Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(4): 4761 – 4776 (2025)
www.ejabf.journals.ekb.eg

Effect of Fish and Mollusk Meal in Feed on Digestive Enzyme Activity, Feed Efficiency, and Growth Performance of Ornate Spiny Lobster (*Panulirus ornatus*)

Agus Kurnia[1*], Yusnaini[1], Wellem H.Muskita[1], Muhaimin Hamzah[1], La Ode Baytul Abidin[1], Muhammad Idris[1], Rahmad Sofyan Patadjai[1], Ruslaini[1], La Ode Aslin, Abdul Muis Balubi[1], Wa Iba[1], Indriyani Nur[1], Abdul Rahman[1], Asis Bujang[1], La Ode Muhammad Aslan[1], Irwan Junaidi Effendy[1], La Usaha[2], La Ode Abdul Razak[2]

[1]Department of Aquaculture, Faculty of Fisheries and Marine Science, Universitas Halu Oleo. Jl. H.E.A Mokodompit No.1 Kendari 93232,Southeast Sulawesi, Indonesia

[2]Study program of Fisheries Science, Graduate School Universitas Halu Oleo. Jl. H.E.A Mokodompit No.1 Kendari 93232,Southeast Sulawesi, Indonesia

[*]**Corresponding Author: aguskurnia@uho.ac.id**

ARTICLE INFO
Article History:
Received: May 29, 2025
Accepted: July 25, 2025
Online: Aug. 10, 2025

Keywords:
Ornate spiny lobster,
Mollusk meal,
Fish meal,
Digestive enzyme activity,
Growth performance

ABSTRACT

The ornate spiny lobster (*Panulirus ornatus*) is a high-value aquaculture species in Indonesia. Developing sustainable and environmentally friendly feed is essential to support the lobster farming industry. This study evaluated the effects of fish meal- and mollusk meal-based formulated diets on digestive enzyme activity, feed efficiency (FE), and growth performance of *P. ornatus*. Four experimental diets were tested: Diet A (20% sardine meal and 20% jack mackerel meal), Diet B (10% telescopium muscle meal, 15% golden snail meal, and 15% mud scallop meal), Diet C (15% telescopium muscle meal, 10% golden snail meal, and 15% mud scallop meal), and Diet D (15% telescopium muscle meal, 15% golden snail meal, and 10% mud scallop meal). Parameters measured included digestive enzyme activity (amylase, protease, and lipase), feed efficiency, and growth performance over a 50-day feeding trial. Lobsters fed mollusk-based diets (Diets B, C, and D) exhibited significantly higher growth, greater feed efficiency, and enhanced digestive enzyme activity compared to those fed the fish meal-based diet (Diet A). In conclusion, mollusk meal-based diets can improve digestive enzyme activity, FE, and growth performance in *P. ornatus*.

INTRODUCTION

Ornate spiny lobster (*Panulirus ornatus*) is one of the most valuable crustacean fishery commodities in Indonesia due to its high economic value. Lobster cultivation has steadily increased in recent years **(Jones *et al.*, 2019; Nguyen *et al.*, 2022)**. This growth is driven partly by a 4.15% increase in global consumption of marine animals, including lobster, resulting from changes in dietary patterns and a greater public understanding of

the health benefits of seafood **(Utama *et al.*, 2021; Bakhsh *et al.*, 2023)**. Another factor is the high market price of Indonesian lobster, which can reach USD 36/kg; during Chinese New Year, the price can rise to USD 65/kg, and upon arrival at restaurants, the selling price may reach USD 90/kg **(Made *et al.*, 2025)**.

Feeding management is a critical determinant of successful lobster cultivation **(Rizqullah *et al.*, 2024)**. Farmers often rely on trash fish or shellfish as feed. However, providing trash fish or other fresh feeds, such as mollusks, is not sustainable **(Astuti *et al.*, 2023)**. Fresh feed can negatively impact aquaculture by reducing water quality through organic pollution and contributing to overexploitation of fish stocks used for feed. In addition, trash fish may act as disease vectors in lobster culture **(Tacon *et al.*, 2013; Yusoff *et al.*, 2024)**. This highlights the need to transition from fresh feed—including trash fish, mollusks, and bivalves—to formulated pellet diets for more sustainable and environmentally friendly cultivation **(Goncalves *et al.*, 2024)**.

Growth in fish and shrimp is strongly influenced by feed intake and nutrient composition **(Evrendilek, 2024; Kurnia *et al.*, 2024; Nunes *et al.*, 2024)**. Feed digestion is facilitated by enzymes such as amylase, protease, and lipase, and growth is linked to the efficiency of these enzymes **(Fuchs, 2022; Guan *et al.*, 2022; Klahan *et al.*, 2023)**. Enzymatic activity ensures efficient nutrient acquisition for growth **(Candiotto *et al.*, 2018; Fang *et al.*, 2019; Muttharassi *et al.*, 2021; Navarro-Guillén *et al.*, 2022)**. Previous studies have examined enzyme activity and growth in juvenile *P. ornatus* **(Genodepa *et al.*, 2023; Saputra & Fotedar, 2024)**, as well as the effects of restricted feeding on *Panulirus homarus* **(Sekartadji *et al.*, 2023)**. Other research has investigated feed formulations, enzyme activity, and growth in lobsters **(Gora *et al.*, 2018; Buckova, 2022; Giri *et al.*, 2023; Goncalves *et al.*, 2024; Sudewi *et al.*, 2024)**.

In addition to enzyme activity, intestinal morphology—specifically villus length and width—also affects digestion. Larger villi increase the absorptive surface area, improving digestion efficiency in fish and shrimp. Feeding habits can influence digestive tract structure and gut microbiota **(Li *et al.*, 2021; Jiao *et al.*, 2023; Fu *et al.*, 2024; Hasanthi *et al.*, 2024; Neves *et al.*, 2024)**. Alterations in intestinal morphology, such as changes in villus width (VW) and muscularis thickness (MT), can impact nutrient absorption and gut microbial communities **(Limbu *et al.*, 2018)**.

Nutritional studies have addressed feed formulation and amino acid profiles in *P. ornatus* fed combinations of three mollusk meals **(Kurnia *et al.*, 2024)**, and the effects of fresh blue mussel (*Mytilus galloprovincialis*) supplementation on juvenile slipper lobster (*Thenus australiensis*) **(Landman *et al.*, 2020)**. The influence of flesh ingredient format and krill meal on growth and feeding behavior of juvenile *P. ornatus* has also been examined **(Marchese *et al.*, 2018)**. However, no studies have specifically focused on the biochemical responses of *P. ornatus* to feed formulations containing both mollusk and fish meal. Therefore, this study aimed to evaluate the effects of formulated diets

containing fish and mollusk meal on digestive enzyme activities and growth performance in ornate spiny lobster.

MATERIALS AND METHODS

Experimental feed

Four experimental feed were formulated to contain a different combination of fish and mollusk meal including 20% jackmackerel meal + 20% sardine fish meal (Diet A), 10% telescopium muscle meal (TMM) + 15% golden snail meal (GSM) + 15 mud scallops meal (MSM) (Diet B), 15% TMM + 10% GSM + 15% MSM (Diet C), and 15% TMM + 15% GSM + 10% MSM (Diet D). All feed ingredients are shown in Table (1).

Table 1. Formulation of all test feed for ornate spiny lobster and results of proximate analysis

	Test Feed (g/100 g feed)			
Feed Ingredient	**A**	**B**	**C**	**D**
Sardine fish meal (SFM)	20	0	0	0
Jackmackerel fish meal (JFM)	20	0	0	0
Telescopium muscle meal (TMM)	0	10	15	15
Golden snail meal (GSM)	0	15	10	15
Mud scallops meal (MSM)	0	15	15	10
Shrimp head meal	15	15	15	15
Soybean meal	25	25	25	25
Corn meal	9	9	9	9
Fine bran meal	5	5	5	5
Sago meal	4	4	4	4
Corn oil	0.5	0.5	0.5	0.5
Fish oil	0.5	0.5	0.5	0.5
Squid oil	0.5	0.5	0.5	0.5
Vitamin and mineral mix*	0.5	0.5	0.5	0.5
Total	100	100	100	100
Results of proximate analysis of the test feed (%)				
Moisture	9.93	9.36	9.15	9.71
Crude protein	38.52	33.76	35.52	35.56
Crude lipid	2.96	1.74	1.99	1.11
Ash	13.17	11.34	10.39	10.9
Fiber	9.66	10.39	11.36	11.12
Carbohydrate	35.42	43.8	42.95	42.72
Lipid energy (Kcal/100 g)	26.64	15.66	17.91	9.99
Total energy (Kcal/100 g)	322.4	325.9	331.79	323.11

* Vitamin E 8.000 IU, Vitamin K3 2.000 mg, Vitamin B12.000 mg, Vitamin B2 5.000 mg, Vitamin A 12.000.000 IU, Vitamin D3 2.000.000 IU,Vitamin B6 500 mg, Vitamin C 25.000 mg, Calcium-D-pantothenate 6.000 mg, Niacin 40.000 mg, Cholin chloride 10.000 mg,Vitamin B12 12.000 ug, Methionine 30.000 mg, Lysine 30.000 mg, Zinc 100.000 mg, Cobalt 200 mg, Copper 4.000 mg Manganese 120.000 mg, Iron 20.000 mg, Iodine 200 mg.

Test lobster

Ornate spiny lobsters were caught in the marine waters of Southeast Sulawesi, Indonesia. They were transported to the Seawater Cultivation Laboratory, Faculty of Fisheries and Marine Science, Halu Oleo University, and placed in a one-ton fiber tank for temporary storage (five days) to reduce stress and acclimate to laboratory conditions. Lobsters were weighed and grouped into three categories based on body weight: 153.3 ± 15.3 g (Group 1), 183.33 ± 15.3 g (Group 2), and 218 ± 12.3 g (Group 3). A total of 24 lobsters were distributed into 12 aquariums (two lobsters per aquarium, 60 × 40 × 50 cm^3) and maintained for one week to adapt to experimental conditions. During acclimatization, lobsters were fed trash fish at 10% of total biomass for five days (17:00 h feeding), then fish flesh was gradually reduced until only pellets were consumed.

Feeding trial

After acclimatization, the 24 lobsters were housed in plastic containers with a seawater recirculation system (salinity: 30–33 ppt) for a 50-day feeding trial. One day before the trial began, lobsters were fasted for 24h to ensure that weight measurements reflected true body weight. Feeding occurred twice daily (09:00 and 17:00) at approximately 2% of body weight. Seawater was replaced weekly (30% of container volume). Weight measurements were taken on days 0, 25, and 50. Each morning, uneaten feed and feces were removed by siphoning. Leftover feed was sun-dried and weighed to calculate feed consumption.

Proximate analysis of test feeds

Test feeds were analyzed for crude lipid, crude ash, moisture, crude protein, and fiber content. Moisture content was determined using the oven-drying method at 110°C (SNI 01-2891-1992, point 5.1). Protein content was determined using the Kjeldahl method (18-8-31/MU/SMM-SIG). Total fat content was measured by Soxhlet extraction (18-8-5/MU/SMM/SIG, point 3.2.1). Ash content was determined by incineration at 600 °C (SNI 01-2891-1992, point 6.1). Crude fiber was measured using strong acid and base digestion (18-11-111/MU/SMM-SIG, gravimetry method).

Sample preparation for enzyme assay

Enzyme activity (protease, lipase, amylase) was measured in the hepatopancreas and intestine at the start (day 0) and end (day 50) of the feeding trial. Lobsters were anesthetized with dry ice for 10 min, dissected, and intestines were removed and weighed. A buffer solution (20 mM HCl, 1 mM EDTA, 10 mM $CaCl_2$, pH 7.5) was added at 10% of tissue weight. Samples were placed in Eppendorf tubes and centrifuged at 12,000 rpm for 10min at 4°C. The supernatant was collected for enzyme assays and stored at −20°C until use **(Ou *et al.*, 2018)**.

Digestive enzyme activity measurement

Protease — Activity was determined according to **Bergmeyer and Grassi (1983)**. Tubes for samples, standards, and blanks were prepared with 1mL of 0.05 M phosphate buffer (pH 7) and 1mL of casein substrate solution (20mg/ mL, pH 7). Sample tubes received 0.2mL of enzyme extract; standard tubes received 0.2mL of 5mmol/mL tyrosine; blanks received 0.2mL distilled water. Tubes were incubated at 37°C for 10min. Then, 2mL of 0.1 M TCA was added to all tubes. Additional reagents (0.2mL of 2mmol/ L $CaCl_2$ for blanks and standards; 0.2mL distilled water for samples) were added. Filtrates (1.5mL) were mixed with 1mL Folin–Ciocalteu reagent and 5mL of 0.4 M Na_2CO_3. Absorbance was measured at 578nm.

Lipase — Activity was measured following **Borlongan (1990)**. A total of 1mL lipase substrate in 1.5mL of 0.1 M Tris–HCl buffer (pH 8.0) was mixed with 1mL enzyme extract and incubated at 37°C for 6 h. Before ending incubation, 3mL of 95% ethanol was added. The mixture was titrated with 0.01 N NaOH using 0.9% thymolphthalein in ethanol as an indicator.

Amylase — Activity was measured according to **Worthington (1993)**. A total of 0.5mL substrate solution was added to 0.5mL enzyme extract and incubated at 95°C for 3min. Then, 0.5mL DNSA reagent was added and incubated again at 95°C for 5min. Absorbance was read at 540nm.

Measurement of intestine somato index (ISI)

Lobsters taken from the container were first weighed to record body weight, then dissected to remove the intestines. The intestinal somatic index (ISI), expressed as a percentage, was used to determine the relationship between intestinal weight and lobster body weight. ISI was calculated using the following equation **(Wu *et al*., 2011)**:

$$ISI = \text{Intestine weight (g)}/\text{Total body weight(g)} \times 100\ \%$$

Growth performance and data analysis

Growth performance of lobsters was assessed by measuring initial weight, final weight, weight gain ($WG = Wt - Wo$), specific growth rate ($SGR = (\ln Wt - \ln Wo) / t \times 100$), feed conversion ratio ($FCR = \text{feed intake} / (Wt - Wo)$), total feed consumption ($TFC = \text{dry feed given} - \text{dry feed remaining}$), and feed efficiency ($FE = (\text{final body weight} - \text{initial body weight}) / \text{feed intake}$). Additional parameters included protein retention ($PR = (\text{amount of lobster body protein at the end} - \text{amount at the beginning}) / \text{protein consumed during maintenance}$), net protein utilization ($NPU = WG / \text{total protein intake}$), protein efficiency ratio ($PER = WG / \text{dry weight of protein}$), and molting frequency **(Farizah *et al*., 2017; Kim *et al*., 2021)**.

All growth performance parameters (WG, SGR, FCR, TFC, FE, PR, NPU, PER) and digestive enzyme activity were analyzed using one-way analysis of variance

(ANOVA). Significant differences between treatments were determined using Duncan's Multiple Range Test (DMRT) in SPSS (Version 20.0), with a significance level of $P < 0.05$.

RESULTS

Digestive enzyme activity

Table (2) presents the digestive enzyme activity (lipase, amylase, and protease) test results. Enzyme activities at the end of the experiment were higher than at the start. Ornate spiny lobsters fed diet B (10% TMM + 15% MSM + 15% GSM) showed the highest digestive enzyme activity at the end of the trial. These results indicate that different combinations of fish and mollusk meal produced significantly different enzyme activity levels.

Table 2. Enzyme activity of ornate spiny lobster at the initial and the end of the experiment.

Enzyme activity	Initial	The end of the experiment			
		A	B	C	D
Amylase (IU/mL)	3.037±0.05	4.159±0.38^{a}	6.599±0.09^{b}	3.717±0.20^{a}	3.799±0.27^{a}
Lipase (IU/mL)	0.175±0.005	0.265±0.01^{b}	0.442±0.01^{c}	0.228±0.02^{a}	0.283±0.03^{b}
Protease(IU/mL)	0.412±0.04	0.478±0.05^{a}	0.782±0.05^{b}	0.440±0.023^{a}	0.495±0.00^{a}

Note: *) The values in same rows with different superscript letters indicate significant differences ($P < 0.05$).

Amylase showed the highest digestive enzyme activity, followed by protease and lipase. At the end of the experiment, the highest amylase activity was recorded in lobsters fed diet B (6.599 ± 0.09 IU/mL), followed by diet A (4.159 ± 0.38 IU/mL), diet C (3.799 ± 0.27 IU/mL), and diet D (3.620 ± 0.32 IU/mL). Statistical analysis revealed that different test feeds resulted in significant differences in amylase activity. Lobsters fed diet B had amylase activity significantly different from those fed diets A, C, and D, while amylase activity in lobsters fed diet A was not significantly different from those fed diets C and D.

The highest lipase activity was found in lobsters fed diet B (0.442 ± 0.01 IU/mL), followed by diet D (0.283 ± 0.03 IU/mL) and diet A (0.265 ± 0.01 IU/mL). Statistical analysis showed that different feeds led to significant differences in lipase activity. Lobsters fed diet B had lipase activity significantly different from those fed diets A, C, and D, while lipase activity in lobsters fed diet A was not significantly different from those fed diet D.

Protease activity in ornate spiny lobsters was higher at the end of rearing compared to the beginning. The highest protease activity was observed in lobsters fed diet B (0.782 ± 0.05 IU/mL), followed by diet D (0.495 ± 0.00 IU/mL), diet A (0.478 ± 0.05 IU/mL), and the lowest in lobsters fed diet C (0.440 ± 0.023 IU/mL).

Statistical analysis confirmed that different test feeds significantly affected protease activity. Lobsters fed diet B had protease activity significantly different from all other treatments, while protease activity in lobsters fed diet A was not significantly different from those fed diets C and D.

Results of the intestine somatic index (ISI), height, and width villi of lobster

The results of ISI, height, and width of villi in ornate spiny lobster after 50-day rearing period are shown in Table (3).

Table 3. Average of ISI, villi height and villi width of ornate spiny lobster (*P. ornatus*) at the end of feeding trial

Parameter	**Treatment groups**			
	A	**B**	**C**	**D**
ISI (%)	0.30±0.11	0.27±0.07	0.30±0.03	0.23±0.06
Villi height (µm)	132.24±0.95^{a}	315.36±11.08^{b}	312.09±16.53^{b}	304.42±1.47^{b}
Villi width (µm)	90.13±5.89^{a}	144.26±22.53^{b}	148.85±19.77^{b}	222.55±11.77^{c}

Different superscripts in the same column show that there are significant differences (P<0.05).

The ISI of ornate spiny lobster given test feed at the end of the experiment ranged from 0.23 ± 0.06 to 0.30 ± 0.11%. Statistical analysis showed that the different test feeds did not significantly affect ISI. Lobsters fed a combination of mollusk meal had greater villus height than those fed fish meal. The villus height of lobsters given mollusk meal ranged from 304.42 ± 1.47 to 315.36 ± 11.08µm, while those given fish meal measured 132.24 ± 0.95µm. The highest villus width was recorded in lobsters fed diet D (222.55 ± 11.77µm), followed by diets C (148.85 ± 19.77µm) and B (144.26 ± 22.53µm). Overall, lobsters fed mollusk meal had wider villi compared to those given a combination of fish meal.

Growth performance and feed conversion ratio (FCR)

The results of growth performance and FCR of lobster given test feed containing fish meal and mollusk meal are presented in Table (4).

Table 4. Weight gain (WG), specific growth rate (SGR), daily growth rate (DGR), feed intake (FI), feed efficiency (FE), FCR, and survival rate (SR) of ornate spiny lobster

Parameter	Treatments			
	A	B	C	D
WG (g)	2.45±1.42^{a}	6.84±3.13^{b}	5.025±0.67^{ab}	3.19 ± 1.26^{a}
DGR	0.049±0.02^{a}	0.137±0.04^{b}	0.100±0.01^{ab}	0.064±0.02^{a}
SGR (%)	0.039±0.02	0.084±0.05	0.056±0.03	0.051±0.02
FI (g)	240.77±4.63^{a}	348.84±9.97^{d}	273.67±8.41^{b}	294.65±0.58^{c}
FE (%)	1.01 ± 0.57	1.97± 0.97	1.83±0.19	1.28±0.35
FCR	117.83 ± 66.60	56.18±26.22	54.84±5.65	81.11±22.18
SR (%)	100	100	100	100

Note: *) The values in same rows with different superscript letters indicate significant differences ($P< 0.05$).

The WG, FI, and DGR of ornate spiny lobster given a combination of mollusk meal were higher than those fed a combination of fish meal. Meanwhile, lobster fed a combination of fish and mollusk meal did not significantly differ in the SGR, FE, FCR and SR. The results also showed that lobster given a combination of mollusk meal had higher FI than those given a combination of fish meal.

DISCUSSION

In this study, digestive enzyme activity increased at the end of rearing, especially in the mollusk-feeding group. This aligns with the theory of enzymatic adaptation, which states that organisms increase the production of specific enzymes to maximize the use of available substrates **(Klahan *et al.*, 2023)**. The increase in amylase, lipase, and protease activity in ornate spiny lobsters at the end compared to the beginning of the experiment indicates that the digestive system had adapted to maximize nutrient extraction from available feed. Lobsters kept for a long period produce more digestive enzymes to break down macronutrients, including proteins, lipids, and carbohydrates, in greater quantities **(Johnston *et al.*, 2004; Saputra & Fotedar, 2024)**. According to a previous study, larger lobsters have a higher basal metabolic rate, which demands a greater energy supply, resulting in more active digestive enzyme performance **(Rodríguez-Viera *et al.*, 2017)**. With increasing age, enzyme production also rises to meet the constant demand for amino acids, fatty acids, and glucose. Increased digestive enzyme activity facilitates the availability of these nutrients **(Kurnia *et al.*, 2024)**.

The increase in amylase, lipase, and protease activity in lobsters fed mollusk-based diets was attributed to nutrients more similar to natural food, containing protein, lipids, and carbohydrates in a balanced composition and being more easily digested. In other words, enzymatic activity maximized the digestion and absorption of nutrients **(Sharifinia *et al.*, 2023; Kurnia *et al.*, 2024)**. A more diverse nutritional composition stimulates the production of digestive enzymes such as amylase (for carbohydrates), lipase (for lipids), and protease (for proteins) **(Johnston *et al.*, 2004)**.

Amylase showed the highest activity, reflecting the high proportion of carbohydrates in the test feed and the fast energy requirements of lobsters. High amylase induction also demonstrates physiological adaptation to feed with significant carbohydrate content, where lobsters prioritize carbohydrate digestion to meet basic energy needs **(Simon *et al.*, 2011)**. Spiny lobsters have a complex relationship with carbohydrate digestion, primarily prioritizing protein and lipid metabolism for energy. Although these species can digest carbohydrates effectively, utilization is limited. Studies have shown that lobsters absorb carbohydrates, with a significant increase in free glucose and glycogen storage when dietary carbohydrate levels rise—particularly with wheat

inclusion. However, metabolic capacity limits the effective use of carbohydrates beyond a certain threshold, typically around 20% of feed **(Rodríguez-Viera *et al.*, 2017; Singha *et al.*, 2023)**.

Although lower in activity than amylase, lipase and protease remain important for digesting lipids and proteins **(Johnston *et al.*, 2004)**. The increase in these two enzymes' activity in the mollusk group indicates the availability of more complex and diverse substrates, which induce the digestive system to produce more enzymes **(Perera *et al.*, 2008)**. This also suggests that lobsters may utilize protein and fat from mollusk more efficiently than from fish meal.

The height and width of intestinal villi can change depending on the type of food consumed **(Perera & Simon, 2015; Kim *et al.*, 2023)**. Lobsters fed mollusk meal had larger villi than those fed fish meal. Larger villi provide a greater surface area for nutrient absorption, aiding digestion and growth. This occurs because mollusk contains essential nutrients—such as amino acids, PUFA, minerals, and vitamins—that help form and repair villi tissue **(Perera & Simon, 2015; Hammel *et al.*, 2024)**. Longer and wider villi increase nutrient absorption efficiency, supporting better growth in lobsters and white shrimp **(Perera & Simon, 2015; Kim *et al.*, 2023)**. Nutrients such as essential amino acids, PUFA, minerals, and vitamins enhance villi tissue formation **(Moniruzaman *et al.*, 2021; Zhu *et al.*, 2023)**. Furthermore, mollusk amino acids are more digestible for lobsters, supporting protein synthesis for villi **(Kurnia *et al.*, 2024)**. Mollusk also contains bioactive peptides, polysaccharides, and natural prebiotics that maintain healthy gut microbiota. Balanced gut bacteria increase vitamin production, boost immunity, and improve intestinal health, promoting villi growth and maintenance **(Rajeev *et al.*, 2021; Liu *et al.*, 2024)**. Mollusk may also provide higher levels of minerals such as zinc, copper, and iron, as well as vitamins including B-complex and D, which are important for processes like cell renewal and tissue synthesis **(Wright *et al.*, 2018)**. These micronutrients contribute to gut health and villi formation **(Anzabi *et al.*, 2023)**.

Lobsters fed mollusk-based diets showed higher weight gain and daily growth rates compared to those fed fish meal-based diets, indicating increased feed efficiency **(Margaret *et al.*, 2009; Kurnia *et al.*, 2024)**. These results are consistent with the findings of **Li *et al.* (2018)** who concluded that, mollusk-based feed is closer to the natural diet of lobsters and can improve digestion and nutrient absorption. Feed rich in essential amino acids and high-quality proteins, such as those found in mollusk, can promote growth **(Muskita *et al.*, 2024; Sharifinia *et al.*, 2024)**. Although fish meal contains a complete amino acid profile, lobsters in the wild do not typically consume fish **(Sudewi *et al.*, 2021)**.

Marchese *et al.* (2019) and **Landman *et al.* (2020)** demonstrated that mollusk-containing feed tends to enhance lobster growth rates compared to fish-based feed. This effect is attributed to the higher omega-3 fatty acid content in mollusk, which supports growth as well as digestive and immune system health. Mollusk-based feed may better

match lobsters' nutritional requirements, improving energy conversion efficiency to biomass. **Goncalves *et al.* (2024)** confirmed that diets aligned with natural feeding habits can improve SGR. Feed intake in lobsters given a mollusk combination (Food B, C, and D) was higher than in those given a fish combination (Feed A), suggesting a preference for mollusk-based diets. Similar trends were observed in feed efficiency (FE), where lobsters fed mollusk meal had higher FE values than those on fish meal-based diets. Higher FE indicates that more energy is allocated to growth rather than metabolism or waste **(Dai *et al.*, 2024)**. This is likely because mollusk nutrients are better suited to lobsters' metabolic needs, as also reported by **Giri *et al.* (2023)**, who found that mollusk-based feed improved FE in various crustacean species.

CONCLUSION

In conclusion, mollusk meal-based feed—comprising telescopium muscle, golden snail, and mud scallop meal—had a greater positive impact on digestive enzyme activity, feed efficiency (FE), and growth performance of ornate spiny lobster than fish meal-based feed made from sardine and jack mackerel meal.

REFERENCES

Anzabi, M.P.; Moghanlou, K.S.; Imani, A. and Tahmasebi. (2023). Effects of dietary vitamin E and C co-supplementation on growth performance, hemato-immunological indices, digestive enzymes activity, and intestinal histology of rainbow trout fed diet contained spoiled fish meal and oil. Aquaculture Reports 33 (2023) 101842

Astuti, N.W.W.; Giri, N.A.; Asih, Y.N. and Slamet, B. (2023). Fish and shrimp hydrolysate as additives in lobster feed formulation: effect on growth, survival, feed consumption of spiny lobster (*Panulirus homarus*). IOP Conference Series: Earth and Environmental Science, 1137(1), 012027. https://doi.org/10.1088/1755-1315/1137/1/012027

Bakhsh, M.; Hussain, G.M.; Yar, M.K.; Channo, A.; Kashif, M.; Ijaz, M.; Subhan, A.; Randhawa, N.K.; Waqar, Z.; Shehzad, A. and Kaka, S. (2023). The Role of Fish in Global Food and Nutrition Security: Current Aspects and Future Prospect. University of Sindh Journal of Animal Sciences, 7(4); 23-35 https://doi.org/10.57038/usjas.v7i04.6643

Baum, R.R. (2022). Functional heterogeneity of immune defenses in molluskan oysters *Crassostrea hongkongensis* revealed by high-throughput single-cell transcriptome. 120, 202–213. https://doi.org/10.1016/j.fsi.2021.11.027

Bergmeyer, H. U. and Grassi, M. (1983). Reagents for Enzymatic Analysis: Enzymes-a-Glucosidase.Methods of Enzymatic Analysis, 2, 205–206.

Borlongan, I. G. (1990). Studies on the Digestive Lipases of Milkfish, *Chanos chanos*. Aquaculture, 89, 315 – 325.

Bučková, T. (2022). Recent advances and future directions in practical diet formulation and adoption in tropical Palinurid lobster aquaculture. Reviews in Aquaculture, 14(4), 1830–1842. https://doi.org/10.1111/raq.12675

Candiotto, F.B.; Freitas-Júnior, A.C.V.; Neri, R.C.A.; Bezerra, R.S.; Rodrigues, R.V.; Sampaio, L.A. and Tesser, M.B. (2018). Characterization of digestive enzymes from captive Brazilian flounder *Paralichthys orbignyanus*. Brazilian Journal of Biology Revista Brasileira de Biologia, 78(2): 281-288.

Dai, P.; Zhu, X.-M.; Luan, S.; Sui, J.; Meng, X.; Cao, J.; Tan, J. and Kong, J. (2024). Quantitative Genetics of Feed-Efficiency-Related Traits for the Pacific Whiteleg Shrimp *Penaeus vannamei* in a Plant-Based Diet Environment. Biology, 13(12), 1012. https://doi.org/10.3390/biology13121012

Evrendilek, G.A. (2024). The effect of aquaculture feed on the nutritional quality of farmed seafood: A review of feed ingredients and their impact on human health. Food Nutrition Chemistry, 2(4), 287. https://doi.org/10.18686/fnc287

Fang, H.; Xie, J.; Liao, S.; Guo, T.; Xie, S.I.; Liu, Y.; Tian, L. and Niu, J. (2019). Effects of Dietary Inclusion of Shrimp Paste on Growth Performance, Digestive Enzymes Activities, Antioxidant and Immunological Status and Intestinal Morphology of Hybrid Snakehead (*Channa maculata* ♀ × *Channa argus* ♂). Frontiers in Physiology, 10(1027): 1-10

Farizah, N.; Zairin, M; Darusman, L.K.; Boediono, A; and Suprayudi, M.A. (2017). Accelarated ovarian maturation of mud crabs (Scilla olivacea) using ethanol extract of Melastoma malabathricium leaf. AACL Bioflux. 10(4) 911 - 921

Fu, S.; Qian, K.; Tu, X.; Lu, J.; Yao, T.; Ye, L. and Ye, J. (2024). Comparative analysis of intestinal structure, enzyme activity, intestinal microbiota and gene expression in different segments of pufferfish (*Takifugu obscurus*). Comparative Biochemistry and Physiology Part D: Genomics and Proteomics, 52, 101341. https://doi.org/10.1016/j.cbd.2024.101341

Fuchs, M. (2022). Determination of Digestive Enzyme Activity in Gilt-Head sea bream (*Sparus aurata*) Feeding with Commercial Feed. Black Sea Journal of Agriculture, 5(2), 69–71. https://doi.org/10.47115/bsagriculture.983542

Genodepa, J.; Zeng, C.; Militz, T.A., and Southgate, P.C. (2023). Influence of Moult Cycles on Digestive Enzyme Activities during Early Larval Stages of *Panulirus ornatus*. Aquaculture Research, 2023, 1–4. https://doi.org/10.1155/2023/9956046

Giri, N.A.; Irvin, S.; Haryanti; Sudewi; Selamet, B.; Jones, C.M. and Mujiono. (2023). Growth Response of Lobster *Panulirus homarus* Reared in Tanks and in Floating Net Cages Fed with Compound and Fresh Feed. Sains Malaysiana, 52(10): 2747-2759

Goncalves, R.; Pfalzgraff, T. and Lund, I. (2024). Impact of live feed substitution with formulated diets on the development, digestive capacity, biochemical composition,

and rearing water quality of European lobster *(Homarus gammarus*, L.) larvae. Aquaculture. https://doi.org/10.1016/j.aquaculture.2024.740776

Gora, A.; Jayasankar, V.; Rehman, S.; Kizhakudan, J.K.; Laxmilatha, P. and Vijayagopal, P. (2018). Biochemical responses of juvenile rock spiny lobster *Panulirus homarus* under different feeding regimes. Journal Of Applied Animal Research, 46(1): 1462–1468.

Guan, M.; Zhang, D.; Sun, X.; Shu, D.; Rao, J. and Tang, D. (2022). Effect of feeding frequency on growth performance, feed transit and digestive enzyme activity of Acipenser dabryanus juveniles. Aquaculture Research, 53(17), 5885–5901. https://doi.org/10.1111/are.16056

Hammel, N.; Cobcroft, J.M. and Nankervis, L. (2024). Postprandial nutrient dynamics and their implications for formulated feed development for the ornate spiny lobster (*Panulirus ornatus*). Aquaculture, Fish and Fisheries. https://doi.org/10.1002/aff2.154

Hasanthi, M.; Chotikachinda, R.; Medagoda, N. and Lee, K. (2024). Exogenous Protease Supplementation in High or Low Fish Meal Diets for Pacific White Shrimp, *Penaeus vannamei*: Comparative Effect on Growth, Innate Immunity, Nutrient Digestibility, Gut Microbiome and Intestinal Morphology. https://doi.org/10.2139/ssrn.4840912

Jiao, F.; Limbu, S.M.; Yin, H.; Xie, Y.; Yang, Z.; Shang, Z.; Kong, L. and Rong, H. (2023). A comparison of digestive strategies for fishes with different feeding habits: Digestive enzyme activities, intestinal morphology, and gut microbiota. Ecology and Evolution, 13(9), e10499. https://doi.org/10.1002/ece3.10499

Johnston, D.; Ritar, A.J.; Thomas, C.W. and Jeffs, A.G. (2004). Digestive enzyme profiles of spiny lobster *Jasus edwardsii* phyllosoma larvae. Marine Ecology Progress Series, 275, 219–230. https://doi.org/10.3354/MEPS275219.

Jones, C.M.; Anh, T.L.; and Priyambodo, B. 2019. Lobster Aquaculture Development in Vietnam and Indonesia. Lobster: Biology, Fisheries and Aquaculture, https://doi.org/10.1007/978-981-32-9094-5_12. 541-570.

Kim, S.; Shin, J.; Medagoda, N.; Choi, S.H.; Park, S.Y.; Park, J. and Lee, K. (2023). Dietary poly-β-hydroxybutyrate improved the growth, non-specific immunity, digestive enzyme activity, intestinal morphology, phagocytic activity and disease resistance against *Vibrio parahaemolyticus* of Pacific white shrimp, *Penaeus vannamei*. https://doi.org/10.21203/rs.3.rs-3582264/v1

Kim, Y; Oh,S.Y.; and Lee, W.S. (2021). Feeding ratio affects growth, body composition, and blood chemistry of mandarin fish (Siniperca scherzeri) in recirculating aquaculture system. Fish Aquat Sci., 24(6):219-227. DOI: https://doi.org/10.47853/FAS.2021.e22

Klahan, R.; Deevong, P.; Wiboonsirikul, J. and Yuangso, B. (2023). Growth Performance, Feed Utilisation, Endogenous Digestive Enzymes, Intestinal

Morphology, and Antimicrobial Effect of Pacific White Shrimp (*Litopenaeus vannamei*) fed with Feed Supplemented with Pineapple Waste Crude Extract as a Functional Feed Additive. Aquaculture Nutrition, 1160015, 1- 13.

Kurnia, A.; Hamzah, M.; Idris, M.; Muskita, W.H.; Abidin, L.O.B.; Sabilu, K.; Balubi, A.M.; Usaha, L.; Fatmawati, F.; Khairunnisa and Razak, L.O.A. (2024). Biochemical Responses of Painted Spiny Lobster, *Panulirus versicolor* Fed with Mollusk Meal and Fish Meal. Aceh Journal of Animal Science (2024) 9 (3): 111 – 118. https://doi.org/10.13170/ajas.9.3.42131

Kurnia, A.; Muskita, W.H.; Hamzah, M.; Abidin, L.O.B.; Ruslaini, R.; Suaida, S. and Amanda, R. (2024). Amino acid profiles and growth performance of spiny lobster *Panulirus ornatus* fed on combination of three mollusk meal. Aceh Journal of Animal Science, 9 (1): 10 – 17

Landman, M.J.; Codabacus, B.M.; Fitzgibbon, Q.P.; Smith, G.G. and Carter, C.G. (2020). Fresh or formulated: A preliminary evaluation of fresh blue mussel (*Mytilus galloprovincialis*) and formulated experimental feed with inclusion of fresh blue mussel on the growth performance of hatchery-reared juvenile slipper lobster (*Thenus australiensis*).Aquaculture, 531.

Li, P. and Wu, G. (2018). Roles of dietary glycine, proline, and hydroxyproline in collagen synthesis and animal growth. Amino Acids, 50(1), 29–38. https://doi.org/10.1007/S00726-017-2490-6

Li, X.; Han, T.; Zheng, S. and Wu, G. (2021). Nutrition and Functions of Amino Acids in Aquatic Crustaceans. Nutrition and Functions of Amino Acids in Aquatic Crustaceans. Part of the book series: Advances in Experimental Medicine and Biology ((AEMB,volume 1285). Book Chapter Springer. 169-198.

Limbu, S. M.; Zhou, L.; Sun, S.-X.; Zhang, M.L. and Du, Z.-Y. (2018). Chronic exposure to low environmental concentrations and legal aquaculture doses of antibiotics cause systemic adverse effects in Nile tilapia and provoke differential human health risk. Environment International, 115 , 205-219.

Liu, P.; Yao, J.; Vasta, G. R.; Wang, J. and Wang, X.-W. (2024). Shrimp Intestinal Microbiota Homeostasis: Dynamic Interplay Between the Microbiota and Host Immunity. Reviews in Aquaculture. https://doi.org/10.1111/raq.12986

Made, S.; Hamzah, M.; Adhawati, S.S.; Cangara, A.S.; Wardani, E.K. and Mas'ud, A.A. (2025). Analyzing the Competitiveness of Indonesia's Lobster Exports: Comparative and Competitive Advantages Using RCA and ECI Indices. International Journal of Religion, 6(1), 77–87. https://doi.org/10.61707/22r9rn67

Marchese, G.; Fitzgibbon, Q.; Trotter, A.; Carter, C.; Jones, C. and Smith, G. (2018). The influence of flesh ingredients format and krill meal on growth and feeding behaviour of juvenile tropical spiny lobster *Panulirus ornatus*. Aquaculture, 499. https://doi.org/10.1016/j.aquaculture.2018.09.019

Marchese, G.; Fitzgibbon, Q.P.; Trotter, A.J.; Carter, C.G.; Jones, C.M. and Smith, G.G. (2019). The influence of flesh ingredients format and krill meal on growth and feeding behaviour of juvenile tropical spiny lobster *Panulirus ornatus*. Aquaculture, 499, 128–139. https://doi.org/10.1016/

Margaret, A.; Rathinam, M.; Kandasami, D.; Kizhakudan, J.K.; Leslie, V.A. and Gandhi, A.D. (2009). Effect of dietary protein on the growth of spiny lobster *Panulirus homarus* (Linnaeus). http://eprints.cmfri.org.in/2214/1/Margaret_114-117.pdf

Moniruzzaman, M.; Sonia, S.; Chowdhury, P.; Tanu, M.B.; Yeasmine, S.; Hossen, M.N.; Min, T.; Bai, S.C. and Mahmud, Y. (2021). Nutritional evaluation of some economically important marine and freshwater mollusk species of Bangladesh. Heliyon 7 (2021) e0708:1-9.

Muskita, W.H.; Kurnia, A.; Hamzah, M.; Khairunnisa, K.; Munadi, L.O.M.; Aku, A.S. and Sahaba, L.O. (2025). Bamboo lobster (*Panulirus versicolor*) hemocyte countdifferentiation given a combination of three molluska meat meal. Sarhad Journal of Agriculture, 41(1): 283-292.

Muskita, W.H.; Kurnia, A.; Subandiyono; Suaida, S.; Usaha, L.; Yusnaini, Y.; Hamzah, M.; Effendy, I.J.; Anwar, A. and Munadi, LOM. (2024). Comparison amino acid profile of pearl lobster (*Panulirus ornatus*) fed with combination of fish meal and mollusk meal. Jurnal Sains Akuakultur Tropis Ed. September : 8(2024)2 :229-235.

Muttharasi, C.; Gayathri, V.; Muralisankar, T.; Mohan, K.; Uthayakumar, V.; Radhakrishnan; Kumar, P. and Palanisamy, M. (2021). Growth performance, digestive enzymes and antioxidants activities in the shrimp *Litopenaeus vannamei* fed with *Amphiroa fragilissima* crude polysaccharides encapsulated *Artemia nauplii*. Aquaculture, 545: 1-7

Nankervis, L. and Jones, C. (2022). Recent advances and future directions in practical diet formulation and adoption in tropical Palinurid lobster aquaculture. Review in Aquaculture, 14:1830–1842.

Navarro-Guillen, C.; Yufera, M. and Perera, E. (2022). Biochemical features and modulation of digestive enzymes by environmental temperature in the greater amberjack, *Seriola dumerili*. Frontiers in Marine Science, 9: 960746.

Neves, M.P.; Amorim, J.P.A.; Delariva, R.L.; Kratina, P. and Fialho, C.B. (2024). Linking anatomical and histological traits of the digestive tract to resource consumption and assimilation of omnivorous tetra fishes. Ecology and Evolution. 2024;14:e11375. | 1 of 16 https://doi.org/10.1002/ece3.11375

Nguyen, N.T.; Tran, S.Q.; Truong, O.T.; Pham, H.T.; Hua, A.T.; Duong, S.V. and Binh, D.T. (2022). Population Genetic Structure of Ornatus Spiny Lobster (*Panulirus ornatus*) in Indo-West Pacific Region. ECS Transactions, 107(1), 14531–14538.

Nunes, A.J.P.; Leite, J.S.; Gomes, C.S.; Dragøy, R. and Burri, L. (2024). The Minimum Dietary Level and Mix Ratio of Krill Meal and Fish Meal to Elicit Feed Intake and Growth Performance in Juvenile *Penaeus vannamei*. Sustainability, 16(11), 4628. https://doi.org/10.3390/su16114628

Ou, Y.; Wilson, R.E. and Weber, S.G. (2018). Methods of Measuring Enzyme Activity Ex vivo and In vivo. Annu Rev Anal Chem (Palo Alto Calif). 11(1): 509–533. doi:10.1146/annurevanchem-061417-125619

Perera, E. and Simon, C.J. (2015). Digestive physiology of spiny lobster: implications for formulated diet development. Reviews in Aquaculture, 7(4), 243–261. https://doi.org/10.1111/RAQ.12066

Perera, E.; Moyano, F.J.; Díaz, M.; Perdomo-Morales, R.; Montero-Alejo, V.; Alonso, E.; Carrillo, O. and Galich, G.S. (2008). Polymorphism and partial characterization of digestive enzymes in the spiny lobster *Panulirus argus*. Comparative Biochemistry and Physiology B, 150(3), 247–254. https://doi.org/10.1016/J.CBPB.2008.03.009

Rajeev, R.; Adithya, K.K.; Kiran, G.S. and Selvin, J. (2021). Healthy microbiome: a key to successful and sustainable shrimp aquaculture. Reviews in Aquaculture, 13(1), 238–258. https://doi.org/10.1111/RAQ.12471

Rizqullah, F. A.; Hartono, B. A.; Pasaribu, V. H.; Sari, L. A.; Sari, P. D. W.; Nindarwi, D. D. and Arsad, S. (2024). Study on Pasir Lobster Enlargement (Panulirus homarus) to Improve Cultivation Productivity with Keong Bakau (*Telescopium telescopium*). 1392, 012018. https://doi.org/10.1088/1755-1315/1392/1/012018

Rodríguez-Viera, L.; Perera, E.; Montero-Alejo, V.; Perdomo-Morales, R.; García-Galano, T.; Martínez-Rodríguez, G. and Mancera, J. M. (2017). Carbohydrates digestion and metabolism in the spiny lobster (*Panulirus argus*): biochemical indication for limited carbohydrate utilization. PeerJ, 5. https://doi.org/10.7717/PEERJ.3975

Saputra, I. and Fotedar, R. (2024). Effect of dietary protein to energy ratios on growth, digestive enzyme activity and body composition of captive juvenile spiny lobster, *Panulirus ornatus* (Fabricius, 1798). Annals of Animal Science, 0(0). https://doi.org/10.2478/aoas-2024-0023

Sekartadji, P.; Ekawati, A.P. and Fadjar, M. (2023). Effect of Restricted Feeding to Nutrients Utilization of Spiny Lobster (*Panulirus homarus*). Journal of Survey in Fisheries Sciences, 10(3S): 3478-3485.

Sharifinia, M.; Bahmanbeigloo, A.Z.; Keshavarzifard, M.; Khanjani, M.; Daliri, M.; Koochaknejad, E. and Jasour, S.M. (2023). The effects of replacing fishmeal by mealworm (*Tenebrio molitor*) on digestive enzymes activity and hepatopancreatic biochemical indices of *Litopenaeus vannamei*. Annals of Animal Science, 0(0). https://doi.org/10.2478/aoas-2022-0098

Simon, C.J.; Simon, C.J.; Simon, C.J. and Jeffs, A.G. (2011). The effect of dietary carbohydrates on the growth response, digestive gland glycogen and digestive enzyme activities of early spiny lobster juveniles, *Jasus edwardsii*. Aquaculture Nutrition, 17(6), 613–626. https://doi.org/10.1111/J.1365-2095.2011.00861.X

Singha, K.P.; Sahu, N.P.; Sardar, P.; Shamna, N. and Kumar, V. (2023). A strategic roadmap for carbohydrate utilization in crustaceans feed. Reviews in Aquaculture. https://doi.org/10.1111/raq.12861

Sudewi, N.W.W.; Astuti; Fahrudin; Giri, I.N.A. and Slamet, B. (2021). Growth and survival of spiny lobster, *Panulirus homarus* fed fresh food and formulated diet. 2nd International Conference on Fisheries and Marine. OP Conf. Series: Earth and Environmental Science 890 (2021) 012036.doi:10.1088/1755-1315/890/1/012036

Sudewi, S.; Slamet, B.; Giri, N.A.; Rusdi, I.; Jones, C.M. and Irvin, S. (2024). Growth and survival of spiny lobster, *Panulirus homarus* juveniles fed with different formulated feed. Biotropia: The Southeast Asian Journal of Tropical Biology, 31(3), 330–338. https://doi.org/10.11598/btb.2024.31.3.2206

Wu, P., L. Feng, S.Y. Kuang, Y. Liu, J. Jiang, K. Hu and X. Q. Zhou. (2011). Effect of dietary choline on growth, intestinal enzyme activities and relative expressions of target of rapamycin and eIF4E binding protein 2 gene in muscle, hepatopancreas and intestine of juvenile Jian carp (*Cyprinus carpio* var. Jian). Aquaculture 317(1-4): 107-116.