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RESEARCH ARTICLE

The Growth and Survival of the European Lobster (*Homarus gammarus* Linnaeus, 1758) Larvae and Juveniles in a Recirculating System

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Abstract: In this study, the growth and survival of *H. gammarus* larvae and juveniles were investigated in two different consecutive trials. In the first trial, newly hatched lobster larvae were raised in 100 liter cylindro-conical tanks in triplicate. Each tank was stocked with 150 lobster larvae (a total of 450 larvae) and the growth and survival of larvae at the end of stage IV were determined. In the second trial, the growth and survival of juvenile lobsters fed on three different diets were determined for a period of 102 days using an integrated recirculating system with 10% daily water renewal. For this purpose, a total of 3 different diets including a mollusk based (M), a crustacean based (C) and a commercial seabass diet (L) were prepared. A total of 135 juvenile lobsters, 45 for each treatment were used for the juvenile growth trial. At the end of the larval growth experiment, the mean carapace and total length of Stage IV larvae were 5.255±0.052 mm and 13.027±0.486 mm, respectively, with no significant differences within tanks ($p>0.05$) and the mean survival rate of lobsters was 13.11%. In the juvenile growth trial, the highest carapace length was 1.371±0.023 cm in treatment C, followed by 1.251±0.039 cm and 1.187±0.095 cm in treatment M and L, respectively. At the end of 102 days, the mean survival rates of juvenile lobsters were 98.7%, 80% and 53.3% in treatments C, M and L, respectively. The most successful diet for juvenile lobsters, with respect to growth and survival, was the crustacean based diet. The findings of this study provide information to help improve the growth and survival rates of larval and juvenile *H. gammarus* in captivity.

Anahtar kelimeler:

Homarid ıstakoz
Decapod
Kanibalizm
Zoea larvası
Yaş yemler

Avrupa Istakozu (*Homarus gammarus* Linnaeus, 1758) Larva ve Jüvenillerinin Kapalı Devre Sistemde Büyüme ve Hayatta Kalmaları

Öz: Bu çalışmada, *H. gammarus* larva ve jüvenillerinin büyüme ve hayatta kalma oranları 2 farklı çalışma ile araştırılmıştır. İlk denemede yumurtadan yeni çıkmış ıstakoz larvaları biyolojik filtrasyon içeren kapalı devre bir sisteme entegre 100 litre hacminde 3 adet silindir-konik tank kullanılmıştır. Her bir tanka 150 adet yumurtadan yeni çıkmış larvanın kullanıldığı bu çalışmada (toplam 450 larva) larvaların büyüme ve hayatta kalma oranları IV evre sonuna kadar tespit edilmiş ve deneme larvalar IV. evreye ulaşınca sona erdirilmiştir. İkinci denemede farklı yemlerin jüvenil ıstakoz büyümesi ve hayatta kalması üzerindeki etkileri incelenmiştir. Büyüme denemesine larvalar bentik aşamaya geçtikleri IV. evreden sonra başlanmıştır. Bu amaçla mollusk (M) veya crustacea (C) içeren 2 farklı yaş yem ile ticari levrek yemi (L) olmak üzere toplam 3 farklı yem kullanılmıştır. Her bir uygulama için 45 adet olmak üzere toplamda 135 adet ıstakoz kullanılmıştır. Larval yetişiricilik denemesinde IV. evre larvalarının ortalama karapaks uzunluğu ve toplam uzunluğu sırasıyla 5,255±0,052 mm ve 13,027±0,486 mm olarak tespit edilmiş ve tanklar arasında karapaks boyu ve toplam boy bakımından istatistiksel açıdan önemli bir fark bulunmamıştır ($p>0,05$) ve ortalama hayatta kalma oranı %13,11 olarak bulunmuştur. Istakoz jüvenillerinin büyütme denemesinde en büyük karapaks boyu 1,371±0,023 cm ile C ile beslenen grupta bulunurken, M ve L ile beslenen gruplarda karapaks uzunluğu sırasıyla, 1,251±0,039 cm ve 1,187±0,095 cm arasında değişiklik göstermiştir. 102 gün süren besleme çalışması sonucunda jüvenil ıstakozların ortalama hayatta kalma oranları, C yemiyle beslenenlerde %98,7, M yemiyle beslenenlerde %80 ve L yemiyle beslenenlerde %53,3 olarak bulunmuştur. Bu çalışmada elde edilen bulgular, *H. gammarus* larva ve jüvenillerinin yetiştiricilik şartları altında hayatta kalma ve büyüme oranlarının arttırılmasına yönelik katkı sağlamaktadır.

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Introduction

In Turkey, wild harvests of the European lobster, *H. gammarus*, have dropped considerably during the last two decades and amounted to 1.8 tons in 2022, a substantial drop from 25 tons in 2003 and 15 tons in 2008 (TÜİK, 2023 www.tuik.gov.tr). However, it is believed that lobster landings are much higher as the commercial lobster fishery in Turkey is mostly by scuba-diving and trammel nets therefore, the majority of lobster catches remains unreported. On the other hand, the development of larval culture methods for *H. gammarus* and their subsequent release to suitable habitats have provided a substantial supply of lobsters to the diminishing wild populations. In the last three decades, restocking programs of *H. gammarus* in Europe through hatchery production has become a successful model (Bannister et al., 1994; Agnalt et al., 2004). For example, on the east coast of England, released lobsters survived in the wild for up to eight years and have been caught in traps by commercial fishermen, with survival estimates of 50-84% (Bannister et al., 1994). In 1998, in southwestern Norway, following a restocking program up to 50-60% of the landings belonged to released lobsters contributing to the reproduction of the natural stocks (Agnalt et al., 2004). A similar management plan for diminishing native stocks of this species can be adopted for the Turkish seas. The recent establishment of mussel farms in northwest Turkey, i.e. in the Sea of Marmara and the Çanakkale Strait, may also provide a refuge by providing a valuable food source for the released lobsters in a no-fishing zone. In addition, in the last decade, reports are promising both for the land-based and sea-based culture systems for the commercial aquaculture of the European lobster (Drengstig and Bergheim, 2013; Daniels et al., 2015). There is currently no commercial-scale hatchery production of *H. gammarus* in Türkiye and therefore, efforts are required for developing hatchery culture methods for restocking purposes and to investigate the aquaculture potential of *H. gammarus*. Land or sea-based lobster aquaculture in Turkish waters may be advantageous due to relatively higher temperature regime throughout the year compared to northern climates.

Although well defined in the literature (Beard et al., 1985; Nicosia and Lavalli, 1999; Fiore and Tlusty, 2005; Ellis et al., 2015; Powell et al., 2017; Hinchcliffe et al., 2022), larval and juvenile lobster culture is still problematic due mainly to low survival rates during zoea stages, lack of effective grow-out systems, high production costs and slow growth (Daniels et al., 2015; Powell et al., 2017). Typically, larvae are reared in 60-100 L cylindro-conical tanks with an upwelling flow pattern using enriched *Artemia* or other plankton types with a stocking density of 50 larvae/L (Hinchcliffe et al., 2022). Lower stocking densities did not improve survival rates (Hinchcliffe et al., 2022; Önal and Baki, 2021). Survival in commercial hatcheries range between 5-20% (Hinchcliffe et al., 2022). and therefore, there is still room to develop successful and standardized methods for larval rearing.

A successful diet development is a crucial part of lobster grow-out operations for economic production. However, information on the nutritional requirements of the European lobster is relatively limited compared to the American lobster, *H. americanus* and spiny lobsters (Goncalves et al., 2020; Hinchcliffe et al., 2020). Although formulated dry diets offer several advantages such as reduced feeding and labor costs, nutritional consistency and sustainable production (Powell et al., 2017), wet feeds (fresh or frozen) such as mussel, krill and squid are preferred over dry diets for *H. gammarus* grow-out (Hinchcliffe et al., 2022). Efforts toward developing dry diets for juvenile European lobsters have resulted in lower growth and/or survival compared to wet or moist diets. For example, growth and survival of *H. gammarus* post-larvae fed on wet shrimp feed were significantly higher than those fed on dried feed ingredients (Hinchcliffe et al., 2020). Similarly, growth of *H. gammarus* juveniles were inferior when they were fed dry, formulated feeds containing 38.5-49.7% protein, 8.5-23.3% lipid and 20.97-34.69% carbohydrate compared to a krill control diet (Goncalves et al., 2020). High protein requirements (50%), along with benefits of carotenoids and chitin supplementation for better growth, survival and wild-type coloration in *H. gammarus* juveniles have been reported (Goncalves et al., 2020; Goncalves et al., 2022; Hinchcliffe et al., 2022). Further studies are required to elucidate nutritional requirements and develop standard feeding protocols for better lobster grow-out practices. Despite the obvious advantages of a formulated pelleted food in lobster culture, a formulated wet diet that supports the growth and survival of all stages of lobsters is still relevant for shedding light on the nutritional requirements and successful grow-out of lobster juveniles.

This study aims to investigate the growth and survival of *H. gammarus* larvae and juveniles in two consecutive trials. In the first trial newly hatched larval lobsters were cultured in 100 L cylindro-conical tanks with low stocking densities. In the second trial, early juveniles (stage V-X) were cultured using locally available feed ingredients. Local supply of feed sources is important in terms of sustainable production of lobsters. For this purpose, the performance of a high protein commercial seabass feed was compared to that of two wet diets containing either crustaceans or mollusks which are locally available. An important objective of the present study is to develop a feeding protocol that will result in high growth and survival rates of juvenile lobsters which will be an important roadmap for future grow-out studies.

Material and Methods

Experimental animals

The experiments were carried out in the Marine Resources Research Laboratory, Faculty of Marine Sciences and Technology, Çanakkale Onsekiz Mart University. (Dardanos, Çanakkale, Türkiye). Larvae were obtained from a single wild-caught ovigerous female caught by commercial fishermen using trammel nets in February 2022. Two experiments were carried out to

determine the growth and survival rates of lobster larvae and juveniles. Water quality parameters were measured daily and included dissolved oxygen, pH, salinity and ammonia (NH_3).

Larval growth and survival experiment

Larvae were reared in a recirculating system, containing 100 L cylindro-conical tanks and a biofilter. Aeration was supplied with air stones to prevent larval settlement on the bottom of tanks and water stratification. The experiment was carried out in triplicate and 150 larvae were added to each tank corresponding a stocking density of 1.5 larvae/L. Densities <20 larvae/L can be considered as low density compared to typical higher stocking densities (>50 larvae/L) used in commercial lobster culture (Hinchcliffe et al., 2022). Larvae were fed with *Artemia* nauplii enriched with RotiGrow OneStep (Reed Mariculture, USA) for a period of 24 h after hatching. *Artemia* nauplii were maintained at a density of 3-5 individuals/ml during the day and no feeding was given between 18:00-09:00. Lighting was ambient with no overhead illumination. Fresh seawater exchange rate was 10% daily. Growth was monitored for each stage by measuring total length (TL) and carapace length (CL). The experiment was terminated once all larvae reached stage IV.

Juvenile growth and survival experiment

In a second experiment, growth and survival of juveniles fed on 3 different diets were determined for a period of 102 days. For this purpose, a crustacean based diet (C), a mollusk based diet (M) and a commercial seabass pellet feed (L) were used. Diets C and M were wet diets (moisture content > %60). Diet M composed of 50% mussel meat, 30% seabass pellet feed and 20% gelatin (w:w). Diet C only composed of 80% crustaceans and 20% gelatin. All ingredients were mixed together in a blender to form a wet paste and bound with gelatin. Wet diets were preferred over dry diets as preliminary experiments indicated higher acceptance of wet diets by lobster juveniles. Only larvae that reached stage IV within 5 days were pooled and used. Juvenile lobsters were kept separately to prevent cannibalism. For the growth study, juveniles were transferred to plastic boxes with 15 individual 4x6 cm compartments. Treatments were randomly assigned to each box (15 lobsters per box) with three replicate per treatment corresponding to a total of 45 juvenile lobsters per treatment. Juvenile lobsters were randomly allocated to compartments and allowed to acclimate for 2 days. Growth was monitored periodically (day 1, 18, 31 and 102) by measuring TL and CL throughout the experimental period. Daily ration was added to each compartment and the juvenile lobsters were allowed to feed for 4 hours. Uneaten feed was then removed from each container. The proximate nutritional compositions of diets are given in Table 1.

Table 1. The proximate nutritional compositions (%) of diets used in the juvenile grow-out experiment. C: crustacean based diet, L: seabass pellet, M: mollusc based diet

Diet	Protein	Lipid	Ash	Moisture
C	36.94±0.60	20.26±0.16	31.15±0.17	76.78±0.60
L	44.86±5.63	19.92±0.88	7.36±0.03	7.56±0.33
M	48.81±0.54	16.48±0.36	7.30±0.03	73.39±1.44

Statistical analysis

Data were analyzed using the statistical software package IBM SPSS Statistics for Windows (Version 19, IBM, Corp., USA). The suitability of data for ANOVA was checked by Bartlett's test for homogeneity. The growth and survival rates of lobsters were analyzed by ANOVA. Differences in growth and survival among treatments were compared using Tukey's HSD multiple range test ($p<0.05$).

Results

Larval growth and survival

Water quality parameters during the experimental period were as follows: Temperature ranged between 17 - 19.2 ºC; dissolved oxygen 7.8-8.3 ppm and salinity 32±1 ppt. NH_3-N levels were below 0.1 ppm.

The carapace and total length of larvae are given in Table 2 and 3. The initial carapace and total length of larvae were 2.602±0.157 mm and 8.094 ±0.118 mm, respectively, with no significant differences between tanks ($p>0.05$). Stage II larvae had a carapace and total length of 3.404±0.116 mm and 9.746±0.252 mm, respectively. Stage III larvae had a carapace and total length of 3.404±0.116 mm and 9.746±0.252 mm, respectively. The mean carapace and total length of Stage IV larvae were 5.255±0.052 mm and 13.027±0.486 mm respectively, with no significant differences between tanks.

The highest growth rate in CL was observed when larvae transformed from stage I to stage II (Table 2). Subsequent stages had lower growth. Changes in carapace length of larvae between stages I-II, II-III and III-IV were %30.8; %16.8 and %32.2%, respectively. Changes in TL were lower than those for CL (Table 3).

The survival rates of larvae at the end of the experiment differed between the tanks with a mean survival of 13.11%. Survival rates were 16.0, 15.3 and 8.0% for tank 1, tank 2 and tank 3, respectively.

Table 2. Changes in carapace length of lobster larvae at different stages

Stage	Tank 1	Tank 2	Tank 3	Mean ± SE
I	2.667±0.22	2.716±0.14	2.423±0.18	2.602 ±0.157
II	3.358±0.17	3.536±0.12	3.319±0.25	3.404±0.116
III	3.744±0.10	3.883±0.11	4.299±0.24	3.975±0.288
IV	5.299±0.28	5.197±0.22	5.269±0.16	5.255±0.052

Table 3. Changes in total length of lobster larvae at different stages

Stage	Tank 1	Tank 2	Tank 3	Mean ± SE
I	8.082±0.26	8.218±0.14	7.983±0.10	8.094 ±0.118
II	9.614±0.32	10.037±0.25	9.587±0.60	9.746±0.252
III	10.332±0.36	10.401±0.33	11.102±0.28	10.612±0.426
IV	13.012±0.69	12.548±0.48	13.520±0.58	13.027±0.486

Juvenile Growth and Survival

Water quality parameters during the experimental period were as follows: Temperature ranged between 17.0 - 19.5 ºC; dissolved oxygen 6.0-6.9 ppm and salinity 32±1 ppt. NH_3-N levels were below 0.1 ppm.

The overall mean initial carapace and total length of larvae were 0.545±0.007 cm and 1.466±0.018 cm, respectively, with no significant differences between treatments. Changes in carapace and total length of juvenile lobsters are given in Table 4.

There were significant differences between treatments 18 days after the start of the experiment (ANOVA; p = 0.0065). The lowest carapace length was 0.775±0.008 cm in treatment L which was significantly lower than that of treatment C (Tukey HSD test; p<0.05). There was no significant difference between treatments M and C with CL of 0.818±0.018 cm and 0.856±0.028 cm, respectively (Tukey HSD test; p>0.05).

There were significant differences between treatments 31 days after the start of the experiment (ANOVA; p = 0.0004). The lowest carapace length was 0.972±0.004 cm in treatment L. Treatment C had the highest CL of 1.030±0.013 cm which was significantly higher than those of other treatments (Tukey HSD test; p<0.05).

There were significant differences between treatments 102 days after the start of the experiment (ANOVA; p = 0.048). The highest mean CL was 1.347±0.023 cm in treatment C, followed by 1.253±0.039 cm and 1.251±0.039 cm in treatment L and M. The CL of treatment C was significantly higher than that of treatment L (Tukey HSD test; p<0.05), but there was no significant difference between treatment C and M (Tukey HSD test; p>0.05).

Table 4. Changes in carapace (CL) and total length (TL) of lobster juveniles fed with 3 different diets. R: Replicate; C: crustacean based diet, L: seabass pellet, M: mollusc based diet. Letters denote significant differences (p<0.05)

Day	T	R1		R2		R3		Mean CL	Mean TL
		CL	TL	CL	TL	CL	TL	± SE	± SE
1	C	0.517	1.472	0.524	1.481	0.589	1.493	0.543 ±0.040^{a}	1.482 ±0.011^{a}
	L	0.543	1.467	0.561	1.496	0.512	1.448	0.539±0.025^{a}	1.470±0.024^{a}
	M	0.576	1.461	0.547	1.454	0.533	1.423	0.552±0.022^{a}	1.446±0.020^{a}
18	C	0.878	1.863	0.825	1.854	0.866	1.848	0.856±0.028^{b}	1.855±0.008^{a}
	L	0.784	1.793	0.771	1.745	0.769	1.734	0.775±0.008^{a}	1.757±0.031^{b}
	M	0.798	1.769	0.831	1.818	0.825	1.789	0.818±0.018^{b}	1.792±0.025^{b}
31	C	1.040	2.289	1.015	2.303	1.034	2.375	1.030±0.013^{b}	2.322±0.046^{a}
	L	0.968	2.147	0.972	2.166	0.976	2.185	0.972±0.004^{a}	2.166±0.019^{b}
	M	0.983	2.119	0.987	2.123	0.992	2.136	0.987±0.005^{a}	2.126±0.009^{b}
102	C	1.325	2.809	1.344	2.822	1.371	2.836	1.347±0.023^{b}	2.822±0.014^{a}
	L	1.269	2.581	1.209	2.518	1.282	2.591	1.253±0.039^{a}	2.563±0.040^{b}
	M	1.210	2.511	1.256	2.568	1.288	2.608	1.251±0.039^{ab}	2.562±0.049^{b}

There were significant differences in the TL of juveniles between treatments after 18 days (ANOVA; P=0.0061). The highest TL was 1.855±0.008 cm in treatment C, followed by 1.792±0.025 cm and 1.757±0.031cm in treatment M and treatment L, respectively. Total length of larvae in treatment C was significantly higher than those of treatments M and L (Tukey HSD test; $p<0.05$).

There were significant differences in the TL of juveniles fed on three different diets 31 days after the start of the experiment. The highest TL was 2.322±0.046 cm in treatment C which was significantly higher than those of 2.166±0.019 cm and 2.126±0.009 in treatment M and L, respectively (Tukey HSD test; $p<0.05$).

There were significant differences between treatments 102 days after the start of the experiment (ANOVA; p=0.002). The highest TL was 2.822±0.014 cm in treatment C, followed by 2.563±0.040 cm and 2.562±0.049 cm in treatment L and M, respectively. The total length of treatment C was significantly higher than those of other treatments (Tukey HSD test; $p<0.05$) and there were no significant differences between treatment M and L (Tukey HSD test; $p>0.05$).

The survival rates of juvenile lobsters were significantly different among treatments by the end of the experimental period. Juveniles fed on diet C had highest survival rate with 99.78%, followed by lobsters fed on diet M with 80% and those fed on diet L with 53.33% (Tukey HSD test; $p<0.05$).

Discussion

In this study, *H. gammarus* larvae were cultured in 100 L cyclindro-conical tanks in a recirculating system achieving a mean survival rate of 13% by stage IV. This survival rate aligns with reported values of 10-15% by previous researchers (Jørstad et al., 2009; Ellis et al., 2015). Enriched *Artemia* nauplii supported the growth of zoea stages and the growth of larvae up to stage IV was consistent with findings from other studies (Agnalt et al., 2013; Middlemiss et al., 2015; Powell et al., 2017; Önal and Baki, 2021). In an earlier study, Önal and Baki (2021) reported a survival rate of 3% using 800 L tanks with a larval density of 1.25 larvae/L. Similarly, lower stocking densities in the present study did not support higher survival rates which is in accordance with Hinchcliffe et al., (2022). Although the feeding regimes and stocking densities were similar between the two studies, considerably higher rates of survival obtained in this study may be due to the smaller volume of the culture tanks. Smaller tank volumes allow a better control of the tank environment in terms of water quality, prey density and distribution, turbulence and flow patterns compared to larger volumes. However, despite similar growth rates, survival rates in tanks ranged between 8-16%. Variations in survival rates between replicates are common in the culture of larval stages of fish and crustaceans and specific reasons for this varying success levels are usually unknown but may indicate differences in tank specific conditions. Since, progeny, nutritional composition, size of live prey (*Artemia* nauplii), prey abundance, feeding regime, illumination, flow rates, water quality and other aspects of overall husbandry practices were similar across all tanks, factors that are difficult to control such as turbulence and conspecific aggression might have contributed to lower survival rates. In fish larvae culture, for example, turbulent water flow reduced the likelihood of cod (*Gadus morhua*) larvae to successfully chase and ingest prey items in larval tanks (MacKenzie and Kiørboe, 2000). However, the raptorial feeding behavior of zoea larvae of *H. gammarus* is in contrast to ambush predation by fish larvae and turbulence, may in fact, facilitate larval lobster feeding through pelagic stages I-III by increasing chance encounter. A larval culture tank design that will maximize encounter and capture rates of prey with respect to turbulence may result in higher survival rates. In addition, a potential improvement in lobster larvae culture may be to maintain a prey density of 3-5 nauplii/ml throughout a 24 h period, particularly during the night because pelagic larvae exhibit active feeding behavior at night (Juinio and Cobb, 1992). Increasing survival rates of larvae remains to be an important challenge for mass production of lobster larvae.

The growth rates of larvae through stages I-IV were similar to those reported in earlier studies (Agnalt et al., 2013; Middlemiss et al., 2015; Powell et al., 2017; Önal and Baki, 2021). Slight differences in growth rates observed with respect to the carapace length and total length is due to the curvature of the abdomen and flexion of abdominal segments which result in differences when taking measurements. Therefore, carapace measurements have inherently lower variations and is a better indicator of growth in early stages of lobster development. In this study, there were differences in growth rates of lobster larvae based on carapace length between consecutive stages (16.8-32.2% through stages I-II, II-III and III-IV). Similar differences in growth rates between stages were reported by other researchers (Agnalt et al., 2013; Önal and Baki, 2021). However, Middlemiss et al. (2015) reported similar rates of changes in carapace length through stages I-IV. Discrepancies between growth rates in succeeding stages may be a factor of prey quality and quantity and may and indicate suboptimal conditions in the culture tank.

The lack of suitable artificial diets has been considered as a major bottleneck for lobster culture (Powell et al., 2017; Hinchcliffe et al., 2020; Goncalves et al., 2021). However, similar to fish larval culture, formulated dry diets inherently resulted in lower growth and survival rates in *H. gammarus* and *H. americanus* juvenile culture (Conklin et al., 1975; Ali and Wickins, 1994; Goncalves et al., 2020). In this study, a crustacean based wet diet (diet C) resulted in higher growth and survival rates in juvenile lobsters compared to those of other diets (diets L and M) containing non-crustacean ingredients. The higher growth of lobster juveniles fed on diet C was noticeable 18 days after the start of the trial and this trend was consistent throughout the experimental period. However, growth rate

exhibited a decreasing trend in all treatments throughout the experimental period. A decreasing trend in growth rates may indicate sub-optimal feeding rate, compartment size limitations or undetected water quality problems. In the present study, juvenile lobsters fed on a commercial seabass pellet feed with a relatively higher protein and lipid contents (44.86%±5.63 and 19.92±0.88, respectively) had the lowest growth and survival rates and proved that this diet did not meet the nutritional requirements of juveniles when fed alone. The mollusk based diet, on the other hand, performed slightly better than the seabass pellet in terms of growth but performed considerably better in terms of survival rates. Both the crustacean based diet and the mollusk based diets performed well in terms of growth and survival for early juveniles. The crustacean based diet supported the growth and survival of juvenile lobsters and only 1 individual out of 45 died during the experimental period of 102 days. The lower protein content of the crustacean diet (36.94%±0.60) compared to those of other diets did not result in reduced growth rates and survival. Similarly, Conklin et al. (1975) suggested a protein requirement of 30% for the American lobster, *H. americanus*. given sufficient non-protein sources in their diet. In contrast, previous studies on dietary requirements of *H. gammarus* suggested higher protein requirement for juveniles (Goncalves et al., 2020; Hinchcliffe et al., 2020; Powell et al., 2017). In the present study, higher growth and survival of juveniles fed on diet C with lower protein level may also indicate that nutritional factors other than protein plays an important role for *H. gammarus* juveniles. For example, chitin along with calcium carbonate and protein was considered as an important component of crustacean shells (No and Meyers, 1995). Dietary supplementation of chitin and its derivatives such as glucosamine were shown to increase survival in crustaceans (Powell and Rowley, 2007; Niu et al., 2013) and *H. gammarus* juveniles (Hinchcliffe et al., 2020; Goncalves et al., 2022). Although chitin and astaxanthine levels were not measured in the experimental diets, both chitin and astaxanthine levels are expected to be much higher in the crustacean diet as indicated by the higher ash content. This finding supports those of earlier reports and indicates that dietary chitin is crucial for juvenile lobster growth and survival (Powell and Rowley, 2007; Niu et al., 2013; Goncalves et al., 2022).

Although, wet diets hold the promise of higher growth and maintaining the natural coloration of cultured lobsters, potential drawbacks such as presentation and delivery of wet or semi-moist feed particles and higher leaching rates should be investigated. The use of different binders may also offer effective solutions to develop better wet/moist diets for juvenile lobsters. Despite the higher growth of juvenile lobsters with wet diets in the present study, optimization of the nutritional contents and intrinsic properties of feed particles along with husbandry protocols and technical and economic aspects of maintaining larger size lobsters are the major obstacles that needs to be addressed in future studies for land-based lobster aquaculture.

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Conflict of Interest

The authors declare no conflict of interest

Author Contributions

Enes Osman carried out all experiments and measurements, analyzed the data and wrote the manuscript. Umur Önal conceived and planned all the experiments and contributed to statistical analyses and interpretation of the results and commented on the manuscript.

Ethics Approval

This research did not need ethical approval as it involved experimental procedures on a decapod crustacean.

References

Agnalt, A-L., Jørstad, K. E., Kristiansen,T. S., Nøstvold, E., Farestveit, E., Næss, H., & Paulsen, O. I. (2004). Enhancing the European lobster (*Homarus gammarus*) stock at Kvitsøy Islands; Perspectives of rebuilding Norwegian stocks. In K. M. Leber, S. Kitada, H. L. Blankenship, and T. Svåsand (Eds.), *Stock Enhancement and Sea Ranching: Developments, Pitfalls and Opportunities*, (pp. 415–426). Oxford: Blackwell Publishing Ltd.

Agnalt, A. L., Grefsrud E. S., Farestveit E., Larsen M., & Keulder F. (2013). Deformities in larvae and juvenile European lobster (*Homarus gammarus*) exposed to lower pH at two different temperatures. *Biogeosciences, 10*, 7883–7895.

Ali, Y. O., & Wickins, J.F. (1994). The use of fresh food supplements to ameliorate moulting difficulties in lobsters, *Homarus gammarus* (L.), destined for release to the sea. *Aquaculture and Fisheries Management*, *25*, 483-496.

Anonymus, Turkish Statistical Institute TÜİK (https://biruni.tuik.gov.tr/medas/?kn=97& locale=tr) accessed 10.07.2023).

Bannister, R. C. A., Addison, J. T., & Lovewell, S. R. J. (1994). Growth, movement, recapture rate and survival of hatchery-reared lobsters (*Homarus gammarus*, L.) released into the wild on the English east coast. *Crustaceana*, *67*, 156–172.

Beard, T. W., P. R. Richards, & Wickins, J. F. (1985). The techniques and practicability of year-round production of lobsters, *Homarus gammarus*, in laboratory recirculation systems. *Minist. Agric., Fish., Food, Directorate Fish. Res., Lowestoft, Engl., Fish. Res. Tech. Rep*. *79*, 1–22.

Conklin, D. E., Devers, K., & Shleser. R.A. (1975). Initial Development of Artificial Diets for the Lobster, *Homarus americanus*. *Journal of the World Aquaculture Society*, 6, (1-4), 235-248.

Daniels, C. L, Wills, B., Ruiz-Perez, M., Miles, Wilson, R.W., & Boothroyd, D. (2015). Development of sea based container culture for rearing European lobster (*Homarus gammarus*) around South West England. *Aquaculture, 448*, 186-195.

Drengstig, A., & Bergheim, A. (2013). Commercial land-based farming of European lobster (*Homarus gammarus* L.) in recirculating aquaculture system (RAS) using a single cage approach. *Aquacultural Engineering, 53*, 14-18.

Ellis, C. D., Hodgson, D. J., Daniels, C. L., Boothroyd, D. P., Bannister, R. C. A., & Griffiths, A. G. F. (2015). European lobster stocking requires comprehensive impact assessment to determine fishery benefits. *ICES Journal of Marine Science, 72*, 35–48.

Fiore, D. R., & Tlusty, M. F. (2005). Use of commercial *Artemia* replacement diets in culturing larval American lobsters (*Homarus americanus*). *Aquaculture, 243*, 291-303.

Goncalves, R., Lund, I., Gesto, M., & Skov, P.V. (2020). The effect of dietary protein, lipid, and carbohydrate levels on the performance, metabolic rate and nitrogen retention in juvenile European lobster (*Homarus gammarus*, L.). *Aquaculture, 525*, 735334.

Goncalves, R., Lund, I., & Gesto, M. (2021). Interactions of temperature and dietary composition on juvenile European lobster (*Homarus gammarus*, L.) energy metabolism and performance. *Comparative Biochemistry and Physiology, Part A 260*, 111019.

Goncalves, R., Lund, I., Sousa, D., & Skov, P.V. (2022). Shrimp waste meal (*Pandalus borealis*) as an alternative ingredient in diets for juvenile European lobster (*Homarus gammarus*, L.). *Animal Feed Science and Technology, 294*, 115478.

Hinchcliffe, J., Powell, A., Langeland, M., Vidakovic, A., Undeland, I., Sundell, K., & Eriksson, S.P. (2020). Comparative survival and growth performance of European lobster *Homarus gammarus* post-larva reared on novel feeds. *Aquaculture Research, 51*, 102–113.

Hinchcliffe, J., Agnalt, A.Lisbeth, Daniels C. L., Drengstig, A., Lund, I., McMinn, J., & Powell, A. (2022). European lobster *Homarus gammarus* aquaculture: Technical developments, opportunities and requirements. *Reviews in Aquaculture, 14*, 919–937.

Jørstad, K. E., Kristiansen, T. S., Farestveit, E., Agnalt, A-L., Prodöhl, P. A., Hughes, M., & Ferguson, A. (2009). Survival of laboratory-reared juvenile European lobster (*Homarus gammarus*) from three brood sources in southwestern Norway. *New Zealand Journal of Marine and Freshwater Research, 43*(1), 59-68.

Juinio. M. A. R., & Cobb, J. S. (1992). Natural diet and feeding habits of the postlarval lobster Homarus americanus. *Marine Ecology Progress Series*, 85, 83-91.

MacKenzie, B. R, & Kiørboe, T. (2000). Larval fish feeding and turbulence: a case for the downside. *Limnology and Oceanography, 45*,1–10.

Middlemiss, K. L., Daniels, C.L., Urbina, M.A., & Wilson, R. W. (2015). Combined effects of UV irradiation, ozonation, and the probiotic *Bacillus* spp. on growth, survival, and general fitness in European lobster (*Homarus gammarus*). *Aquaculture, 444*, 99-107.

Nicosia, F., & Lavalli, K. (1999). Homarid Lobster Hatcheries: Their History and Role in Research and Aquaculture. *Marine Fisheries Reviews, 61*(2), 1-57.

Niu, J., Lin, H.Z., Jiang, S.G., Chen, X., Wu, K.C., Liu, Y.J., Wang, S., & Tian, L.X. (2013). Comparison of effect of chitin, chitosan, chitosan oligosaccharide and N-acetyld-glucosamine on growth performance, antioxidant defenses and oxidative stress status of *Penaeus monodon*. *Aquaculture 372–375* (6), 1–8.

No, H. K., & Meyers, S. P. (1995). Preparation and Characterization of Chitin and Chitosan - A Review. *Journal of Aquatic Food Product Technology, 4*(2), 27-52.

Önal, U., & Baki, H. (2021). The Growth and Survival of the European lobster (*Homarus gammarus*) Larvae in Pseudo-Green Water and Clear Water under Low Density Conditions. *COMU Journal of Marine Sciences and Fisheries, 4*(2), 202-207.

Powell, A., & Rowley, A. F. (2007). The effect of dietary chitin supplementation on the survival and immune reactivity of the shore crab, *Carcinus maenas.* *Comp. Biochem. Physiol. - A Mol. Integr. Physiol., 147*, 122–128.

Powell, A., Hinchcliffe, J., Sundell, K., Carlsson, N., & Eriksson, S. P. (2017). Comparative survival and growth performance of European lobster larvae, *Homarus gammarus*, reared on dry feed and conspecifics. *Aquaculture Research, 48*(2), 1-11.