38.029	19.015	62.683	**< 0.0001**
	Losses (%)		0.072	0.036	1.639	0.203

Table 2

Analysis of differences determined by Tukey's HSD test between modalities in mussel biomass production with 95% confidence intervals (significant results [$p < 0.05$] are in bold)

Overall production (*APP*)							
	Seed-size of spat (mm)			Spat Sources			
	10 – 30	30 – 60	>60	Ain Tagourait	Study site	Tenes	Tlemcen
P-value	**< 0.0001**	**< 0.0001**	**0.003**	0.810	0.682	0.537	0.406
Estimated means	2.189 ± 0.07	1.276 ± 0.04	0.949 ± 0.09	1.401 ± 0.13	1.450 ± 0.06	1.261 ± 0.14	1.595 ± 0.09
Groups	A	B	C	A	A	A	A
Gained mussel biomass (%)							
	Seed-size of spat (mm)			Spat Sources			
	10 – 30	30 – 60	>60	Ain Tagourait	Study site	Tenes	Tlemcen
P-value	**< 0.0001**	0.382	0.382	0.528	0.803	0.640	**0.033**
Estimated means	126.7 ± 06.7	39.4 ± 04.7	19.0 ± 14.7	169.9 ± 14.5	151.0 ± 05.4	155.8 ± 16.2	215.0 ± 10.1
Groups	A	B	B	A / B	B	B	A
Losses mussel biomass (%)							
	Seed-size of spat (mm)			Spat Sources			
	10 – 30	30 – 60	>60	Ain Tagourait	Study site	Tenes	Tlemcen
P-value	0.673	0.354	0.583	0.278	**0.019**	0.415	0.262
Estimated means	14.6 ± 7.4	24.2 ± 2.6	18.1 ± 2.9	9.6 ± 3.7	35.2 ± 3.9	17.1 ± 3.9	21.9 ± 2.4
Groups	A	A	A	C	A	B / C	B

3.2. Variation in biomass relative to spat size

The distribution of total production according to the size of seeded mussel (Fig. 5) showed APP values that were clearly asymmetric for the small seeded spat (10–30 mm), becoming visibly symmetric for the medium (30–60 mm) and large (>60 mm) seeded individuals. Furthermore, the highest variability in overall production was observed in the small spat (10–30 mm), with an interquartile range of

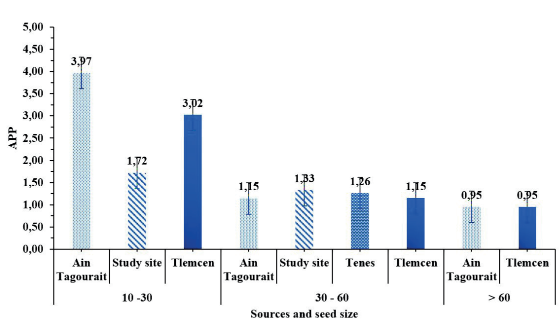

Figure 4

The average physical product according to different sources and sizes of spat

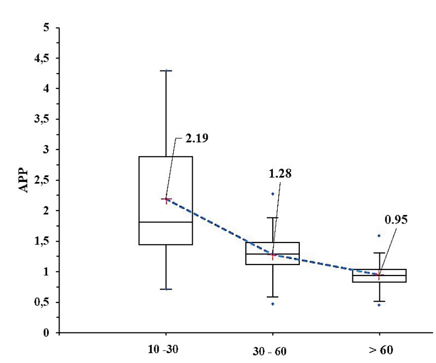

Figure 5

Average physical product with three sizes of spat

1.45. This variability decreased significantly in the medium (30–60 mm) and large (>60 mm) spats, with interquartile ranges of 0.36 and 0.21, respectively. In addition, this distribution also indicates that the biomass decreased significantly as spat size increased. The amount of biomass produced ranged from 0.72 to 4.29, with 50% of the values being below 1.81 for mussels with small spat (10–30 mm). For mussels with medium-sized spat (30–60 mm) this value was between 0.58 and 1.88, with 50% of the values being below 1.29. In the case of mussels with large spat (>60 mm), the biomass was between 0.52 and 1.31, with 50% of the values being less than 0.95 (Fig. 5).

A gradual decrease of the mean biomass gain rate, from 127% to 19%, was observed with increasing seeded size. The average biomass loss rate was 15% for spat 10–30 mm in size, 24% for the 30–60 mm spat and 18% for the largest class (>60 mm) (Fig. 6). However, the differences between the three spat sizes in terms of biomass gain and loss rates were significant. The small spat mussels (10–30 mm) presented a difference of 115% between the average gain and average loss in biomass. The medium-sized mussels (30–60 mm) had a relatively high growth rate (15%) compared to the biomass loss. The gain and loss rates of the large mussels, on the other hand, were almost identical (Fig. 6).

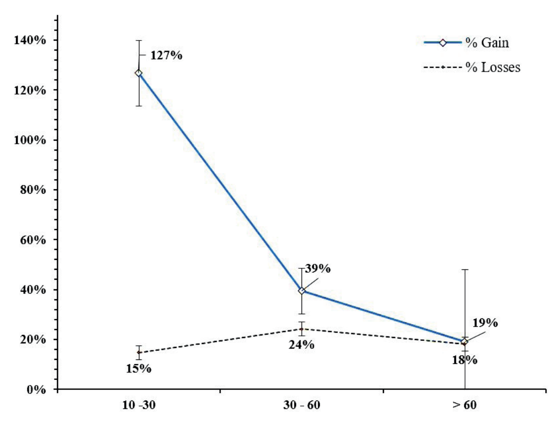

Figure 6

Average gain and loss rate of mussel biomass according to the size of the spat

3.3. Variation of the biomass produced according to the spat's origin

The distribution of biomass measured by APP (Fig. 7) clearly showed a visible asymmetry and high variability when the mussels originated the farthest (Tlemcen) from the study site, with an interquartile range of 1.4. This distribution appeared to be more

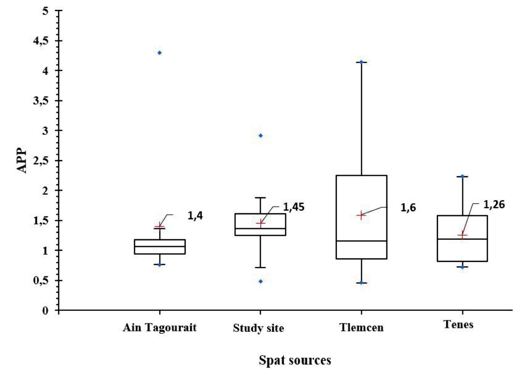

Figure 7

Variation in the average physical product for the four sources of spat

symmetric and showed less variability for the spat obtained closer to the study site (Tenes and Ain Tagourait, with interquartile ranges of 0.76 and 0.24, respectively). The APP distribution for mussels native to the study site were relatively asymmetric and more variable than in the other cases: the biomass was between 0.72 and 1.88, with 50% of the values being above 1.25 and with an interquartile range of 0.36.

Compared to the native mussels at our study site, this distribution revealed that the biomass was higher when the spat was collected near a finfish cage (Fig. 7). When the mussels were native to Tenes, the distribution was between 0.72 and 2.23, with 50% of the values being greater than 1.19. With the mussels from Tlemcen, it was between 0.46 and 4.14, with 50% of the values being above 1.16. The mussels originating from Ain Tagourait produced a biomass distribution between 0.77 and 1.4, with 50% of the values being above 0.94 (Fig. 7).

The mean gain rate according to the mussels' origin (Fig. 8) had an important variation between the four spat sources: It was 70% for spat from Ain Tagourait,

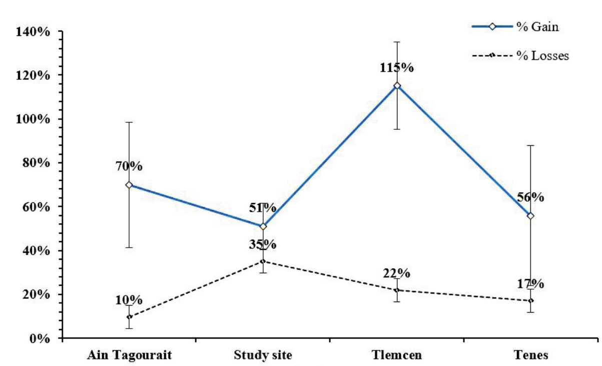

Figure 8

Variation in the average physical product for the four sources of spat

51% for mussels native to the study site, 115% for mussels from Tlemcen and 56% for spat from Tenes. However the mean biomass loss rate comparing the four spat origins (Fig. 8) was minimal for Ain tagourait spats by 10% followed by Tenes with 17% of loss, then 22% for Tlemcen spats, the maximum biomass loss was 35% when the mussels were native of the study site.

Moreover, differences between the four seed origins in terms of biomass gain and loss rates were clearly visible (Fig. 8). Mussels native to the study site exhibited a relatively high growth rate (16%) compared to the biomass loss rate. The mussels from Tlemcen presented the highest gap (93%) between the average gain and loss of biomass, followed by those from Ain Tagourait (60%) and Tenes (39%).

3.4. Marketability indices of mussels by seed size and spat origin

Two initial seeding size classes (10–30 and 30–60 mm) were identified with three spat sources (Tlemcen, Tenes and the study site). The ANOVA analysis showed a significant difference in TW, CI, PE and STI across several mussel size classes compared by spat size and origin, though the difference between the three spat sources was not statistically significant for CI (see Table 3). Tukey's test also confirmed the results of the marketability indices, which favoured the small seed size (10–30 mm) and spat from Tlemcen (see Table 4).

At the study site, relatively large values were found for the TW, PE and CI of the mussels sampled in the

Table 3

Statistical analysis of variance of the marketability indices and total weight of mussels, sampled according to two initial seeding sizes and three origins of the seeded spat stocks

		df	SS	MS	*F*	*P*
Spat Sources : Study site; Tlemcen; Tenes	Total weight of mussels *(g)*	2	1730.454	865.227	15.325	**< 0.0001**
	Percentage edibility *(PE)*		0.090	0.045	4,101	**0.017**
	Condition index (*CI*)		0.316	0.158	1.188	0.305
	Shell thickness index (*STI*)		7.557	3.779	8.61	**<0.0001**
Seed-size of spat (mm) 10 – 30; 30 – 60	Total weight of mussels (g)	1	2275.739	2275,739	40.676	**< 0.0001**
	Percentage edibility (PE)		0.493	0.493	35.898	**< 0.0001**
	Condition index (*CI*)		13.195	13.195	32.190	**< 0.0001**
	Shell thickness index (*STI*)		3.992	3.992	9.06	**0.003**

Table 4

Analysis of the differences determined by Tukey's HSD test between the modalities for mussels with 95% confidence intervals (significant results [$p < 0.05$] are in bold)

Total weight of mussels *(g)*					
	Seed-size of spat (mm)		Spat Sources		
	10 – 30	30 – 60	Study site	Tenes	Tlemcen
P-value	**< 0.0001**	**< 0.0001**	**0.001**	**0.001**	**0.001**
Estimated means	**14.539 ± 0.415**	11.430 ± 0.256	12.221 ± 0.265	10.107 ± 0.571	**14.393 ± 0.526**
Groups	**A**	B	B	C	**A**
Percentage edibility (PE) %					
	Seed-size of spat (mm)		Spat Sources		
	10 – 30	30 – 60	Study site	Tenes	Tlemcen
P-value	**< 0.0001**	**< 0.0001**	0.507	**0.035**	0.528
Estimated means	**27.7 ± 0.006**	23.8 ± 0.003	27.8 ± 0.004	**25.3 ± 0.008**	27.8 ± 0.007
Groups	**A**	B	**A**	**B**	**A**
Condition index (CI) %					
	Seed-size of spat (mm)		Spat Sources		
	10 – 30	30 – 60	Study site	Tenes	Tlemcen
P-value	**0.0004**	**0.0004**	0.590	0.453	0.412
Estimated means	**66 ± 2**	57.7 ± 1.2	59.9 ± 1.3	57.1 ± 2.8	62.8 ± 2.6
Groups	**A**	B	A	A	A
Shell thickness index (STI)					
	Seed-size of spat (mm)		Spat Sources		
	10 – 30	30 – 60	Study site	Tenes	Tlemcen
P-value	**0.003**	**0.003**	0.230	0.356	**0.0001**
Estimated means	**1.468 ± 0.033**	1.357 ± 0.017	1.421 ± 0.018	1.342 ± 0.045	1.265 ± 0.034
Groups	**A**	B	A	A	B

different size classes. This clearly indicated that the mussels seeded when small had more efficient growth and physiology than those seeded with a medium STI value and revealed a slight difference between the small and medium seeded spat size (Figs. 9a–d).

The variability in marketability indices of mussels grown at the study site according to spat origin over the different size classes is illustrated in Figure 10. Excluding STI, considerable differences between the three spat origins were observed in TW, PE and CI.

The Tlemcen mussels showed more efficient growth and physiology for commercial-sized individuals, followed by the mussels native to the study site. However, the mussels from Tenes recorded the lowest values (Figs. 10a–d).

4. Discussion

The production generated by different combinations of stocks at a single farm site, using the traditional techniques and criteria of mussel producers, has never been evaluated in Algeria. This study investigated the growth performance of mussels grown from spat from four different sources in three different initial seeding size categories. The density was controlled and did not exceed 1200 ind/m, depending on the initial seeding size, in order to eliminate any smothering effect. After three years of mussel farming, the yield expressed as APP was inversely proportional to the initial size. It differed significantly from one stock to another, favouring small spat, with a maximum production of 4.3 kg harvested per kg seeded. These results are consistent with previous work from seeding to harvest. An average of 1.5–2.5 kg harvested per kg seeded of *M. edulis* was reported in the Wadden Sea, and often less than 1 kg harvested per kg seeded in Ireland (Calderwood et al. 2015; Wijsman et al. 2014). Along the Moroccan Atlantic coast, reported relative biomass production shows more variation for this species (2.8–5.7 kg harvested per kg seeded) (Idhalla et al. 2017). For *M. galloprovincialis* culture, a maximum of 7 kg harvested per kg seeded has been modelled (Ferreira et al. 2007a).

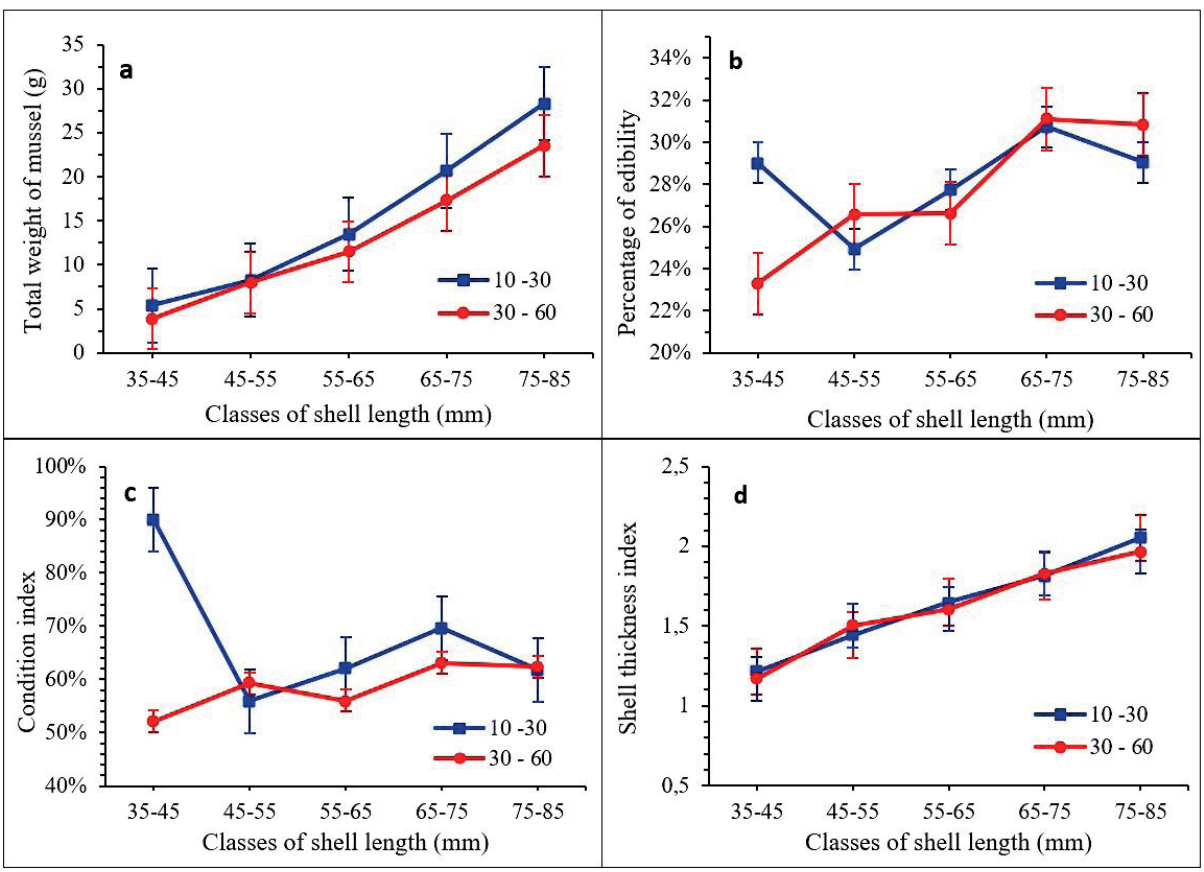

Figure 9

Changes in marketability indices and the total weight of mussels sampled according to initial spat size over different shell lengths (a: total weight, b: percentage of edibility, c: condition index, d: shell thickness index)

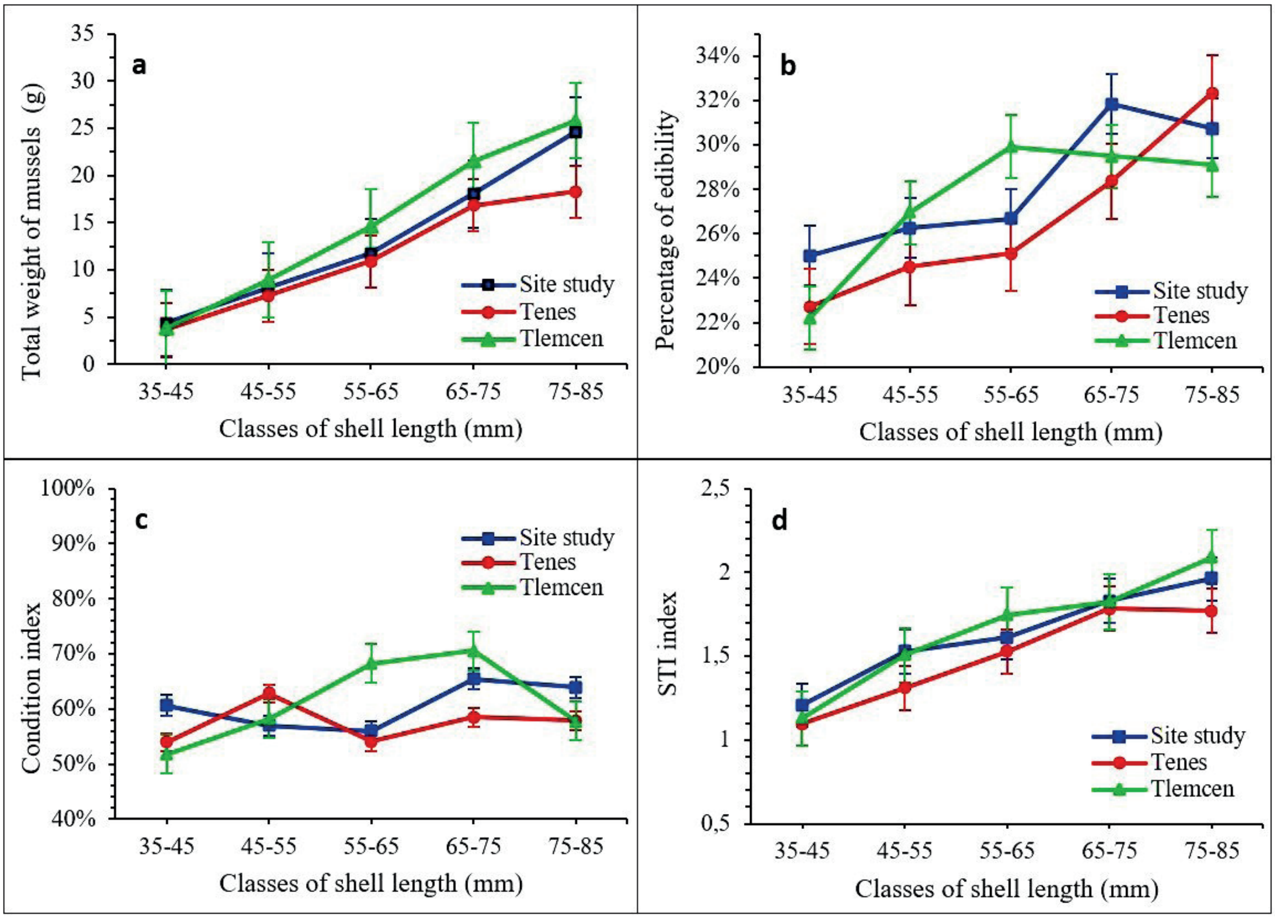

Figure 9

Variation of marketability indices and the total weight of mussels sampled according to spat origin with shell lengths (a: total weight, b: percentage of edibility, c: condition index, d: shell thickness index)

The production cycle of mussels depends on their growth and optimal harvesting conditions (Petersen et al. 2020), including local environmental conditions such as temperature, salinity (Bayne & Worrall 1980; Fuentes et al. 2000; Karayücel & Karayücel 2000; Waite et al. 2005), concentration of food particles (Camacho et al. 1995; Celik et al. 2009; Filgueira et al. 2008; Lök et al. 2007; Waite et al. 2005; Hatzonikolakis et al. 2017), seeding density and farming system design (Drapeau et al. 2006; Ferreira et al. 2007a; Lauzon-Guay et al. 2005; Raman-Nair & Colbourne 2003; Strohmeier et al. 2008). In fact, the mussel density on a rope will decrease as the mussels grow in size and take up more space (Bonardelli et al. 2019). In this study, the final biomass production decreased as the spat size increased. The percentage of biomass lost was greatly compensated for by the gain in biomass for small mussels, followed by a remarkable gain from the medium-sized spat. This stands in contrast to large mussels, in which there was almost no difference between the seeded and harvested weights. The growth rate of the small mussels in suspension was higher than that of the large mussels (Lauzon-Guay et al. 2005) and the growth rate was slower in older mussels (Lauzon-Guay et al. 2005; Lök et al. 2007; Seed 1969). Although smaller mussels may be more sensitive to the effects of desiccation or other stressors occurring during their transfer from harvest to the nursery site (Webb & Heasman 2006; Jenewein & Gosselin 2013) and may have higher losses (Lauzon-Guay et al. 2005), they also have a higher potential for biomass production (Petraitis 1995). The existence of high inter-individual variability in growth is a major problem for aquaculture and positions bivalves as prime candidates for size-based selective breeding programmes to increase the production of shellfish farms (Fernández-Reiriz et al. 2016). Although the difference in overall production between the four spat origin sites was not statistically significant in this study, the variation in the rates of biomass gain and loss was significant depending on the source, showing the best values for the Tlemcen mussels. Mussels from the on-site collection were not affected by a change in their living environment. They experienced the stress of the grow-out process for the first time, after attaching to the collectors of the farm. The spat from the other three sources was placed into water after remaining out of water for more than 24 hours during transport, selection and socking. Transfer-associated factors such as emersion, desiccation, temperature variations and fasting have been shown to affect the fitness, behaviour and subsequent losses of juvenile mussels (Calderwood et al. 2014; Carton et al. 2007; Theodorou et al. 2017, 2018; South et al. 2020). Contrary to our expectations, the mussels from the study site were not the most efficient in terms of biomass yield, though they did compensate with the biomass gained. The biomass loss rate was the highest from this source, testifying to their fragility.

In this study, the Tlemcen mussels – followed by those from Tenes – showed more efficient growth and physiology for a commercial size, reflected by greater variation in the APP compared to the other two sources. This is in agreement with the study by Phillips (2002). The variation in growth can be explained by the nutritional status of the juveniles, as their native environment was very rich in suspended matter, due to artificial feeding and waste from the floating fish cages cultivated near the mussel lines. Thus, food supply seems to be the principal factor that can limit production in suspended culture systems (Babarro & Zwaan 2008; Navarro et al. 1991) absorption efficiencies and metabolic rates. The availability of food and the nutritional status of the mussels have been described as some of the many factors influencing production (Babarro & Zwaan 2008; Clarke 1999). Moreover, growth is also influenced by a genetically determined trait (Prieto et al. 2020). Consequently, growth between populations can vary markedly, even when the individuals are exposed to identical environmental conditions (Prieto et al. 2018). The large variation in APP can be also attributed to the genetic characteristics that make some mussels more efficient and resistant to environmental changes than others. This also may have resulted from adaptation to regional environments in which animals have developed stock-related traits of genetic variation (Camacho et al. 1995; Pace et al. 2006; Wang et al. 2012). As mussels grow, their requirements for limitied resources increase and intraspecific competition becomes more pronounced (Cubillo et al. 2012a).

In this study, the highest APP was recorded for the Ain Tagourait mussels, but this can only be due for some plots where the yield was maximum. On the other hand, the variation in global production of this source has not been efficient compared to others, meaning that inter-individual differences are present even among the same stock origin and size, and that mussel growth can vary despite all breeding and transfer conditions being the same. This hypothesis has been investigated in a few bivalves (Fernández-Reiriz et al. 2016; Tamayo et al. 2011) and is supported by physiological experiments on *Mytilus galloprovincialis* and *Ruditapes philippinarum* (Fernández-reiriz et al. 2016; Tamayo et al. 2011). At the medium seeding size, the biomass yield showed a small variation in gain, between 33% and 15% on average for all sources, in favour of those from the study site. This suggests that medium-sized mussels are less fragile than smaller ones at the same site. Additionally, the resistance was not developed at this size, as it was with the large mussels. This category of large individuals from Tlemcen and Ain Tagourait lost their initial biomass. The production seems to be balanced between the small mussels' fragility and the large ones' resilience and lack of adaption to new environments.

In the present study, a significant difference in the marketability indices, the STI, TW and PE was noted between three sources (the study site, Tlemcen and Tenes), in favour of the Tlemcen mussels, followed by those from the study site. This confirms that certain stocks will be more efficient than others, even at the same site, and that the mussels have as a genetic trait the ability to adapt to changes in the environment when they have good conditions in the larval state. However, the mussels from Tlemcen were genetically more robust and developed genetic plasticity, as they were born in a rich environment under IMTA conditions. They were implemented in the study site and they exhibit better production efficiency, confirmed that mussels in proximity to multiculture farms have more flesh in their shell than those growing on a typical mussel farm, as reported by Chatzivasileiou et al. (2022). The authors indicated that the areas near fish farms may be an exception for the oligotrophic Mediterranean, due to the significant amount of nutrients released from fish cages (Chatzivasileiou et al. 2022). According to Wenne et al. (2022), seascape genetic analyses suggest that a complex mix of environmental variables help explain the genetic variation in *M. galloprovincialis* populations within the Mediterranean Sea, which most likely reflects the complex geological history of formation, isolation and reconnection among the regional sub-basins of the Sea. These authors also analysed one population from the west of Algeria (Oran) and identified it as being intermediate between the two main groups from the Mediterranean Sea and the Atlantic Ocean. As Tlemcen is on the western coast of Algeria, mussels from this area are more likely to have similar characteristics and may be influenced by the Atlantic form of *M. galloprovincialis*, whereas mussels from sites east of Oran – Tenes, Tipaza (the study site) and Ain Tagourait – most likely represent populations of *M. galloprovincialis* that have been influenced by the Mediterranean (Simon et al. 2021; Wenne et al. 2022).

The STI and the marketability indices showed significant differences in the length of individuals between small and medium seeded mussels, in favour of the small spat, and confirmed that growth is faster in small individuals, slowing as size increases. Also, their rapid adaptation to environmental changes makes them more efficient. However, the larger mussels were resistant to a different environment at the beginning of their transfer, especially those in the advanced stage of the reproductive cycle. Stressing them at this stage causes a significant part of their body reserves to be lost. This can be clearly seen in the changes in CI and PE and in the evolution of the TW of the mussels across the initial size categories. Differences in shell morphology – the shape or thickness of bivalve molluscs – are influenced by key environmental parameters such as food competition, substrate type, crowding, temperature, wave impact and the activity of predators (see Alunno-Bruscia et al. 2001; Beadman et al. 2003; Steffani & Branch 2003; Valladares 2010). Some growers use the stress method of shaking socks every month. This method develops resistance in the mussels, which leads to a longer life. This stress slows down the growth in the flesh and encourages the mussels to use their reserves to thicken and harden their shells, as well as to manufacture byssal threads, which reduces the loss rate at the end of the cycle (Personal communication. M. Khoudja, mussel grower in the centre of the Algerian coast).

Capital expenses have not been included in this work (e.g. buildings, boats, vehicles, equipment and land travel), nor have expenses related to licences, taxes, insurance and quality analysis, as they are too variable and depend on the governance of the farm. These expenses should be included by individual producers in order to obtain a true manufacturing estimate. However, our productivity and revenue estimates for each mussel stock have been standardised on the basis of spat supply from a long line of collectors, so that commercial performance is linked to the characteristics of the origin of the stocks and their biological characteristics, density and spat size.

5. Conclusion and perspectives

This study focuses on the aquaculture of *M. galloprovincialis* in the central Algerian coast, and it contributes to the knowledge of mussel farming. After investigating mussel production according to seeding size and spat origin, it was found that production was greatest in the small seeded mussels. Mussel origin is also an important parameter for selecting the optimal stock. Mussels from sites east of Oran – Tenes, Tipaza (the study site) and Ain Tagourait – most likely represent populations influenced by the Mediterranean, in comparison to those from Telemcen, which were influenced by the Atlantic form of *M. galloprovincialis*. They have also developed genetic traits for environmental sensitivity and seem more robust, as they were born in a rich environment under IMTA conditions.

Mussel farming does not seem to be closely monitored, as no strategic management system has been established to ensure efficient cultivation. According to several aquaculture farmers who were asked about the strategy of management, all of them confirmed that they do not perform any studies to follow their production. Their cultivation does not take into account the physiological aspects of the organisms or the factors that influence their growth and productivity. As no data collection or statistical analysis are available at any institution, including the Ministry of Fisheries and Fish Resources, we recommend the creation of a database of aquaculture. As Cultmare is the first farm to analyse the production of each lot of mussels from its beginning, we encourage other farmers to perform this kind of study and to use IMTA methodology, which is suitable for use in the oligotrophic Western Mediterranean. In order to improve knowledge on the biology and production cycle of *Mytilus galloprovinciallis*, it is important to establish a production calendar to better manage mussel farming. It is also recommended to use spat originating near fish farms because of the environmental enrichment in nutrients, which helps ensure that the spat is suitable at the beginning of the mussel production. Moreover, the construction of new hatcheries specialised in spat quality for aquaculture in Algeria is essential to ensure better larval nutrition and optimal production by shellfish farmers. Also, further studies on shell fragility and spat resilience to new environments will complement and enrich the existing knowledge and improve aquaculture practice in Algeria; for instance, we suggest investigating how shaking socks can impact mussel culture and improve shell thickness. This can be performed by studying the structure and molecular composition of the byssus from *M. galloprovencialis* and analysing environmental parameters related to shell thickness and mussel genetic plasticity that act as stressors and positively affect mussel production.

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Conflict of interest

There is no actual or potential conflict of interest concerning this manuscript.

Author contributions

All authors contributed significantly to this work.

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