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Growth performance of Mediterranean Sea species under high temperatures

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Abstract

Diversifying aquaculture in Saudi Arabia with the inclusion of finfish species already reared in the Mediterranean Sea requires a sufficient understanding of the preferences and limits of cultured fish under local conditions. This study was conducted using three finfish species, juveniles (135–155g), meager (*Argyrosomus regius*), European seabass (*Dicentrarchus labrax*), and greater amberjack (*Seriola dumerili*), to assess their growth performance under high temperatures for three-month-long thermal trials. Each species trial was performed in triplicates in a recirculating aquaculture system, while three temperature ranges, 24°C–25°C, 28°C–29°C, and 33°C–34°C, were tested, representing the average temperatures in the Mediterranean and Red Seas. Both meager and European seabass performed similarly between the first two temperatures, indicating that the optimum range lies within that thermal window. Growth performance indicates that it is lower for meager than it is for European seabass. The greater amberjack's growth performance was similar for the first two temperatures. The temperature of tolerance was 33°C for all species. The species appeared to have similar thermal tolerance with notable differences in the preferable temperature for optimum performance. The findings of this study can be used to improve the growth performance and feed efficiency of Mediterranean species farming in temperature ranges ranging from 24°C–28°C.

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Introduction

Fish culture is becoming essential for aquaculture due to the sustainable economic development and food security in Saudi Arabia. Moreover, mariculture is more suitable than freshwater fish because of the limiting factor policies and the natural environment (Young et al. 2021a; Young and AlMoutiri 2022). Therefore, the Saudi Arabian fisheries authority (Ministry of Environment, Water, and Agriculture) has been promoting coastal cage culture and mariculture to sustain national policies' development and food security (Young et al. 2021a; Dickson 2022; Young and Shaikhi 2022).

Currently, the major mariculture fish species in Saudi aquaculture industries are Asian sea bass (*Lates calcarifer*), gilthead bream (*Sparus aurata)*, and Sabaki tilapia (*Oreochromis spilurus*) (Food and Agriculture Organization of the United Nations, 2022). Because of potential market demand, fisheries authority selected meager (*Argyrosomus regius*), European seabass (*Dicentrarchus labrax*), and greater amberjack (*Seriola dumerili*) as target species of the mariculture development projects, while the commercial culture of these species has not been developed in Saudi Arabia (Young et al. 2021b; Dickson 2022; Young et al. 2022). A profitable enterprise has been established for the meager European seabass, and greater amberjack, in Mediterranean countries, including Spain, Egypt, France, Italy, Morocco, Turkey, and Greece, exploiting the great farming potential of those species. In contrast, in Saudi Arabia, the fingerling source of those species depends on imports from Turkey and European countries (Young et al. 2021b; Young and Shaikhi 2022). Moreover, mariculture in Saudi Arabia faces several challenges, such as high-water temperature and salinity (Saunders et al. 2016; Young et al. 2021b; Young and AlMoutiri 2022). High water temperatures have limited the culture species and periods in Saudi Arabia (Young and AlMoutiri 2022; Young et al. 2022; Young and Shaikhi 2022). With its long coastline and different climatic conditions, Saudi Arabia is particularly advantaged in developing mariculture through warmer waters to improve productivity, particularly in the winter. However, most Mediterranean species fish farms are in northern Saudi Arabia to avoid high water temperatures (**Figure 1**). Moreover, On the coastline of Saudi Arabia, the salinity of seawater is approximately 42‰ – 45‰ (Saunders et al. 2016; Young and Shaikhi 2022).

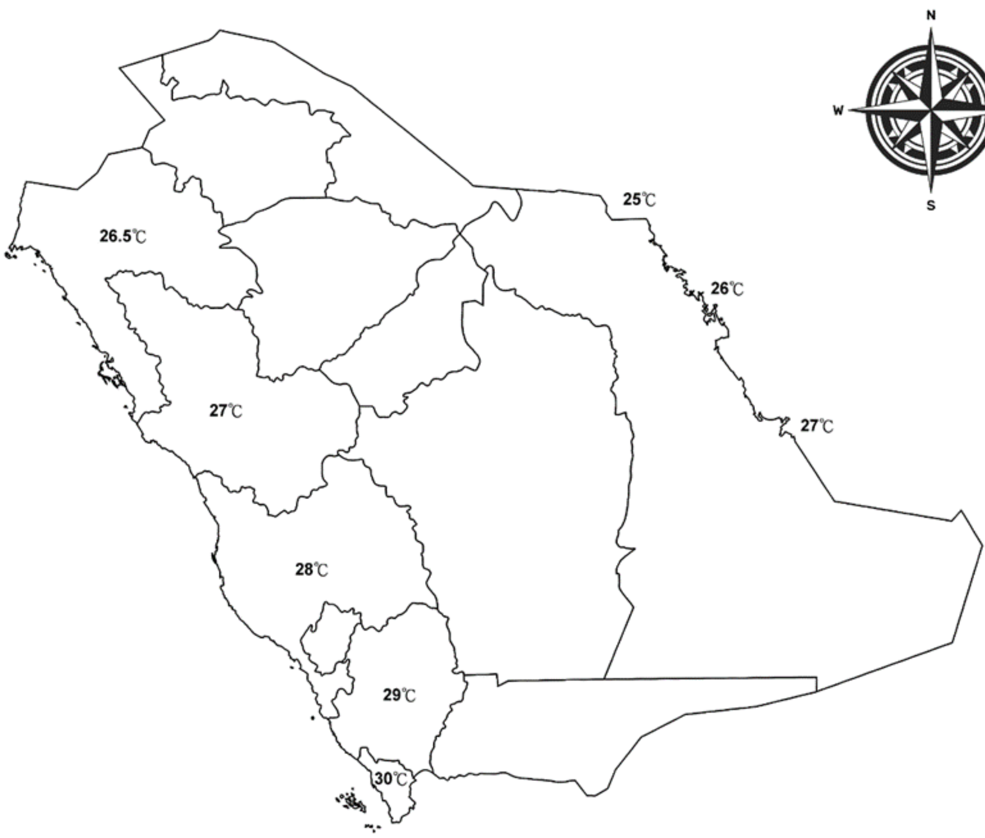

Figure 1 The average water temperature of the location of primary aquaculture companies in Saudi Arabia. Source: Young and Shaikhi, 2022.

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Although Mediterranean Sea finfish species are becoming important in Saudi Arabia's aquaculture production because of diversifying aquaculture, the farming sector requires a sufficient understanding of the species' thermal preferences and limits. More information must be provided regarding the growth performance of Mediterranean Sea finfish species under prolonged exposure to high temperatures. Related research on the growth performance of Mediterranean Sea finfish species to temperature is mainly focused on investigating short-term responses (<three months) and fingerling (4–5 g) stage (Abbink et al. 2012; Ozolina et al. 2016; Kir et al., 2017; Islam et al. 2020). Against this background, this study was designed to understand the temperature tolerance and growth performance of sea cage farming under Red Sea conditions.

Materials and Methods

Experimental design. This study was conducted from April 2019 to February 2020. Juveniles of meager, European seabass, and greater amberjack, were collected directly from the local farm. In April 2019, juveniles were transferred from the scale farm to the facilities. The fish were transferred in oxygenated 2-m^3 containers, and antibiotic treatment (oxytetracycline) was administered during transit. Fish were subjected to a freshwater bath (ten minutes) and distributed into nine experimental tanks upon arrival. The temperature in the tanks was adjusted to the ambient temperature of farming, which was 23°C. For the next week, fish behavior was monitored, mortality was removed, and feed was provided by hand according to fish appetite. Once fish showed signs of normal feeding behavior, they were anesthetized (clove oil, 10 ppm), individually measured for the weight (135–155 g) and length (21.8- 22.3cm) and re-distributed into the tanks. In three-month-long thermal trials, 59 of meager, 62 of European seabass, and 49 of greater amberjack were placed in each tank.

Onwards temperature per treatment was raised at a rate of 0.7°C daily until the experimental temperatures of 24°C (T24), 28°C (T28), and 34°C (T34) were reached via electronic thermo-controller unit (Omega, Taiwan), representing the average temperatures in the Mediterranean and Red Sea. Each treatment was performed in triplicate tanks (2 m^3 fiber reinforced plastics tank), all connected to a recirculating aquaculture system (RAS), following the established experimental protocol in fish growth studies (Thorarensen et al. 2015).

The fish were fed by hand twice daily until visual satiation, and any uneaten feed was collected and measured at the end of the day. A commercial feed with 45% crude protein and 16% crude fat was provided (IRIDA, Greece). The photoperiod was adjusted to a 12L:12D hour cycle, and water renewal in the RAS ranged from 10% to 20% daily. Temperature and dissolved oxygen (DO) in the tanks were monitored continuously using automated loggers (Hach Lange SC1000, Colorado, United States). In contrast, additional oxygen was provided in cases of oxygen saturation that dropped 90% below. Water quality parameters, including pH, ammonia, nitrite, and nitrate, were monitored weekly through manual measurements using a parameter (Hach Lange HQ40D, Colorado, United States) and photometer powder pillows (Hach, Colorado, United States). These parameters did not exceed the standard safe limits for the trial duration. The salinity in the rearing tanks was 41‰–42‰, the pH was 7.27–7.30, and the dissolved oxygen level was 6.10–7.10 mg/l. The tanks were kept clean by flushing drain valves daily and siphoning uneaten feed and feces from the tank bottom.

Sampling and growth parameters. Samplings occurred monthly, leading to three samplings at 30, 60, and 90 d after each experimental group reached their respective experimental temperature. The growth parameters were determined as follows:

The number of survivors determined the percentage survival rate at the end of the experiment × 100/initial number stocked.

Average daily weight gain (ADG) = (final weight g – initial weight g) / duration (in days)

The feed conversion ratio (FCR) was determined by the feed weight/fish weight gain.

Statistical analysis. Data were analyzed using the IBM Predictive Analytics Software (PASW) 18.0 (IBM, USA) through ANOVA and Duncan's multiple range test for post hoc comparisons of mean values. $P < 0.05$ was considered to be significant.

Results

Regarding the growth performance of the meager, the temperature significantly affected the specific growth rate ($P < 0.05$), with all treatments being significantly different from each other. The T34 was consistently different from the other groups in all three samplings, and the fishes performed poorly, with the growth rate marginally above zero for the first sampling and exhibiting negative values in the second and third samplings (**Table 1**).

There were signs of slow acclimation to temperature change, as reflected by the low appetite for all treatments during the first trial month of the European seabass (**Table 2**). Weights maintained a linear increase over the third month for T24 and T28, with insignificant differences between the T24 and T28 groups. As for T34, the growth remained unsubstantial but positive in the third month (**Table 2**). Regarding feed efficiency, during the first month, the low growth of T24 and T28 treatments caused high FCR values, whereas it was negative for T34 due to the weight loss observed for that treatment.

Overall, treatments T24 and T28 showed comparable growth, while the fishes in T34 exhibited signs of growth retardation of the greater amberjack. Yet, significant differences appeared in the growth pattern between T24 and T28. For both treatments, growth was appreciable, with the fish tripling in size during the three months and reaching a final weight of approximately 500 g (**Table 3**).

Table 1 The survival rate and growth performance of meager at different temperature ranges (24°C–34°C)

	1st month			2nd month			3rd month		
	T24	T28	T34	T24	T28	T34	T24	T28	T34
Weight (g)	233± 5.3^{a}	238.7±3.1^{a}	154.2±4.4^{b}	310.9±7.9^{a}	294.7±9.9^{a}	143.4±11.0^{b}	379.4±5.4^{a}	318.1±5.3^{b}	141.1±9.0^{c}
ADG (d^{-1})	2.8±0.06^{a}	2.96±0.01^{a}	0.05±0.06^{b}	2.68±0.13^{a}	2.42±0.14^{a}	−0.1±0.18^{b}	2.56±0.04^{a}	1.87±0.06^{b}	−0.01±0.14^{c}
FCR	1.02±0.14^{a}	1.30±0.1^{b}	−2.88±2.18^{c}	1.10±0.10^{a}	1.90±0.30^{b}	−0.10±0.02^{c}	1.31±0.20^{a}	2.30±0.40^{b}	−1.26±3.42^{c}
Survival (%)	100^{a}	100^{a}	78.7 ± 14^{b}	100^{a}	100^{a}	34.7 ± 6^{b}	100^{a}	100^{a}	11.3 ± 4^{b}

In each column, different letters indicate a significant difference ($P < 0.05$).

Table 2 The survival rate and growth performance of European seabass at different temperature ranges (24°C–34°C)

	1st month			2nd month			3rd month		
	T24	T28	T34	T24	T28	T34	T24	T28	T34
Weight (g)	137.3±1.4^{a}	139.7±1.4^{a}	116.8±1.3^{b}	173.7±5.4^{a}	179.3±4.3^{a}	119.7±3.0^{b}	208.3±9.8^{a}	217.5±6.3^{a}	127.5±0.9^{b}
ADG (d^{-1})	0.0±0.1^{a}	0.1±0.1^{a}	−0.4±0.1^{b}	1.2±0.2^{a}	1.3±0.1^{a}	0.1±0.0^{b}	1.0±0.1^{a}	1.3±0.1^{b}	0.3±0.1^{c}
FCR	7.5±0.12^{a}	6.4±0.2^{b}	−2±0.8^{c}	1.7±0.3^{a}	1.9±0.2^{a}	13.7±5.6^{b}	2.0±0.0^{a}	1.9±0.1^{a}	7±2.8^{b}
Survival (%)	97±0^{a}	97±1^{a}	88±1^{b}	97±0^{a}	97±1^{a}	52±9^{b}	97±0^{a}	97 ±1^{a}	49±1^{b}

In each column, different letters indicate a significant difference ($P < 0.05$).

Table 3 The survival rate and growth performance of greater amberjacks at different temperature ranges (24°C–34°C)

	1st month			2nd month			3rd month		
	T24	T28	T34	T24	T28	T34	T24	T28	T34
Weight (g)	300.8±17.0^{a}	249.9±9.8^{b}	184.1±6.1^{c}	394.7±30.7^{a}	342.4±14.4^{a}	197.9±7.4^{b}	490.1±67.0^{a}	499.1±16.1^{a}	213.3±7.0^{b}
ADG (d^{-1})	4.2±0.3^{a}	2.3±0.2^{b}	3.6±0.7^{c}	3.1±0.7^{a}	3.3±0.3^{a}	0.5±0.2^{b}	3.2±1.1^{a}	5.2±0.6^{b}	0.5±0.1^{c}
FCR	1.3±0^{a}	2.1±0.2^{b}	3.6±0.7^{c}	2.1±0.4^{a}	2.2±0.2^{a}	6.0±0.9^{b}	2.2±0.4^{a}	1.8±0.3^{b}	5.7±1.2^{c}
Survival (%)	100^{a}	100^{a}	52^{b}	100^{a}	100^{a}	45.2 ± 1^{b}	100^{a}	100^{a}	30 ± 4^{b}

In each column, different letters indicate a significant difference ($P < 0.05$).

Discussion

Overall, the husbandry findings of the trial suggest that meager perform similarly at 24°C, while the temperature of 32°C–34°C is sharply close to the upper end of its temperature tolerance range. Fountoulaki et al. (2017) reported growth rates of 0.5% daily and FCR values greater than 2 for juvenile meager grown in marine under natural seasonal, photoperiod, and temperatures ranging from 16°C–26°C. Therefore, the lower biological performance compared with our findings for 24°C could be attributed to the low winter temperatures, which are suboptimal for growth. According to Kir et al. (2017), the optimal temperature for juvenile

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meager is between 26°C and 30°C. Our findings suggest that the optimum growth temperature is in the 24°C–29°C area, which is most likely closer to the lower end of that range. Indicative of that are the long-term effects of temperature on treatment at 29°C. Although growth was similar between 24°C and 29°C during the first month, the performance of the 29°C group eventually deteriorated during the three months. Therefore, although meagers can survive and grow well at high temperatures, prolonged exposure to them has an additive effect that reduces their overall performance. Such limitations were particularly pronounced at 34°C, where appetite was significantly reduced, and growth ceased, reflecting the high energetic costs in that temperature for basic metabolism. Furthermore, mortality was particularly high at 34°C.

The husbandry findings of the trial suggest that the European seabass performs similarly at 24°C and 29°C. In comparison, the 32°C–34°C are sharply close to the upper end of its temperature tolerance range. Considering the initial trial phase, which included the gradual rising of temperatures (1°C daily), it appears that acclimation to the experimental conditions, particularly under a gradual temperature increase, is a slow process for European seabass and may require up to a month. At both 24°C and 29°C, the growth performance was appreciable, with no substantial difference in growth and FCR between the two groups. For these treatments, ADG ranged from 1–1.2 d^{-1} during the trial, falling within the range commonly reported for the European seabass in temperate climates. For European seabass of similar size, Maricchiolo et al. (2011) reported a comparable specific growth rate ranging between 0.5 and 1.1 d^{-1} for the summer months (23°C–25°C), while for juveniles reared at 25°C, Yilmaz et al. (2019) reported an FCR of 1.4.

In our study of European seabass, T28 did not differ in their main husbandry parameters. There was a dramatic deterioration of the overall biological performance at the highest temperatures of T34. Based on the current understanding of the thermal optimum, growth performance is expected to be the highest for a narrow temperature range that falls within a species-specific optimal temperature range. Growth progressively declines outside this normal range and eventually ceases completely when critical temperature thresholds, often noted as critical temperatures are attained. Past these thresholds, the organism relies mostly on anaerobic processes to fuel metabolism, resulting in weight loss and eventually death if exposure to such temperatures is prolonged (Pörtner 2010; Pörtner et al. 2017). Given that growth for T24 and T28 did not differ, this indicates that the temperatures of 24°C and 29°C lay bilaterally to the optimum temperature, which should be located between them. This comes in parallel with the findings of Person-Le Ruyet et al. (2004), who reported maximum growth for juvenile European seabass at 26°C–27°C.

The overall husbandry findings of the trial suggest that greater amberjack has a high potential for growth at high temperatures (29°C). In comparison, temperatures above 33°C are sharply close to the upper end of its temperature tolerance range. Fish grew well at both T24 and T28 at a typical rate for the species. Existing literature suggests that temperatures exceeding 26°C may promote optimal growth for the species. Particularly at 26°C, greater amberjack grows fast, from 141 to 384 g in only two months (Fernandez-Montero et al. 2018). A similar weight gain was observed for T28 in this study. Similar findings are reported for the optimum temperature of the congeneric *Seriola lalandi* (Abbink et al. 2012). However, while the fishes reached the same final size at both T24 and T28, there were notable differences in their growth pattern, requiring further investigation. Temperature trials on other species have shown that fish have considerable capacity for growth compensation when transferred from suboptimal to optimal conditions. Such trials have predominantly explored how low temperatures can suppress growth temporarily in a way that can be reversed once the fish are subjected to higher temperatures (Peng et al. 2017). While the opposite is unreported, findings of this trial suggest that g. amberjack can exhibit a form of growth compensation at higher temperatures. Although initially, the fish grew the fastest at 24°C, by the end of the trial, the growth rate at T28 surpassed that of T24, reaching the same final size. This suggests that the temperature of 29°C constitutes a challenging regime for greater amberjack, requiring substantial acclimation time for the long-term regulation of physiological mechanisms. However, once this is achieved, appreciable growth is exhibited. Further analysis of the physiological variables is required to shed light on this process.

Consequently, the species appeared to have similar thermal tolerance to the upper end of the tolerance range but with some notable differences in the preferable temperature for optimum performance. This became evident from the husbandry findings and was further corroborated by the growth performance analysis. Both meager and European seabass performed similarly between 24°C and 29°C, indicating that the optimum range lies within that thermal window. However, growth and FCR indicate that it is lower for meager than for the European seabass. The greater amberjack's growth performance was similar for the first two temperatures. Yet, the high growth rate at 29°C during the second and third month of the trial suggest a high capacity for compensatory growth and the potential to achieve appreciable growth in high-temperature regimes, unlike the other species. The findings of this study can be used to improve the growth performance and feed efficiency of Mediterranean species farming in temperature ranges ranging from 24°C–28°C, even where sea surface temperature varies during summer and winter. These findings can guide future research and aquaculture development in the higher temperature region.

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