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Integrated Multitrophic Aquaculture of the Seabass (*Dicentrarachus labrax)* with Two Types of Clams and the Whiteleg Shrimp (*Litopenaeus vannamei*) for Increased Production and Better Sustainability in Egypt

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ABSTRACT

Integrated multitrophic aquaculture (IMTA) is an innovative approach for sustainable aquaculture development and ecosystem services. The present study aimed to compare the growth performance, production, and quality of the culture environment in integrated systems with different species combinations in tanks, in parallel with the natural dynamics of aquaculture. The experiment was designed to assess the feasibility of using seabass (*Dicentrarchus labrax*) as the fed component of the IMTA system, in combination with two clam species—the carpet-shell clam (*Ruditapes decussatus*) and short-necked clam (*Paphia undulata)*—and the whiteleg shrimp (Litopenaeus vannamei) as extractive species. The control experiments (T0 and G0) involved monocultures of seabass (*D. labrax*), while other treatments were IMTA systems. Over a 60-day culture period, the results showed a significant decrease in ammonia levels in the clam-seabass integrated groups, whereas increasing shrimp density significantly raised ammonia levels in shrimp-seabass integrated ponds. Additionally, fish reared with 0.5kg/ 0.5m³ of *P. undulata* and 0.5kg/ 0.5m³ of *R. decussatus* exhibited better growth performance, protein efficiency ratio (PER), proximate composition (PPV), protein ratio, and ash content. Fish reared with 20 shrimp (*L. vannamei*) exhibited the highest values for protein ratio, ether extract, ash, and fiber content. Clams reared in treatment T5 showed better growth performance, while shrimp reared in G1 exhibited superior growth. The findings of this study suggest that IMTA systems outperform monoculture systems, highlighting the potential of IMTA for sustainable aquaculture by improving growth performance and reducing environmental impact.

INTRODUCTION

Aquaculture is currently one of the fastest growing animal food production industries globally, accounting for an average of 46% of fish output worldwide, up from 25.7% in 2000 **(Salah El Deen & Khairy, 2024)** based on average annual growth rates of 5.3% from 2001 to 2018. Aquaculture techniques are the only path to a safe and sustainable seafood production supply in order to guarantee a sufficient supply of seafood **(Yue & Shen, 2022)**.

Egypt is a major aquaculture producer in the Mediterranean and the third-largest producer of marine species including seabass and sea bream **(Abd-Elhady *et al*., 2024)**. However, the marine aquaculture industry is facing obstacles in its development. Marine aquaculture has primarily been practiced as a single-species (monoculture) approach in most farms, with many farmers focusing on the cultivation of marine fish, particularly those that require a two-year cultivation period. Furthermore, given the rapid global warming brought on by climate change, it is imperative that the fragile state of the world's water resources be addressed **(Sukanya & Sabu, 2023)**. Thus, worries about depleting freshwater supplies have given rise to the development of the marine aquaculture industry **(Sadek 2000; Shaalan *et al*., 2018)**. Integration of multiple species in aquaculture systems has its roots in Asia and the Middle East and dates back to the beginnings of the industry **(Strand *et al*., 2019)**. The foundation of integrated multitrophic aquaculture is the simultaneous production of certain aquacultural species using all food levels in a manner that promotes social acceptance and environmental sustainability (bio control). The detrimental impacts in the culture systems can be reduced by using more feed from high-trophic animal cultures that can enhance the production of low-trophic species and by discarding the organic matter from wastewater **(Khanjani *et al*., 2022)**.

With the application of an ecosystem-oriented approach, IMTA is a new generation of aquaculture that was created with the goals of increasing profitability, minimizing environmental effects, expanding commercial production, and improving the intensive sustainability in aquaculture systems **(Sanz-Lazaro & Sanchez-Jerez, 2020)**. One novel approach for the sustainable growth of aquaculture and ecosystem services is the integrated multi-trophic aquaculture (IMTA) concept **(Papageorgiou *et al*., 2023)**, which is becoming in Egypt a widely used production system but fraught with several constraints.

The European seabass (*Dicentrarchus labrax*) is a fish known for its tasty flesh, and efforts to breed it in fish farms have been successful. Seabass production offers several benefits, including rapid growth and the ability to feed them with inexpensive fish or artificial feed. Additionally, it offers consumers flavored white meat **(Singh *et al*., 2000)**. In marine fish farming, the European seabass *(Dicentrarchus labrax)* and seabream *(Sparus aurata)* are essential species **(FAO, 2023)**. The aquaculture industry in the European Union is dominated by the production of seabass and seabream, with salmon coming in second **(Llorente *et al*., 2020; Gras *et al*., 2023)**. In the Mediterranean aquaculture, the European seabass (*Dicentrarchus labrax*) has grown to be one of the most lucrative and farmed commercial fish **(Elhetawy *et al*., 2023)**. Since the European seabass is a significant and lucrative marine finfish species for aquaculture throughout Europe, especially in the Mediterranean, it was chosen as the feeding component **(Guillen *et al*., 2023)**, great cultural and economic significance throughout Europe

(Reyes & Rodríguez *et al*., 2020). Due to the limitations imposed by the restricted availability of wild fish, which is expected to be around 20,000 tonnes in 2021, most countries in the region will primarily focus on aquaculture of the European seabass (*Dicentrarchus labrax*) and seabream (*Sparus aurata*). Furthermore, there is a noteworthy but restricted output of additional fish species. Furthermore, other fish species are produced to a notable, but limited extent **(FAO, 2023)**. Between 1992 and 2021, the production of farmed seabass and seabream increased dramatically, rising from approximately 20,000 tonnes to an astounding 600,000 tonnes. As a result, these species are now widely cultivated; in 2021, 28 countries were either cultivating both seabass and seabream or just one of these species **(FAO, 2023)**.

The second-largest class of mollusks, Bivalvia, includes several economically significant species found worldwide in coastal and intertidal areas, such as those in the Mediterranean and Red seas. *Ruditapes decussatus*, the carpet-shell clam, is one of Egypt's most well-known and significant bivalves in terms of commerce. One of the most popular and commercially valuable mollusk species found in Mediterranean lagoons and coastal areas is *Ruditapes decussatus*. In 2016, global production of this species reached 6,324.34 tonnes **(FAO, 2016)**. According to **Pinello *et al.* (2020)**, production in Egypt varied between 690 and 4,036 tonnes. Clams develop a rich and diverse bacterial microbiota due to their filter-feeding behavior **(Balboa *et al.*, 2016)**. As a filter-feeding marine organism, *Ruditapes decussatus* is commonly found in locations such as Marsa Matrouh, Alexandria, Port Said, Suez, Fayed, and Ismailia **(Hamza, 2009)**. This species is also used as a bioindicator to identify areas highly contaminated with heavy metals and other toxicants **(Hazrat *et al.*, 2019)**.

The short-necked clam (*Paphia undulata*) is significant both ecologically and commercially in terms of biomass, impacts on communities, and use as a food source **(Yu *et al.*, 2019)**. This saltwater edible bivalve is consumed locally in Egypt and globally. It is an important source of high-quality protein, making it economically valuable. In many coastal nations worldwide, the short-necked clams are considered a major component of the shellfish market. In several Asian countries, *Paphia undulata* has become a widely consumed dish. It contains approximately 68.77% crude protein on a dry weight basis, making it a rich protein source **(Abd-El-Aziz, 2021)**. Locally in Egypt, clams are commonly eaten, although over the past decade, the population of Egyptian fisheries has declined. Additionally, numerous histo-cytological changes in fish have been identified as biomarkers for pollution monitoring **(Au, 2004)**.

Worldwide, prawns are the most highly prized commercial crustaceans. Right now, prawns are the second-best value food. In terms of protecting natural resources, prawn aquaculture can lessen the strain that fisheries have on overfished wild stocks **(FAO, 2022)**. With over 70% of the global prawn aquaculture industry's output, the whiteleg shrimp (*L. vannamei*) is the species with the highest economic value **(FAO, 2018)**. *L. vannamei* has many benefits, including the ability to grow at the highest average rates (up to 3g per week) in a wide range of water parameters (salinity, temperature, and humidity), the ability to culture with both high and low protein feed, better feed conversion rates, and lower protein requirements around 35% **(Abdel-Rahim *et al.*, 2021)**. It may be raised to higher stocking densities, and in culture settings, they consume a variety of feeds and feed particles **(Naser *et al.*, 2022)**. Owing to the penaeid shrimp's significant global economic impact, especially in aquaculture, a significant effort has been recently made to understand the ecology of *Penaeus* spp. expansion. Egypt's annual growth rate between 2015 and 2018 was higher than in the years prior (**CAPMAS, 2020)**.

Egypt's history with shrimp farming began in the early 1980s, when the country's first shrimp farm was built close to Alexandria **(Sadek *et al.*, 2002)**. At present, there are more than six marine hatcheries, including those located in Harraz, Alwafa, El-Sharif, El-Aasir, El-Sayed Abou Omar, and Berket Ghalioun. They facilitate the hatching of the Pacific white shrimp and contribute to their increased cultivation. The purpose of this project was to maximize the advantages of ponds for raising seabass fish and to produce oysters by utilizing the pond infrastructure to purify water, encourage fish growth, increase output, and enhance the surrounding area. Additionally, the project aimed to assess the feasibility of using integrated farming systems (IMTA) to raise fish and prawns in the same pond.

MATERIALS AND METHODS

1. Experimental location and water source

This study was carried out in cooperation with the Zoology Department of Tanta University's Faculty of Science at the El-Max Station for Applied Research of the National Institute of Oceanography and Fisheries (NIOF) in Alexandria, Egypt. *Dicentrarachus labrax* juveniles were reared in underground seawater. Fish were kept in a natural light environment (photoperiod: 13hr light: 11hr dark), with a daily water exchange rate of 2 or 5% according to the cultivated animals.

Water quality analyses

The saltwater used in this experiment had the following chemical characteristics and heavy metal content: salinity (36± 0.5ppt), pH (7.93± 0.003), ammonia (0.47± 0.005ppm), manganese (105.5± 1.6µg/ l), iron (93.6± 2.7µg/ l), copper (8.7± 0.009µg/ l), zinc (5.2± 0.005µg/ l), cadmium (20± 5.3µg/ l), chromium (39± 4.9µg/ l), cobalt (12.3± 2.8µg/ l), nickel (38.5± 4.5µg/ l), lead (16± 3.2µg/ l), and total hardness (83.0± 0.8ppm).

2.2. Experimental animals and rearing techniques

2.2.1. European seabass

The juvenile *Dicentrarchus labrax* (European seabass) used in this investigation were purchased from the K21 marine hatchery, where the juveniles were generated using water from the Mediterranean Sea. They were fed for two months after arrival.

2.2.2. Clams

Two species of clams were used to perform this experiment. The carpet-shell clam (*Ruditapes decussatus)* and the short-necked clam (*Paphia undulata*) were used in this experiment. Clams were purchased from local distributor in Alexandria. The initial weight of *R. decussatus* was 4.00 ± 0.004g, while the initial weight of *P. undulata* was 12.53 ± 0.015g. During the period of experimental preparation, only these sizes of the carpet-shell clam were available. Six kilograms of each species were used to perform the experiment.

2.2.3. Shrimp

The whiteleg shrimp (*Litopenaeus vannamei*) used in this experiment were purchased from private shrimp farm located in Alexandria, and then transferred and put inside the hapa. Initial body weight of shrimp was 5.49± 0.023gm.

2.3.Experimental design

2.3.1. Experiment 1

European seabass (*Dicentrarachus labrax*) cultivation with two clam species with densities

Six treatments were tested in triplicate to determine the potential benefits of integrating two species of clam with varying densities on the performance, feed utilization of the European seabass. Eighteen hapas were used, with each hapa stocked with five seabass. Three hapas were placed in each cement pond, representing one treatment. The duration of the experiment was 60 days.

The six experimental treatments were:

T0 = control, seabass juveniles in hapas without clams;

T1 = seabass juveniles in hapas and 0.5 kg/0.5 m^3 *Ruditapes decussatus* (carpet-shell clam);

T2 = seabass juveniles in hapas and 1.0 kg/0.5 m^3 *Ruditapes decussatus* (carpet-shell clam);

T3 = seabass juveniles in hapas and 0.5 kg/0.5 m^3 *Paphia undulata* (short-necked clam);

T4 = seabass juveniles in hapas and 1.0 kg/0.5 m^3 *Paphia undulata* (short-necked clam);

T5= seabass juveniles in hapas and 0.5 kg/0.5 m^3 *Ruditapes decussatus* (carpet-shell clam) and 0.5 kg/0.5 m^3 *Paphia undulata* (short-necked clam).

2.3.2 Experiment 2

European seabass (*Dicentrarachus labrax*) integrated with different stocking densities of the whiteleg shrimp (*Litopenaeus vannamei)*

Six treatments were tested in triplicate. This experiment utilized 18 circular fiberglass tanks, each measuring $4m^3$ water, and each was supported with one net hapa measuring 1*1*1m, and water volume inside the hapa was $0.5m^3$. In each tank, 7 fish were stocked. One net hapa was used to keep the whiteleg shrimp (*Litopenaeus annamei*) at the tested stocking densities. The total shrimp juvenile used in this experiment was two hundred twenty five. The duration of the experimental period was 60 days. The experimental treatments were:

G0: seabass (*D. labrax*); without shrimp;
G1: seabass (*D. labrax*) + 5 shrimps (*L. vannamei*) per hapa;
G2: seabass (*D. labrax*) + 10 shrimp (*L. vannamei*) per hapa;
G3: seabass (*D. labrax*) + 15 shrimp (*L. vannamei*) per hapa;
G4: seabass (*D. labrax*) + 20 shrimp (*L. vannamei*) per hapa;
G5: seabass (*D. labrax*) + 25 shrimp (*L. vannamei*) per hapa

2.4. Diet and feeding regime in both experiments

The fish were fed a commercial diet purchased from Skretting Egypt **(https://skretting.com/en-EG/)** with 46/16 crude protein (CP)/crude fat (CF). The commercial diet contained 46% crude protein, 16% ether extract, 3.03% fibers, 19.99% NFE, 14.98% ash, and 492.64cal/100g of total energy. Fish were fed at 2% of body weight three meals a day, six days a week. The whiteleg shrimp (*Litopenaeus vannamei*) was fed high quality special shrimp feed produced from ALLER AQUA feed company **(https://www.aller-aqua.com/press/3rd-production-line-in-egypt)**. Feed specifications were 40% crude protein, 7% crude fat, 33.1% nitorgen free extract (NFE), 8.7% ash, and 3.2% fiber. The pellet size of feed was 2.3mm. Shrimp was fed at 2% of body weight.

2.5. Tested traits

2.5.1. Water quality measurement

Water quality testing was bi-weekly conducted at the same designated time (10:30–11:00 AM) throughout the period of study. Water quality parameters including temperature (°C), pH, dissolved oxygen (DO, mg/L), and total ammonia nitrogen (TAN, mg/L) were analyzed in real-time. A portable multi-meter (Lovibond model SensoDirect 150, Germany) was used to measure temperature, pH, salinity, and dissolved oxygen. The bi-weekly measurement of total ammonia nitrogen (TAN) concentration was conducted using an ammonia medium-range analyzer (HANNA, model H196715, Romania). Calculation of un-ionized ammonia (NH_3) was performed using data on total ammonia nitrogen (TAN), temperature, and salinity.

2.5.2. Growth performance

For growth measurements, biweekly samples of fish fingerlings were collected, and the feed quantity was changed for each treatment. The following formulae were used to calculate body weight (g), weight gain, average daily gain (g/day), and specific growth rate (SGR %/fish /day):

Weight gain (g⁄f ish) = final weight − intial weight; specific growth rate (SGR, %⁄fish⁄day) = 100 × (ln final weight − ln initial weight)⁄days; relative growth rate (RGR, %) = 100 × (weight gain⁄initial weight); survival (%) = 100 × (final number of fish⁄initial number of fish).

2.5.3. Fish and feed analytical methods

The **AOAC (2000)** method was used to analyze the estimated moisture, crude protein, crude fat, fibre, and ash compositions of the experimental seabass at the start and finish of the trial, as well as their commercial diets. Three sets of samples were gathered for every analysis.

2.5.4. Feed utilization

Feed conversion ratio (FCR), protein efficiency ratio (PER), protein productive value (PPV %) and energy utilization (EU, %) were all calculated. The following equations were used: Feed conversion ratio (FCR, g) = feed consumption (g)⁄weight gain; protein efficiency ratio (PER, g) = total weight gain (g)⁄protein intake; energy utilization (EU, %) = 100 × (energy gain (kcal)⁄energy intake (kcal)).

2.6. Biometric indices

At the end of the experiments, three fish from each hapa were sacrificed to obtain their final biological records, including liver and viscera weights to determine hepatosomatic (HSI), viscerosomatic (VSI) indices. The following equations were used: Viscerosomatic index (VSI, %) = 100 × (viscera weight (g)⁄fish body weight (g)); hepatosomatic index (HSI, %) = 100 × (liver weight (g)⁄fish body weight (g)).

2.7. Statistical analysis

For each parameter, the mean values and the standard error of the mean (mean ± SEM) were presented. We statistically analyzed the data from each treatment using one-way analysis of variance (ANOVA) and the Duncan test at a 5% probability level. We used SPSS version 26 to perform the statistical analyses.

RESULTS

1. Experiment 1: The effect of cultivated two clam species with varying densities on water quality, growth performance, feed utilization, and carcass composition of the European seabass (*Dicentrarachus labrax)*

1.1. Water quality findings

The results of the study validate that there were no significant differences ($P > 0.05$) in temperature or pH readings in both experiments. The average recorded reading of temperature, salinity and pH was 24.1 ± 0.09ºC, 33.38 ± 0.06ppt and 8.11 ± 0.01, respectively. However, significant differences ($P \leq 0.05$) were found among the treatments in dissolved oxygen, total ammonia, and unionized ammonia. Moreover, significant differences were noted in oxygen levels between the clam-treated treatments and the control group. The control treatment had an average reading of 6.05ppm, whereas the clam-treated treatments recorded results ranging from 6.45 to 6.95ppm. Other than T1 and T5, no significant ($P > 0.05$) differences were found between the five clam-treated regimens. Additionally, the clam-treated treatments exhibited significant differences ($P \leq 0.05$) in total ammonia and ionized ammonia levels compared to the control treatment (Fig. 1). Furthermore, the treatments with high densities of clams had much reduced values of both total and ionized ammonia. The short-necked clam outperformed the carpet-shell clam with lower values of TAN and NH3.

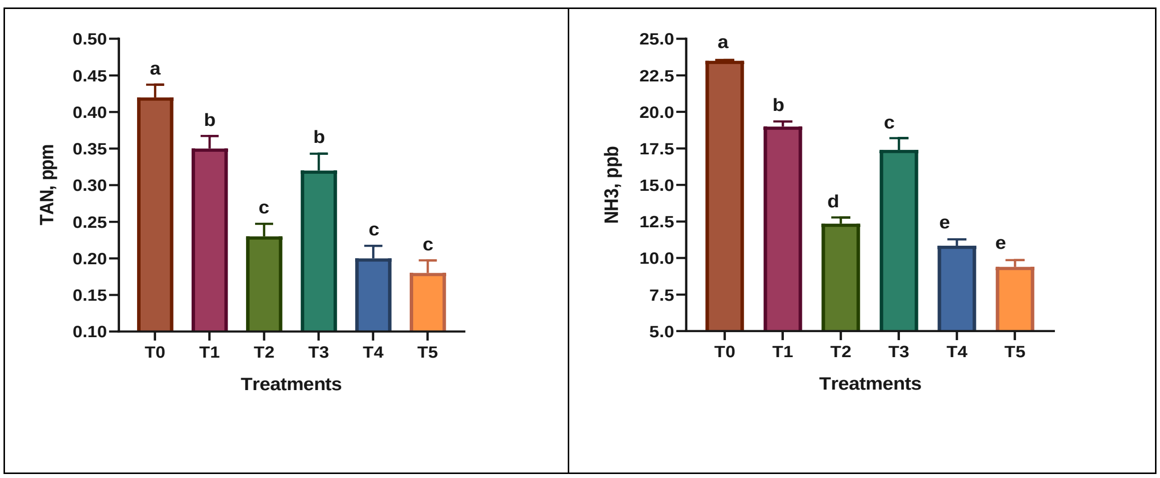

Fig. 1. Total ammonia nitrogen (TAN) and un-ionized ammonia (NH3) in tank water of the of the European seabass (*Dicentrarachus labrax*) cultivated with two clam species with varying densities in the same pond. *T0=control; T1=seabass and 0.5kg/ 0.5m^3 Carpet-shell clams; T2=seabass and 1.0kg/ 0.5m^3 carpet-shell clams; T3= seabass and 0.5kg/ 0.5m^3 short-necked clam; T4= seabass and 1.0kg/ 0.5m^3 short-necked clam; T5= seabass and 0.5kg/ 0.5m^3 carpet-shell clams and 0.5kg/ 0.5m^3 short-necked clam; Values in the same bars with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA

1.2. Growth performance and survival of seabass

The European seabass, (*Dicentrarachus labrax*) was cultivated with two clam species using varying densities for 60 days of feeding showing improvement in the growth performance. At the start of the experiment, the mean initial weight of the seabass was approximately 99.5 g per fish. By the end of the experiment, the final body weight of the seabass had significantly increased ($P \leq 0.05$) in all treatment groups. Treatments T4 and T5, which involved cultivating seabass with 1.0kg/ 0.5m³ of *Paphia undulata* (short-necked clam) and seabass with 0.5kg/ 0.5m³ of *Ruditapes decussatus* (carpet-shell clam) and 0.5kg/ 0.5m³ of *Paphia undulata*, respectively, showed the highest final weight, weight gain, average daily gain (ADG), survival growth rate (SGR), and relative growth rate (RGR) compared to the control and other treatments, as shown in Table (1).

Table 1. Growth performance and biometric data of the European seabass, *Dicentrarachus labrax* cultivated with two clam species with varying densities. Data are means ± SEM

Growth parameter	**Treatments***					
	T0	**T1**	**T2**	**T3**	**T4**	**T5**
Initial weight (gm/fish)	99.87±0.13	99.40±0.35	99.60±0.23	99.47±0.29	99.27±0.18	99.73±0.24
Final Weight (gm/fish)	129.70±0.40^{f}	132.60±0.53^{e}	137.83±0.32^{c}	135.33±0.18^{d}	141.80±0.23^{b}	144.10±0.29^{a}
Gain (gm/fish)	29.83±0.30^{f}	33.20±0.20^{e}	38.23±0.30^{c}	35.87±0.44^{d}	42.53±0.18^{b}	44.37±0.09^{a}
ADG (gm/fish/day)	0.497±0.005^{f}	0.553±0.003^{e}	0.637±0.005^{c}	0.598±0.007^{d}	0.709±0.003^{b}	0.739±0.001^{a}
SGR (%/fish/day)	0.436±0.003^{f}	0.480±0.001^{e}	0.542±0.004^{c}	0.513±0.007^{d}	0.594±0.002^{b}	0.613±0.001^{a}
RGR, %/fish	129.9±0.27^{f}	133.4±0.12^{e}	138.4±0.34^{c}	136.1±0.54^{d}	142.8±0.20^{b}	144.5±0.11^{a}
Survival, %	100	100	100	100	100	100

Mean of the initial weight = 99.56±0.1gm; *T0=control; T1=seabass and 0.5 kg/0.5 m^3 carpet-shell clams; T2=seabass and 1.0 kg/0.5 m^3 carpet-shell clams; T3= seabass and 0.5 kg/0.5 m^3 short-necked clam; T4= seabass and 1.0 kg/0.5 m^3 short-necked clam; T5= seabass and 0.5 kg/0.5 m^3 carpet-shell clams and 0.5 kg/0.5 m^3 short-necked clam; Values in the same row with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA.

1.3. Morphological digestive system of European seabass

Table (2) shows the cultivation of *D. labrax* with varying densities of two clam species significantly affected the morphological digestive system of *D. labrax*. The measured parameters showed significant value of viscerosomatic indices (VSI) and hepatosomatic indices (HSI). It was noted that, the highest values of VSI and HSI ratio were recorded in T1 compared to the control group T0 and other treatments. Remarkably, no significant difference of VSI and HSI ratio was detected between T2, T3, T4, and T5 compared to control T0.

Table 2. Morphological digestive system of the European seabass, *Dicentrarachus labrax* cultivated with two clam species with varying densities. Data are means ± SEM

Morphological digestive system	**Treatments**					
	T0	**T1**	**T2**	**T3**	**T4**	**T5**
HSI, %	1.497±0.09^{abc}	1.894±0.12^{a}	1.187±0.02^{bcd}	0.972±0.03^{d}	1.535±0.29^{ab}	1.049±0.12^{cd}
VSI, %	7.36±0.08^{b}	9.33±0.19^{a}	7.76±0.01^{b}	7.91±0.14^{b}	7.55±0.60^{b}	7.74±0.83^{b}

*T0=control; T1=seabass and 0.5 kg/0.5 m^3 Carpet-shell clams; T2=seabass and 1.0 kg/0.5 m^3 carpet-shell clams; T3= seabass and 0.5 kg/0.5 m^3 short-necked clam; T4= seabass and 1.0 kg/0.5 m^3 short-necked clam; T5= seabass and 0.5 kg/0.5 m^3 carpet-shell clams and 0.5 kg/0.5 m^3 short-necked clam; Values in the same row with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA.

1.4. Feed utilization parameters of the European seabass

All treatments showed improvement in feed utilization parameters after 60 days of feeding. However, the highest feed intake was recorded in T5, which involved cultivating seabass with 0.5kg/ 0.5m^3 of *Ruditapes decussatus* (carpet-shell clam) and 0.5kg/ 0.5m^3 of *Paphia undulata* (short-necked clam). The data also showed a significant decrease ($P \leq 0.05$) in the food conversion ratio (FCR) of seabass. The lowest FCR values were observed in T4 and T5, while the highest values were found in T0 and T1. Furthermore, significant increases ($P \leq 0.05$) were observed in the protein efficiency ratio (PER), protein productive ratio (PPV), energy gain, and energy utilization of seabass in all treatments. Notably, the highest values for PER, PPV, and energy gain were recorded in T5 (Table 3). The energy utilization ratio reached its highest in T2, while T3 had the lowest value. It is clear that T0, T1, T4, and T5 exhibited similar significant values for the energy utilization ratio of seabass.

Table 3. Feed utilization indices of European seabass, *Dicentrarachus labrax* cultivated with two clam species with varying densities. Data are means ± SEM

Feed utilization parameter	Treatments*					
	T0	T1	T2	T3	T4	T5
Feed Intake, gm	67.47±0.26[bc]	66.58±1.13[c]	67.06±0.51[bc]	68.91±0.70[b]	68.79±0.38[b]	71.26±0.24[a]
FCR	2.26±0.01[a]	2.00±0.02[b]	1.75±0.02[d]	1.92±0.01[c]	1.62±0.01[e]	1.60±0.01[e]
PER (gm)	1.05±0.01[e]	1.18±0.02[d]	1.35±0.02[b]	1.24±0.00[c]	1.47±0.00[a]	1.48±0.01[a]
PPV (%)	187.8±0.64[d]	209.0±2.69[bc]	212.5±1.84[b]	205.6±1.23[c]	224.2±0.34[a]	226.3±1.10[a]
Energy gain (Kcal)	493.4±1.71[c]	489.7±2.12[c]	507.8±0.83[a]	477.8±1.34[d]	502.3±0.37[b]	511.0±1.55[a]
Energy utilization (%)	149.3±0.54[bc]	150.2±1.87[b]	154.6±1.11[a]	141.6±1.09[d]	149.1±0.89[bc]	146.4±0.64[c]

*T0=control; T1=seabass and 0.5 kg/0.5 m^3 Carpet-shell clams; T2=seabass and 1.0 kg/0.5 m^3 carpet-shell clams; T3= seabass and 0.5 kg/0.5 m^3 short-necked clam; T4= seabass and 1.0 kg/0.5 m^3 short-necked clam; T5= seabass and 0.5 kg/0.5 m^3 carpet-shell clams and 0.5 kg/0.5 m^3 short-necked clam; Values in the same row with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA.

1.5. Carcass chemical composition of European seabass

The biochemical composition of seabass body carcass showed significant increase ($P \leq 0.05$) in the major components of carcass protein and ash in all treatment's groups. T5 recorded the highest value of protein ratio and ash followed by T4 compared to the control T0. For ether extract ratio, fiber and total energy of all treatments showed significant decrease ($P \leq 0.05$) compared to the control (Table 4)

Table 4. Carcass chemical composition of the European seabass, *Dicentrarachus labrax* cultivated with two clam species with varying densities. Data are means ± SEM

Carcass biochemical analyses	**Initial**	**Treatments (Final)***					
		T0	**T1**	**T2**	**T3**	**T4**	**T5**
Protein, %	56.43	55.83±0.16[f]	58.48±0.07[c]	57.34±0.01[e]	58.12±0.12[d]	59.18±0.10[b]	60.34±0.01[a]
Ether extract, %	25.57	22.36±0.23[a]	19.19±0.04[b]	19.24±0.05[b]	17.39±0.08[c]	16.18±0.15[d]	15.37±0.05[e]
Ash, %	15.77	19.36±0.08[d]	20.74±0.05[c]	21.74±0.44[b]	21.64±0.05[b]	25.08±0.16[a]	24.49±0.16[a]
Fiber, %	0.14	0.65±0.03[a]	0.10±0.01[d]	0.11±0.01[d]	0.12±0.01[d]	0.47±0.01[b]	0.24±0.02[c]
Carcass energy, Kcal/100gm	567.7	525.96±1.30 a	510.98±0.06[b]	505.02±0.50 c	491.96±0.08[d]	486.51±0.83[e]	485.41±0.53 e

*T0=control; T1=seabass and 0.5 kg/0.5 m^3 Carpet-shell clams; T2=seabass and 1.0 kg/0.5 m^3 carpet-shell clams; T3= seabass and 0.5 kg/0.5 m^3 short-necked clam; T4= seabass and 1.0 kg/0.5 m^3 short-necked clam; T5= seabass and 0.5 kg/0.5 m^3 carpet-shell clams and 0.5 kg/0.5 m^3 short-necked clam; Values in the same row with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA.

1.6. Survival rate and growth performance of two species of clams

The final weight of both clams of *Ruditapes decussatus* and *Paphia undulata* were increased in all treatments compared with the initial weights. The data in Table (5) show an increase in weight increment across all treatments, with the highest value recorded in T5. Additionally, the highest survival rate for *Ruditapes decussatus* was observed in T5, at 75.20 ± 1.60%. Meanwhile, the highest survival rate for *Paphia undulata* was recorded in T3, at 85.00 ± 1.44%.

Table 5. Growth performance and survival of two species of clams cultivated in seabass ponds under integrated system

Treatment	**T1**	**T2**	**T3**	**T4**	**T5**
Initial Weight, g*	4.00±0.007	4.00±0.005	12.53±0.03	12.50±0.02	4.00±0.01/12.54±0.03
Final Weight, g**	5.80±0.06^{de}	5.63±0.09^{e}	16.80±0.06^{b}	16.40±0.06^{c}	6.00±0.12^{d} /17.87±0.12^{a}
Weight increment, g	1.83±0.05^{de}	1.64±0.08^{e}	4.27±0.03^{b}	3.90±0.07^{c}	2.01±0.12^{d} /5.33±0.09^{a}
Survival, %	73.07±1.16^{c}	72.67±1.04^{c}	85.00±1.44^{a}	80.83±0.417^{b}	75.20±1.60^{c} /79.17±0.83^{b}

* Initial Weight clam 1 = 4.00 ± 0.004 g; ** Initial Weight clam 2 = 12.53 ±0.015g; * T1=seabass and 0.5 kg/0.5 m^3 carpet-shell clams; T2=seabass and 1.0 kg/0.5 m^3 carpet-shell clams; T3= seabass and 0.5 kg/0.5 m^3 short-necked clam; T4= seabass and 1.0 kg/0.5 m^3 short-necked clam; T5= seabass and 0.5 kg/0.5 m^3 carpet-shell clams and 0.5 kg/0.5 m^3 short-necked clam; Values in the same row with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA.

1.7. Percentage of meat, shell and water content of two species of clams

The percentage of meat, shell, and water content of two species of clams cultivated in seabass ponds under an integrated system is shown in Table (6). The results indicate that T5 had the highest percentage of *Ruditapes decussatus* meat weight to total weight, at 30.21 ± 2.39%, compared to T1 and T2. Additionally, T5 exhibited the highest percentage of *Ruditapes decussatus* shell weight to total weight, at 58.24 ± 3.16%, compared to T1 and T2. Furthermore, T5 showed the highest percentage of *Paphia undulata* meat to total weight, at 29.27 ± 1.95%, compared to T3 and T4. However, the data also revealed a decrease in the percentage of *Paphia undulata* shell weight to total weight in T5 compared to T3 and T4.

Table 6. Percentage of meat, shell and water content of two species of clams cultivated in seabass ponds under integrated system

Treatment	T1	T2	T3	T4	T5	
Meat weight /total weigh, %	27.95±4.61	25.92±3.56	24.10±0.76	28.65±2.53	30.21±2.39/	29.27±1.95
Shell weight /total weight, %	52.76±4.14	53.05±2.77	51.53±0.43	52.72±0.93	58.24±3.16/	50.73±2.83
Water content/total weight, %	19.28±8.39	21.03±6.24	24.38±1.18	18.64±3.46	11.56±5.01/	24.38±1.18

T1=seabass and 0.5 kg/0.5 m^3 carpet-shell clams; T2=seabass and 1.0 kg/0.5 m^3 carpet-shell clams; T3= seabass and 0.5 kg/0.5 m^3 short-necked clam; T4= seabass and 1.0 kg/0.5 m^3 short-necked clam; T5= seabass and 0.5 kg/0.5 m^3 carpet-shell clams and 0.5 kg/0.5 m^3 short-necked clam; Values in the same row with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA.

2. Experiment 2: Effects of Integrated aquaculture system of the European seabass (*Dicentrarchus labrax*) and different stocking densities of the whiteleg shrimp *(Litopenaeus vannamei)* on the growth performance and survival rate of seabass

2.1. Water quality findings

The study results confirm that there were no statistically significant changes ($P > 0.05$) in the experimental measurements of salinity, temperature, pH, or dissolved oxygen. The mean measured values for temperature, pH, oxygen, and salinity were 23.03± 0.06ºC, 8.11± 0.01, 6.73± 0.08ppm, and 32.86± 0.05ppt, respectively. Statistically significant variations ($P < 0.05$) were observed in total ammonia nitrogen (TAN) and unionized ammonia (NH3) among the treatments. A higher stocking density of shrimp in seabass ponds resulted in a statistically significant rise ($P < 0.05$) in TAN and NH3 levels. Treatments G2 and G3 demonstrated acceptable levels of ammonia by-products in comparison to the control treatment (seabass monoculture). The ammonia levels (NH_4 and NH_3) in the G1 group were not statistically significant in comparison to the control group G0. Ammonia levels were substantially highest in groups G4 and G5 (Fig. 2).

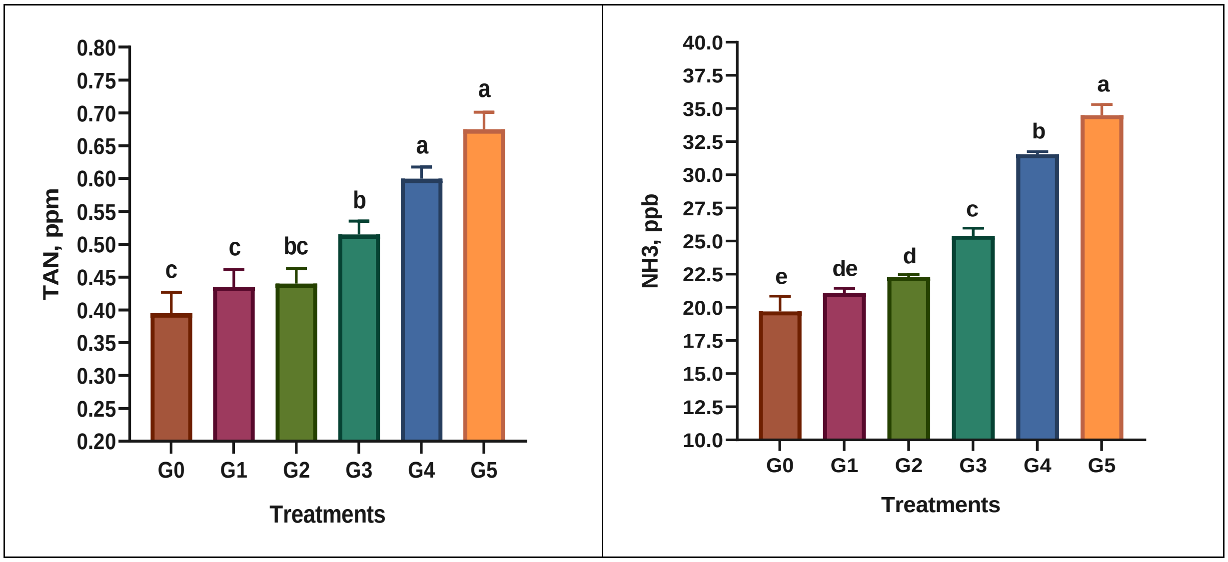

Fig. 2. Total ammonia nitrogen (TAN) and un-ionized ammonia (NH3) in tank water of the European seabass (*Dicentrarchus labrax*) integrated with different stocking densities of Whiteleg shrimp (*Litopenaeus vannamei*) in the same pond. *(G0) seabass + zero shrimp per hapa; (G1) seabass + 5 shrimps per hapa; G2) seabass + 10 shrimp per hapa; (G3) seabass + 15 shrimp per hapa; (G4) seabass + 20 shrimp per hapa; and (G5) seabass + 25 shrimp per hapa; Values in the same bar with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA.

2.2. Growth performance and survival of seabass

As shown in Table (7), the final body weight of seabass increased significantly ($P \leq 0.05$) in all treatment groups compared to the control (G0). G2, where seabass were cultivated with 10 shrimp per hapa, recorded the highest final body weight. However, G4, where seabass were cultivated with 20 shrimp per hapa, showed the same final body weight as the control (G0). Based on these results, G2 had the highest values for weight gain (WG), average daily gain (ADG), survival growth rate (SGR), and relative growth rate (RGR). Additionally, G4 shared the same significant values for WG, ADG, and RGR as the control (G0), while G5 showed a decrease in final body weight. In addition, G5 had the lowest values for WG, ADG, SGR, and RGR. Remarkably, G0, G1, G2, G3, and G4 all shared the same significant value for SGR, while G5 had the lowest SGR. It is worthy to note that there was no mortality in any of the treatments until the end of the experiment.

Table 7. Growth performance of *Dicentrarchus labrax* integrated with different stocking densities of *Litopenaeus vannamei* in the same pond

Growth parameters	Treatments*					
	G0	G1	G2	G3	G4	G5
Initial Weight, (gm/fish)[1]	120.33±0.88	121.83± 0.44	121.33± 0.73	120.63 ± 0.68	120.07±0.47	121.47 ± 0.29
Final weight, (gm/fish)	200.64±1.61^{c}	215.45±1.58^{a}	219.82±1.63^{a}	209.00 ± 1.24^{b}	197.50±1.94^{c}	186.82±2.49^{d}
Weight gain, (gm/fish)	80.31 ± 2.28^{c}	93.62± 2.02^{ab}	98.49 ± 0.91^{a}	88.37 ± 0.75^{b}	77.43 ± 2.34^{c}	65.35 ± 2.62^{d}
ADG, (gm/fish/day)	1.34 ± 0.04^{c}	1.56 ± 0.03^{ab}	1.64 ± 0.02^{a}	1.47 ± 0.01^{b}	1.29 ± 0.04^{c}	1.09 ± 0.04^{d}
SGR, (%/fish/day)	0.852± 0.02^{ab}	0.950 ± 0.02^{a}	0.990 ± 0.01^{a}	0.916 ± 0.01^{a}	0.829± 0.02^{ab}	0.717 ± 0.02^{b}
RGR, (%/fish)	166.77± 2.31^{c}	176.85±1.93^{ab}	181.17±0.29^{a}	173.25 ± 0.56^{b}	164.50±2.19^{c}	153.81±2.23^{d}
Survival, %	100	100	100	100	100	100

Mean of the initial weight = 120.89 ± 0.27 gm; *(G0) seabass + zero shrimp per hapa; (G1) seabass + 5 shrimps per hapa; G2) seabass + 10 shrimp per hapa; (G3) seabass + 15 shrimp per hapa; (G4) seabass + 20 shrimp per hapa; and (G5) seabass + 25 shrimp per hapa; Values in the same row with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA.

2.3. Feed utilization of seabass

As shown in Table (8), there was a significant decrease ($P \leq 0.05$) in the feed conversion ratio (FCR) of seabass in all treatments compared to the control (G0). The lowest FCR and feed intake values were recorded in G4. However, significant increases ($P \leq 0.05$) in the protein efficiency ratio (PER) and protein productive value (PPV) were observed in all treatments compared to G0. The highest PER values were recorded in G4 and G5, while the lowest value was recorded in G1. G2 and G3 shared the same significant PER value. The highest PPV was recorded in G3, while G2 had the lowest value, followed by G1 and G5.

Additionally, G1, G3, and G4 had the highest values for energy gain and energy utilization, while the lowest values were recorded in G5, G2, and the control (G0). The highest energy gain values were reported in G3, followed by G1 and G4. The lowest energy gain values were recorded in G5, G2, and G0. Energy utilization in the control (G0) was reported as 3.297 ± 0.55%. The energy utilization values were highest in G4, followed by G3 and G1, with the lowest values recorded in G2 and G5.

2.4. Carcass chemical composition of seabass

The analysis of the body chemical composition (including dry matter, crude protein, crude ether extract, crude ash, crude fiber, and total body energy) of seabass integrated with different stocking densities of *Litopenaeus vannamei* in the same pond after 60 days of feeding is presented in Table 9. The results showed a significant decrease ($P \leq 0.05$) in the dry matter content of seabass in all treatments compared to the control (G0). The lowest dry matter values were recorded in G2, G4, and G5.

There was a significant increase ($P \leq 0.05$) in protein content and body energy in seabass in all treatments compared to the control (G0). The highest protein content and body energy values were recorded in G4, followed by G5 and G3, while the lowest values were reported in G1 and G2. Additionally, G4 recorded the highest value for ether extract, followed by G5. G1, G2, and G3 shared the same significant ether extract value as the control (G0), as shown in Table (3).

G1, G3, and G4 had the highest values for ash content, while G2 and G5 had ash values close to the control (G0). On the other hand, the highest fiber values were recorded in fish reared in G3 and G4, whereas G1, G2, and G5 shared the same significant fiber value as the control.

Table 8. Feed utilization of the European seabass (*Dicentrarchus labrax*) integrated with different stocking densities of the whiteleg shrimp (*Litopenaeus vannamei*) in the same pond

Parameter	Treatments*					
	G0	G1	G2	G3	G4	G5
Feed Intake, gm	161.96 ± 1.50^{b}	181.34 ± 4.71^{a}	187.44 ± 1.17^{a}	166.12 ± 0.76^{b}	142.87 ± 5.03^{c}	118.52 ± 4.90^{d}
FCR	2.02 ± 0.06^{a}	1.94 ± 0.01^{b}	1.90 ± 0.01^{bc}	1.88 ± 0.01^{bcd}	1.84 ± 0.01^{cd}	1.81 ± 0.01^{d}
PER, (gm)	1.08 ± 0.03^{d}	1.12 ± 0.01^{c}	1.14 ± 0.00^{bc}	1.16 ± 0.01^{bc}	1.18 ± 0.01^{ab}	1.20 ± 0.01^{a}
PPV, (%)	8.06 ± 0.73^{d}	9.73 ± 0.20^{bc}	7.74 ± 0.14^{d}	11.49 ± 0.24^{a}	11.13 ± 0.21^{ab}	8.58 ± 0.77^{cd}
Energy gain, (Kcal)	26.33 ± 4.64^{c}	43.23 ± 3.24^{a}	23.45 ± 1.91^{c}	43.83 ± 1.67^{a}	40.91 ± 3.74^{a}	11.50 ± 7.43^{d}
Energy utilization, (%)	3.297 ± 0.55^{bc}	4.835 ± 0.23^{ab}	2.543 ± 0.20^{c}	5.367 ± 0.20^{a}	5.799 ± 0.32^{a}	1.928 ± 1.14^{c}

*(G0) seabass + zero shrimp per hapa; (G1) seabass + 5 shrimps per hapa; G2) seabass + 10 shrimp per hapa; (G3) seabass + 15 shrimp per hapa; (G4) seabass + 20 shrimp per hapa; and (G5) seabass + 25 shrimp per hapa; Values in the same row with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA.

Table 9. Carcass composition of the European seabass (*Dicentrarchus labrax*) integrated with different stocking densities of the whiteleg shrimp (*Litopenaeus vannamei*) in the same pond

Body composition	Initial sample	Final sample					
		Treatments*					
		G0	G1	G2	G3	G4	G5
Dry matter, %	34.81 ± 0.21	25.22 ± 0.16^{a}	24.71 ± 0.04^{b}	22.26 ± 0.08^{f}	24.26 ± 0.60^{c}	23.78 ± 0.12^{d}	23.35 ± 0.22^{e}
Protein, %	56.83 ± 0.21	58.94 ± 0.86^{e}	60.55 ± 0.16^{d}	62.72 ± 0.10^{c}	64.39 ± 0.08^{b}	66.20 ± 0.16^{a}	65.86 ± 0.04^{a}
Ether extract, %	26.40 ± 0.31	20.26 ± 0.01^{c}	20.50 ± 0.01^{c}	19.71 ± 0.57^{c}	20.66 ± 0.12^{c}	23.39 ± 0.03^{a}	21.91 ± 0.52^{b}
Ash, %	16.14 ± 0.03	13.79 ± 0.35^{bc}	15.54 ± 0.49^{a}	13.77 ± 0.35^{bc}	16.34 ± 0.05^{a}	14.97 ± 0.34^{ab}	13.54 ± 0.71^{c}
Fiber, %	2.24 ± 0.05	2.44 ± 0.01^{b}	2.53 ± 0.01^{b}	2.38 ± 0.03^{b}	3.30 ± 0.12^{a}	3.47 ± 0.03^{a}	2.81 ± 0.35^{b}
Body energy	0000 ± 4.75	523.64 ± 4.75^{e}	535.03 ± 1.04^{de}	539.78 ± 5.42^{d}	558.21 ± 1.59^{c}	594.20 ± 1.01^{a}	578.25 ± 5.06^{b}

*(G0) seabass + zero shrimp per hapa; (G1) seabass + 5 shrimps per hapa; G2) seabass + 10 shrimp per hapa; (G3) seabass + 15 shrimp per hapa; (G4) seabass + 20 shrimp per hapa; and (G5) seabass + 25 shrimp per hapa; Values in the same row with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA.

2.5. Growth performance, survival and feed utilization of shrimp

The final weight of shrimp showed a significant increase ($P < 0.05$) compared to the initial weight in all groups. The highest final weight was recorded in G1, followed by G2 and G4. Remarkably, the highest values for weight gain (WG), average daily gain (ADG), survival growth rate (SGR), and relative growth rate (RGR) were observed in G1. As shown in Table (10), G5 reported the lowest values for WG, ADG, SGR, and RGR, while G2, G3, and G4 had WG, ADG, SGR, and RGR values that were similar to each other, following the highest values observed in G1.

The highest survival rate for shrimp was recorded in G2 (96.67 ± 3.33%) and G4 (95.00 ± 2.89%) (Table 10). Additionally, the highest feed intake was recorded in G1, while the lowest feed intake was recorded in G5, with G2, G3, and G4 sharing similar feed intake values. Furthermore, the data showed that G4 and G5 had the highest food conversion ratio (FCR) compared to G1, G2, and G3.

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Table 10. Growth performance, survival and feed utilization of the whiteleg shrimp (*Litopenaeus vannamei*) cultivated with different stocking densities and integrated with the European seabass (*Dicentrarchus labrax*) in the same pond

Growth parameters	Treatments*				
	G1	G2	G3	G4	G5
Final weight, g [1]	13.167 ± 0.12^{a}	12.443 ± 0.08^{b}	12.087 ± 0.16^{bc}	11.907 ± 0.11^{c}	11.100 ± 0.12^{d}
Weight gain, g/day	7.68 ± 0.14^{a}	6.96 ± 0.10^{b}	6.60 ± 0.15^{bc}	6.42 ± 0.11^{c}	5.61 ± 0.10^{d}
Average daily gain, g/day/shrimp	0.137 ± 0.002^{a}	0.124 ± 0.001^{b}	0.118 ± 0.003^{bc}	0.115 ± 0.002^{c}	0.100 ± 0.002^{d}
SGR, %/ shrimp/ day	1.56 ± 0.02^{a}	1.46 ± 0.02^{b}	1.41 ± 0.02^{bc}	1.38 ± 0.02^{c}	1.26 ± 0.01^{d}
RGR, %	240.0 ± 2.94^{a}	226.8 ± 2.19^{b}	220.3 ± 2.61^{bc}	217.0 ± 2.01^{c}	202.3 ± 1.44^{d}
Survival, %	93.33±6.67	96.67±3.33	91.11±5.88	95.00±2.89	88.00±2.31
Feed intake, g/shrimp	11.90 ± 0.25^{a}	11.00 ± 0.13^{b}	10.65 ± 0.21^{b}	10.70 ± 0.17^{b}	9.85 ± 0.21^{c}
FCR	1.55 ± 0.01^{e}	1.58 ± 0.01^{d}	1.61 ± 0.01^{c}	1.67 ± 0.01^{b}	1.75 ± 0.01^{a}

* (G1) seabass + 5 shrimps per hapa; G2) seabass + 10 shrimp per hapa; (G3) seabass + 15 shrimp per hapa; (G4) seabass + 20 shrimp per hapa; and (G5) seabass + 25 shrimp per hapa; Values in the same row with a different superscript are significantly different ($P \leq 0.05$). Data were analyzed by one-way ANOVA.

DISCUSSION

Fish development and health are directly correlated with the culture system employed and the quality of the water in which they are raised **(Elhetawy *et al.*, 2020)**. Countless factors, such as the rearing population density, the kind of culture system, the raising environment, and management practices, affect the growth of fish raised in traditional monocultures **(Cheyadmi *et al.*, 2023)**. However, IMTA systems absorb and recycle fish waste effectively, and subsequently reducing concentrations in water bodies and mitigating environmental damage **(Tacon *et al.*, 2022)**. The findings of the present study verify that the integrated cultivation of marine fish and clams has a notable beneficial impact on the reduction of ammonia levels in water within seabass farming ponds. The reduction rates varied between 20 and 60% in ponds that included clams, as compared to the control group. In consistent with the current result, **Domingues *et al*. (2020)** stated that bivalves are great for IMTA since they can help get rid of extra nutrients and nitrogen in sediments through bioturbation and have great filtration abilities. Furthermore, bivalves have the ability to sequester nitrogen in sediments and promote the denitrification process by stimulating microbial activity in bivalve sediments **(Kellogg *et al*., 2014)**. Concerning the water quality in the combined seabass-shrimp aquaculture ponds (second experiment), the research discovered that the number of shrimp farmed in the seabass ponds increased and so did the amount of ammonia residues, and the other way around. Regrettably, we cannot refer to or cite any international studies in this regard. Nevertheless, the results were within acceptable limits for both seabass **(Moretti *et al.*, 1999)** and shrimp **(Tong *et al*., 2023)**.

The results showed that organisms cultured in the IMTA set up realized better growth and production than those in the control monoculture system. Individual weight gain and total production differed among cultured species in the different treatments which agree with studies by **Cunha *et al*. (2019)**. The utilization of growth performance indicators, along with water and sediment quality assessments facilitated a deeper understanding of organism-environment interactions **(Cotou *et al*., 2024)**. Farmers and scientists deem it reasonable to evaluate growth performance using vital indicators including survival rate, body weight gain (WG), specific growth rate (SGR), feed conversion ratio (FCR), relative growth rate (RGR), and average daily gain (ADG). The survival rate is a reliable indicator of fish growth performance, as it is influenced by several key factors, including the development stage, stress levels in the rearing environment, and disease resistance. Therefore, there is a correlation between the survival rate and the economic value of the fish biomass produced **(Cotou *et al.*, 2024)**.

According to the present results, the highest growth performance values for *D. labrax* (final weight [FW], weight gain [WG], average daily gain [ADG], survival growth rate [SGR], relative growth rate [RGR], and survival) were observed when *D. labrax* was cultivated with 0.5kg/ 0.5m^3 *Ruditapes decussatus* and 0.5kg/ 0.5m^3 *Paphia undulata*. Additionally, the highest feed utilization values (feed intake [FI], protein efficiency ratio [PER], protein productive value [PPV], and energy gain) were observed in this treatment, with the lowest feed conversion ratio (FCR) recorded. In aquaculture systems, a low FCR is crucial because it indicates reduced uneaten feed and fish waste in the system, leading to lower feed requirements and reduced feeding costs **(Cotou *et al.*, 2024)**.

Since they have a highly effective filtration mechanism that allows them to collect a lot of phytoplankton and other suspended particulate matter, bivalves have been employed in IMTA systems **(Pensa *et al*., 2022)**. Additionally, in this study, clams were used as filter feeders and contributed to the increased biomass and efficiency of the system. Furthermore, it was discovered that integrating clams into the co-culture IMTA pond system with seabass was possible due to the improvement of water quality and the increase in sea bass productivity. Several studies have shown that extractive species in IMTA systems grow faster than in monoculture which implies that IMTA farms can provide greater economic gains and environmental benefits **(Sanderson *et al*., 2012)**.

The current study's outcomes demonstrated the viability of integrating *L. vannamei* with seabass. Significant differences were seen in the performance of *L. vannamei* between populations with low and high densities ($P< 0.05$). It was displayed at parameters with greater values, such as the average final weight, survival rate, daily growth, and FCR. On the other hand, compared to 5, 10, 15, and 20 shrimp per hapa, the biomass output is higher with a density of 25 shrimp per hapa. The average weight, survival rate, daily growth, and FCR of *L. vannamei* all seem to be impacted by stocking density. With five shrimp produced with seabass per hapa, the G1 shrimp culture in the study had the highest survival rate. Despite the fact that the densities used were usually comparable, some researchers have treated. **Suriya *et al.* (2016)** reported maintaining 65 and 85 prawn's m^2 density to produce an 80–90% survival rate of *L. vannamei*. **Sookying *et al.* (2011)** obtained survival rate between 45 and 47% with density of 10 and 20 shrimp m^2. While **Gaber *et al* (2012)** reported survival rate of 51.60-89.0% with density of 5, 15 and 25 shrimp m^3, where the survival rate decreased with increasing of the density. The highest feed conversion ratio (FCR) for the whiteleg shrimp was recorded in G4 and G5, which is congruent with the findings of **Wyban *et al*. (1995)**, who reported an FCR value of 1.8 when *L. vannamei* was cultured at a density of 50 individuals/m^2. Since growth performance is influenced by diet, the highest growth performance parameters were recorded in G1, followed by G2, G3, G4, and finally G5. These findings suggest that the whiteleg shrimp grown in an integrated multitrophic aquaculture (IMTA) system exhibit superior growth performance compared to shrimp grown in a monoculture system **(Effendi, 2016)**.

Using conventional techniques like clam baskets, clams were successfully grown in IMTA settings and proved to be an efficient bioremediatory in integrated farming systems with fish, since the nutrient concentration in the surrounding environment resulted considerably reduced as when integrating seaweeds into marine aquaculture systems **(Chopin *et al*., 2001)**. The present IMTA system showed that, the cultivation of seabass with 0.5kg/ 0.5 m^3 *Ruditapes decussatus* (Carpet-shell clams) and 0.5kg/ 0.5m^3 **Paphia undulata** (The short-necked clams) resulted in a good biomass increase. This conclusion is significant because it implies that the biomass of *R. decussatus* and *P. undulata* may be used as a possible source of chemicals that are advantageous to human diet. It was obtained that survival was greater or equal to 75% for *Ruditapes decussatus* (Carpet-shell clams) and greater or equal to 85% for *Paphia undulata* (Short-necked clam), in addition the survival rate was greater or equal 95%.

An integrated bivalve-fish culture paradigm is an appealing notion that seems to have a lot of potential. There have been a few researches done on the possibility of polyculture in open water. According to some researchers, bivalves may utilize the waste products from fish farms as a source of additional food **(Mazzola & Sarà 2001)**. This could explain, for instance, the enhanced growth of oysters **(Jones & Iwama, 1991)** raised next to fish cages. However, in the present study, T5 achieved the best final clam biomass. A comparison of particle retention efficiency and clearance rate (CR) among various bivalves was conducted by **Pouvreau *et al.* (1999)**. In the case of *Ruditapes decussatus* (Carpet-shell clams) and *Paphia undulata* (Short-necked clams), a certain level of biomass was produced in the aquaculture facility. These clam species were cultivated in an integrated multitrophic aquaculture (IMTA) system to remove waste and generate a valuable byproduct for bioremediation. Upon comparing the clams produced in this system with natural populations, significant discrepancies in weight and length measurements were observed. This suggests that clams can successfully thrive in multitrophic environments. While some studies report that oysters grown in fish cages exhibit faster growth, others find no significant increase in growth at all **(Troell *et al.*, 2009)**. Previous research on co-cultivating mussels and salmon showed no difference in metal levels or antibiotic usage compared to conventional monoculture **(Hughes *et al.*, 2016)**. Additionally, investigations into the safety of holothurians' food found no significant differences in metal concentrations when compared to natural populations **(Robinson *et al.*, 2019)**.

To meet market demand, prawn farming needs to be developed as one of the marine commodities with economic worth. When the IMTA system is applied, the whiteleg shrimp are used as a byproduct that can boost earnings, while seabass fish use the leftover shrimp feed and bio-fouling, which stops shrimp growth. According to **Shah *et al*. (2017)**, seabass fish can develop and grow using the IMTA system, proving that fish at various trophic levels may be raised using this method. Seabass, the main commodity on the IMTA system, should perform better than the monoculture system in better water conditions. The growth performance with IMTA system is superior than monoculture, as indicated by the final weight of seabass in the monoculture system (G0) of 200.64± 1.61g and the final weight of seabass in IMTA (G1, G2, and G3) having greater value than G0. According to the results of **Abreu *et al*. (2009)**, the utilization of integrated cultivation systems can potentially mitigate the negative effects of feed used in cultivation activities on the water environment. A byproduct of cultivation, high ammonia from the aquatic environment can also be used with the help of seaweed when it is included into the IMTA system. Shrimp farming using the IMTA technology can contribute to the sustainability and well-being of the ecosystem **(Aghuzbeni *et al.*, 2017)**.

CONCLUSION

Egypt's marine aquaculture industry, particularly seabass and sea bream farming, is facing significant challenges, especially for species that require a two-year cultivation period with no sales or returns during this time. This situation places considerable stress on fish producers. Integrated multi-trophic aquaculture (IMTA) is considered an ideal solution. IMTA involves growing multiple organisms within the same fish cages, which helps optimize resource use and improve sustainability. The selection of organisms in local IMTA practices is largely influenced by customs, commercial values, and market demand. This flexibility allows fish farmers to adjust their strategies based on market conditions and their management skills. The species combination and pond environment are key factors in increasing production, indicating that IMTA is not only a profitable business but also helps maintain a cleaner culture environment while reducing costs and inputs. Growth performance of seabass was better in IMTA treatments than in the control (monoculture). Additionally, the co-cultured species, such as clams and shrimp, showed good growth in the IMTA system. Researchers and scientists in the aquaculture field have been actively developing technology in recent years to help marine aquaculture communities achieve higher production levels.

ETHICAL ASPECTS

All animal experiments and protocols were approved by the ethical committee of the Faculty of Science, Tanta University, Tanta, Egypt **(code no. IACUC-SCI-TU-0175)**. This article is derived from a doctoral dissertation titled: "Bio-Economic Assessment of Marine Integrated Multi-Trophic Aquaculture (IMTA) versus Monoculture in Egypt Using Sea Bass Fish as an Experimental Model."

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