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Original Article

Effect of selected seaweed crude extracts as feed additives on growth performance, survival, and feed utilisation in whiteleg shrimp (*Penaeus vannamei*)

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Abstract
Seaweed crude extracts are a promising source of bioactive compounds for use in the aquaculture feed industry. In present study, five different seaweed crude extracts (*Ulva* spp., *Caulerpa* spp., *Sargassum* spp., *Cystoseira* spp., and *Gracilaria* spp.) were incorporated into the diets of whiteleg shrimp (*Penaeus vannamei*) at a supplementation level of 5 g kg^{-1} to check the effects on growth performance, feed utilization and survival rate. Whiteleg shrimp with an initial weight ranging from 0.050±0.001 g to 0.053±0.002 g were fed the experimental diets for 75 days. At the end of the experiment, the results indicated that the *Ulva*–crude extract supplemented diet produced the highest mean growth rate (11.804±0.437 g) and specific growth rate (7.24±0.10 % day^{-1}), followed by the *Sargassum* spp., *Gracilaria* spp., *Cystoseira* spp., and *Caulerpa* spp. diets. The higher survival rate of whiteleg shrimp was observed in *Sargassum* spp. treatment (97.78±2.22%), followed by the *Ulva* spp. treatment. These findings suggest that all tested seaweed crude extracts possess bioactive potential; however, *Ulva* spp. and *Sargassum* spp. crude extracts were the most promising feed supplements among the seaweed evaluated.

Keywords: feed utilisation; growth performance; *Penaeus vannamei*; seaweed crude extract

1 | INTRODUCTION

Aquaculture production has become the major contributor to global aquatic food supply in recent years, overtaking capture fisheries. In 2023, the sector produced around 98.5 million tons of aquatic animals, or about 52% of the world's production of aquatic food (Tacon *et al.* 2026). The increase in aquaculture is primarily stimulated by the expanding global need for seafood and aquatic protein sources. Along with this expansion, there is a considerable increase in the average per capita consumption of fish, which has grown from 9.9 kg in 1960 to 20.5 kg in 2021 with estimates pointing to an increase to 21.5 kg by

2030 (FAO 2025).

The cultivation of shrimps is one of the most popular forms of aquaculture as they are high producers of marine creatures with faster growth rates and shorter production cycles, and higher market responsiveness. Global production of shrimps is mainly influenced by the cost of feeds, efficiency of production, and accessibility of international markets (Gomathy *et al*. 2026). Induction of shrimps is one of the profiting activities of aquaculture, with the compound annual growth rate (CAGR) for 2024 being 4.8% (roughly 0.2% less than the previous average of 5.8% during 2011–2021 (Jory 2023; CAA 2023). *Penaeus vannamei* is the leading species in world shrimp aquaculture and contributes more than 80% of the total world shrimp aquaculture. This is possibly owing to higher body productivity and shorter duration of growth over native species, with much better adaptability and relatively poorer resistance to diseases (SJ *et al.* 2026). In 2024, the Asian shrimp industry is projected to grow by 4% after the decline in 2023 production. It is projected that Indian shrimp production would increase by 2%, and Vietnam is expected to bounce back from the 2023 fall and expand by 6% (Jory 2023).

The shrimp industry export is also revised to USD 697.67 million from USD 348.84 million for the rest of the time (Mandal and Singh 2025). As revealed by IMARC (2023), India, 1st most significant exporter of shrimp. The Indian shrimp industry assets in 2022 were nearly USD 7.3 billion and are expected to reach nearly USD 14 billion by 2028. Commercial shrimp farming began in the late 1980's mainly due to increasing demand from the global market. The leading shrimp production states are Andhra Pradesh, West Bengal, Tamil Nadu, Gujarat and Orissa. About 1.2 million ha of coastal area is available in India for brackish water aquaculture, of which 1,40,656 ha are presently being used. This sector contributed to a production of seafood worth about 244,267.4 million and accounted for about 6.62% of world aquaculture production (Jayanthi *et al*. 2018).

Seaweeds are commonly used as feed additives nowadays in aquaculture. Shrimp farming, cuttlefish, squid, and lobster cultures have all primarily considered the beneficial role of seaweed in enhancing the quality of the product. Many seaweed species such as *Hypnea* spp., *Cryptonemia* spp., *Ulva* spp., *Sargassum* spp., *Gracilaria* spp., *Caulerpa* spp., *Enteromorpha* spp., *Chnoospora* spp., *Cystoseira* spp., and *Kappaphycus* spp. are commonly included in the feed formulation of shrimp (Rajauria 2015). It has been proven that incorporating seaweeds in feed would result in less operating costs and more benefits from improved shrimp performance and feed conversion ratio (FCR) as well (Huong *et al*. 2026). Furthermore, this application of seaweed in aquafeeds is also helpful in the improvement of water quality management systems through reduced waste generated in the form of leftover food and excreta in the wastewater effluent; thus, leading towards a more sustainable and efficient aquaculture system (Rajauria 2015).

The present study was conducted to determine the potential of five macroalga species, namely *Ulva* spp., *Caulerpa* spp., *Sargassum* spp., *Cystoseira* spp., and *Gracilaria* spp., as feed additives in a whiteleg shrimp. *Ulva* (green algae) is a rich source of protein content and contain ulvan which is a sulfated polysaccharide with antibacterial, antioxidant and immunostimulatory activities (Abdel-Razek *et al*. 2024; Zaghloul *et al*. 2026). *Cystoseira* (brown algae) contains of polyphenolic compounds, including phlorotannins which possess antioxidant to help eliminate ROS and to alleviate oxidative stress, a common condition of intensive aquaculture (Zahran *et al*. 2024; Mekhaimar *et al*. 2026). *Gracilaria* (red algae) are known for their antibacterial activities and sulfated galactans, which inhibit the growth and biofilm of some pathogenic bacteria (Sarjito *et al*. 2020; Elshopakey *et al*. 2024). *Sargassum* (brown algae) was chosen because higher contents of sulfated polysaccharides known as fucoidan were found in this algal species which has powerful immunomodulating, antioxidant, and antibacterial characteristics (Abbas *et al*. 2023a; Hurriyani *et al*. 2026). The *Caulerpa* (green algae) is generally used as natural feed additive due to the presence of bioactive compounds like sulfated polysaccharides, antioxidants, polyphenols, vitamins and minerals (Esquer-Miranda *et al*. 2016; Lee *et al*. 2023; Maulana *et al*. 2023).

This study investigated the impacts of supplementing animal feed with crude extracts of specific seaweeds (*Ulva* spp., *Caulerpa* spp., *Sargassum* spp., *Cystoseira* spp., *and Gracilaria* spp.) on the growth performance, survival, and feed utilization of whiteleg shrimp (*P. vannamei*). It was anticipated that select bioactive compounds that were present in the seaweeds would enhance nutrient utilization and positively impact the growth and survival of shrimp when compared to those that were provided the control diet, with variations in effectiveness among the different seaweed species.

2 | METHODOLOGY

2.1 Duration of study and location

The present experimental study was conducted in the Aquaculture Laboratory, Department of Aquaculture, College of Fisheries Science, Kamdhenu University, Veraval, Gujarat, India. The period of experimentation was 75 days, from 15 May to 29 July, 2025.

2.2 Study species

Specific pathogen-free (SPF) whiteleg shrimp (*P. vannamei*) seeds (PL-12) were obtained from a commercial hatchery (West Coast Shrimp Hatchery - Kotada, Kodinar, Gir Somnath, Gujarat). The seeds were transported to the

Aquaculture Laboratory, College of Fisheries Science, Kamdhenu University, Veraval, in a polythene bag with properly aerated saline water.

2.3 Experimental design

Fifteen PL 12 of *P. vannamei* were stocked with mean weight 0.050±0.001 g to 0.053±0.002 g into six treatments (each in triplicate) on a completely randomized design (CRD) to achieve random allocation of treatment to tank (2×1×1 feet). The experiment tanks were filled with 20 ppt water, and daily 25% water exchanged during the study period. Shrimps were fed with their respective experimental diet at 07:30 hr, 11:30 hr, and 18:30 hr, three times a day (Table 1). The feeding rate was set at 10% body weight of shrimp as the initially (Tanjung *et al*. 2022) and adjusted on the basis of fortnightly samples to observe the growth of shrimp.

TABLE 1 The experimental diets group used in the study.

Treatment	Feed additive composition
Control diet (T0)	Diet prepared without additives (Control)
Diet (T1)	Diet prepared with 0.5% *Ulva* spp. crude extract
Diet (T2)	Diet prepared with 0.5% *Caulerpa* spp. crude extract
Diet (T3)	Diet prepared with 0.5% *Sargassum* spp. crude extract
Diet (T4)	Diet prepared with 0.5% *Cystoseira* spp. crude extract
Diet (T5)	Diet prepared with 0.5% *Gracilaria* spp. crude extract

2.4 Collection of seaweed

Macroalga *Ulva* spp., *Caulerpa* spp., *Sargassum* spp., *Cystoseira* spp., and *Gracilaria* spp. were collected from intertidal zone of Veraval (20°54′35.6″N 70°21′08.7″E), on the Arabian Sea to prepare crude extracts of macroalgae. Collected macroalgae were properly washed with clean water to remove debris and epiphytes. After cleaning, the seaweed was dried at room temperature. Fresh macroalgae were sampled and rinsed thoroughly with freshwater to wash off any impurities such as debris, epiphytes, sand, and other contaminants present. Samples were air-dried in a shaded place until room temperature and then pulverised in a grinder to form fine powder and stored in an airtight container at 4°C until extraction procedures could begin (Figure 1).

2.5 Preparation of the solvent-based seaweed crude extract

The extraction was performed separately for each species of seaweed using three replicates. Extraction was done by mixing 50 g of dried powder with 500 ml methanol (1:10 w/v) and then macerated for 48 hours at room temperature in the dark with regular stirring. Then mixture was filtered through Whatman no.1 filter paper and residues were discarded. Filtrate was concentrated under reduced pressure by rotary vacuum evaporator at 40°C, then further dried at 40°C in hot air oven to ensure complete evaporation of the leftover solvent, yielding crude extract. The extract was finally stored at –20°C in a sealed container for further analysis (Rusli *et al*. 2016; Prasedya *et al*. 2018). The extraction yields from the dried seaweeds were 8.6%, 11.2%, 9.4%, 7.8%, and 10.1% for *Ulva* spp., *Caulerpa* spp., *Sargassum* spp., *Cystoseira* spp., and *Gracilaria* spp., respectively (Figure 2).

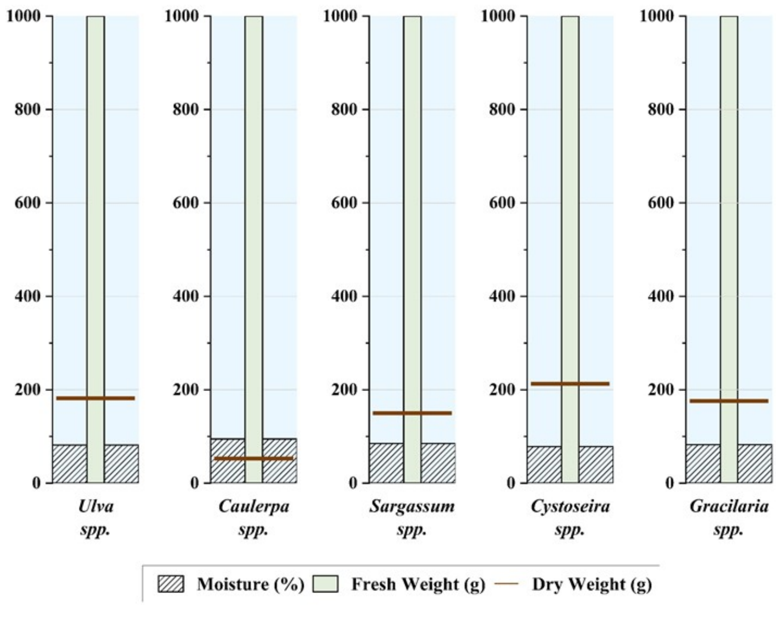


FIGURE 1 Comparative analysis of moisture content, fresh weight and dry weight of selected seaweed species.

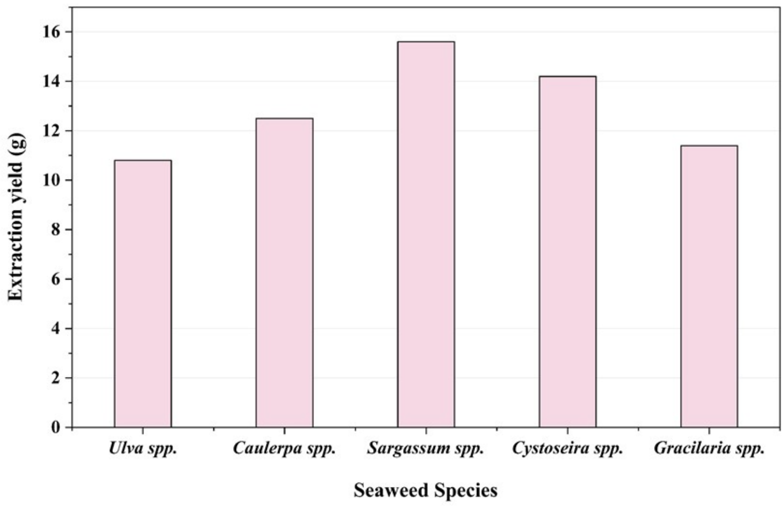


FIGURE 2 Comparative extraction yield of selected seaweed species.

2.6 Preparation of experimental diets

Six experimental diets were formulated. The ingredients used in the experimental diets were fish meal (sterile A-grade), wheat flour, soybean flour, tapioca powder, fish oil, sunflower oil, and vitamin and mineral supplements. All experimental diets were formulated using the Pearson's square method to achieve an isonitrogenous composition with a target protein level of 35%, achieved by proximate analysis of feed ingredients and feed utilizing locally available feed ingredients. The required quantities of each ingredient were precisely weighed in accordance with the formulation presented in Table 2.

TABLE 2 Ingredient composition (%) of experimental diets containing 35% crude protein.

Ingredient (%)	Grams of ingredients per 100 grams of feed					
	T0	T1	T2	T3	T4	T5
Sterilized Fish meal	40.00	40.00	40.00	40.00	40.00	40.00
Soyabean Meal	27.00	27.00	27.00	27.00	27.00	27.00
Wheat flour	15.00	15.00	15.00	15.00	15.00	15.00
Tapioca powder	12.00	11.50	11.50	11.50	11.50	11.50
Fish oil	2.00	2.00	2.00	2.00	2.00	2.00
Sunflower oil	2.00	2.00	2.00	2.00	2.00	2.00
Vitamin & minerals	2.00	2.00	2.00	2.00	2.00	2.00
Ulva spp. crude extract	0.00	0.50	0.00	0.00	0.00	0.00
Caulerpa spp. crude extract	0.00	0.00	0.50	0.00	0.00	0.00
Sargassum spp. crude extract	0.00	0.00	0.00	0.50	0.00	0.00
Cystoseira spp. crude extract	0.00	0.00	0.00	0.00	0.50	0.00
Gracilaria spp. crude extract	0.00	0.00	0.00	0.00	0.00	0.50
Total	100.00	100.00	100.00	100.00	100.00	100.00

2.7 Growth indices

The growth assessment of *P. vannamei* was carried out at fortnightly intervals. Individual *P. vannamei* from each treatment replicate were weighed using a digital electronic balance, and the measurements were systematically recorded. Growth indices of *P. vannamei* were evaluated by analysing parameters such as mean weight gain, specific growth rate (SGR) (Bai *et al*. 2022), feed conversion ratio (FCR), protein efficiency ratio (PER) and survival rate (%) D'Abramo *et al*. 1997) over the period of the experiment.

Mean weight gain = Final average body weight (g) – initial average body weight (g)

SGR (% day^{-1}) = Ln final body weight – Ln initial body weight / culture period (days) × 100

FCR = Total feed consumed (g) / total weight gain (g)

PER = Body weight gain (g) / protein intake (g)

Survival rate (%) = Number of shrimp survived / total number of shrimp stocked × 100

2.8 Physico-chemical parameters of water

During the experimental period, selected physico-chemical parameters of the rearing water like temperature (digital thermometer ELICO), pH (pH meter), salinity (refractometer), dissolved oxygen (Winkler method) and alkalinity (titration method) were recorded weekly according to the standard procedures described in APHA (2005).

2.9 Data analysis

All of the experimental data were analysed using a completely randomized design (CRD) consisting of six treatments with three replicates per treatment. Standard statistical analyses were performed using INM SPSS Statistics Version 27 for analysis of variance (ANOVA), and mean comparisons using DMRT were followed. One-way analysis of variance (ANOVA) was used to determine significant differences among the treatment groups, and Duncan's Multiple Range Test (DMRT) was subsequently applied for mean separation at a significance level of $p < 0.05$, following the procedures described by Snedecor and Cochran (2014).

3 | RESULTS

3.1 Growth performance

Mean weight gain and specific growth rate (SGR) were measured fortnightly (Figure 3). The initial weight showed no significant differences among the experimental groups, ranging from 0.050±0.001 g to 0.053±0.002 g. The mean weight gain (g) of *P. vannamei* was calculated for all experimental treatments. No significant differences were observed in initial body weight among the experimental groups, which ranged from 0.050±0.001 g to 0.053±0.002 g. Treatment T1 exhibited highest mean weight gain with an average value of 0.228±0.001 g at 15 days. This finding suggests that the initial growth rate was higher in the treatment T1 compared to other treatments. Similarly, the performance of T3 treatment (0.188±0.017 g) was better than the controls but non-significant compared to the better-performing treatment. The T0 control group (0.173±0.009 g), together with T2 (0.176±0.019 g), T4 (0.178±0.010 g), and T5 (0.177±0.014 g) groups, recorded relatively similar and lower mean weight gains during the first 15 days of the experimental period. The T1 treatment continued to exhibit the highest growth performance, with a mean weight gain of 2.150±0.106 g at 30 days. The second highest weight gain was exhibited by treatment T3 with 1.636±0.096 g, while the treatment T5 exhibited moderate growth, with a weight gain of 1.430±0.015 g. The treatments T0, T2, and T4 recorded 1.197±0.038 g, 1.220±0.123 g, and 1.246±0.008 g weight gains, respectively.

There was a noticeable increase in weight gain in the T1 treatment at 45 days of culture (4.748±0.436 g), while treatment T3 also exhibited a comparatively high mean weight gain (4.438±0.101 g). Both treatments showed significantly enhanced growth performance. The T5 treatment (4.020±0.223 g) also demonstrated a considerable improvement in mean weight gain compared with the control group. Moderate growth rates were observed in the T2 (3.350±0.051 g) and T4 (3.704±0.088 g) treatments, whereas the lowest mean weight gain was recorded in the T0 treatment (3.201±0.091 g). At 60 days of culture, T1 again exhibited the highest mean weight gain (7.763±0.273 g). T3 (6.851±0.115 g) and T5 (6.822±0.160 g) achieved moderate mean weight gains; both were superior to T0. Moderate growth improvement was observed in T4 (6.294±0.065 g), whereas only a slight improvement over the T0 treatment (5.333±0.123 g) was observed in treatment T2 (5.890±0.187 g).

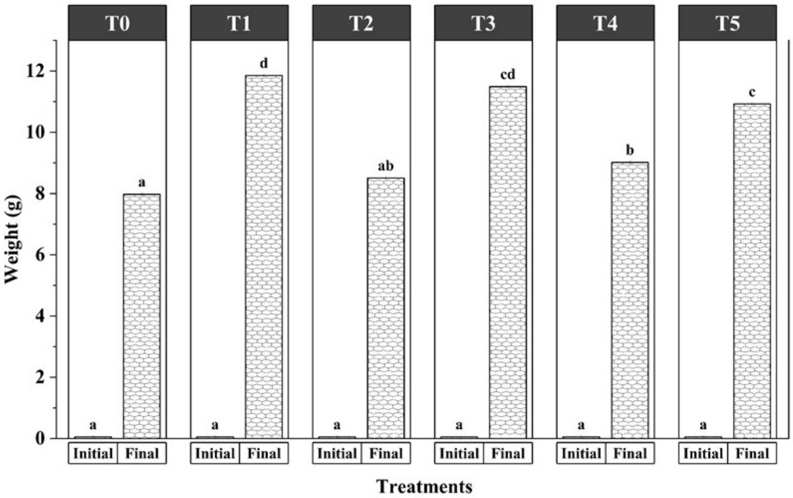
The highest mean weight gain at the end of the experimental period (75 days) was recorded in the treatment T1 (11.804±0.437 g), which exhibited maximum growth performance among all treatments. A similar growth trend was observed in the treatment T3 (11.438±0.101 g). Treatment T5 (10.871±0.141 g) also gave significant growth promotion for *P. vannamei*, T4 (8.966±0.149 g) showed moderate growth enhancement. While the T2 treatment (8.453±0.100 g) exhibited only a slight improvement compared with the control group T0 (7.925±0.020 g). The mean weight gain recorded in the T0 treatment remained lower than that of the other treatments throughout the feeding trial period (Figure 3).

The highest specific growth rate (SGR) was recorded in T1 (7.239±0.100% day^{-1}), followed by T3 (7.200±0.071% day^{-1}), and T5 (7.105±0.031% day^{-1}). Treatments T1 and T3 exhibited statistically similar growth performance and produced significantly higher SGR compared to the control group. T4 recorded a moderate SGR value of 6.920±0.051% day^{-1}, while T2 showed comparatively lower growth performance, with an SGR of 6.840±0.047% day^{-1}. The lowest SGR was observed in the control group T0 (6.695±0.029% day^{-1}) (Figure 4). In all, the results clearly demonstrated that dietary supplementation positively influenced the growth performance of *P. vannamei*, with treatments T1 and T3 consistently producing superior mean weight gain and SGR throughout the culture period.

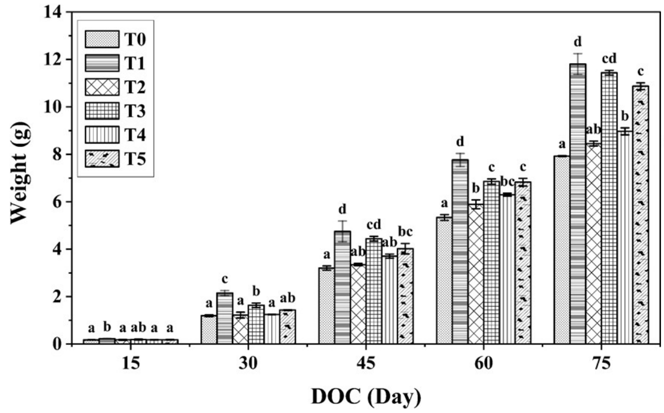
3.2 Feed utilisation

The lowest feed conversion ratio (FCR) was observed in the T1 treatment (1.40 ± 0.03), followed by the T3 treatment (1.55 ± 0.04). These two treatments were statistically at par, indicating that both T1 and T3 exhibited efficient feed conversion. However, the FCR value recorded in the T1 treatment was lower than that of the T3 treatment. T5 treatment exhibited an FCR of 1.66 ± 0.08, which was significantly lower than those recorded in the T2 (1.91 ± 0.06), T4 (1.86 ± 0.01), and the control T0 (2.13 ± 0.10). No significant difference was observed between the T2 and T4 treatments. However, T5 performed significantly better than T2, T4, and T0 treatments. The highest FCR was recorded in the control treatment T0.

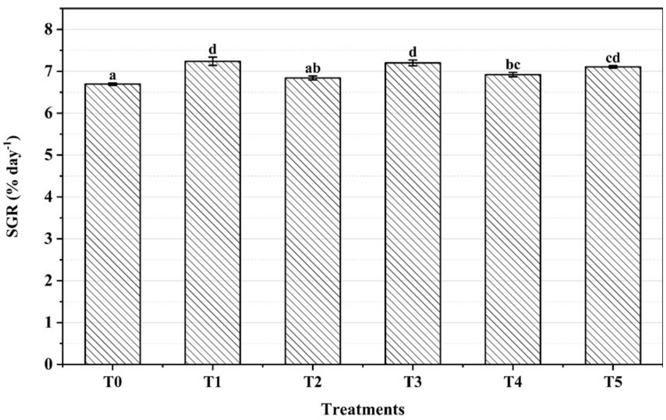
The highest protein efficiency ratio (PER) was recorded in T1 treatment (2.38 ± 0.05), followed by T3 (1.84 ± 0.05), and T5 (1.73 ± 0.08). Statistical analysis indicated that T3 and T5 did not differ significantly from each other, demonstrating similar protein utilization efficiency, although T3 exhibited a comparatively higher PER value. T4 treatment recorded a PER value of 1.54 ± 0.01, which was significantly higher than the control treatment T0 (1.35 ± 0.07), but lower than the values observed in T1, T3, and T5. T2 treatment showed a PER of 1.50 ± 0.03 and was statistically comparable to the T0-control. The lowest PER was observed in the control treatment T0, indicating reduced protein utilization efficiency in the absence of dietary supplementation.



(a)



(b)



(c)

FIGURE 3 Growth performance of *Penaeus vannamei* (a); initial and final weight; mean weight gain (b); specific growth rate (SGR) (c).

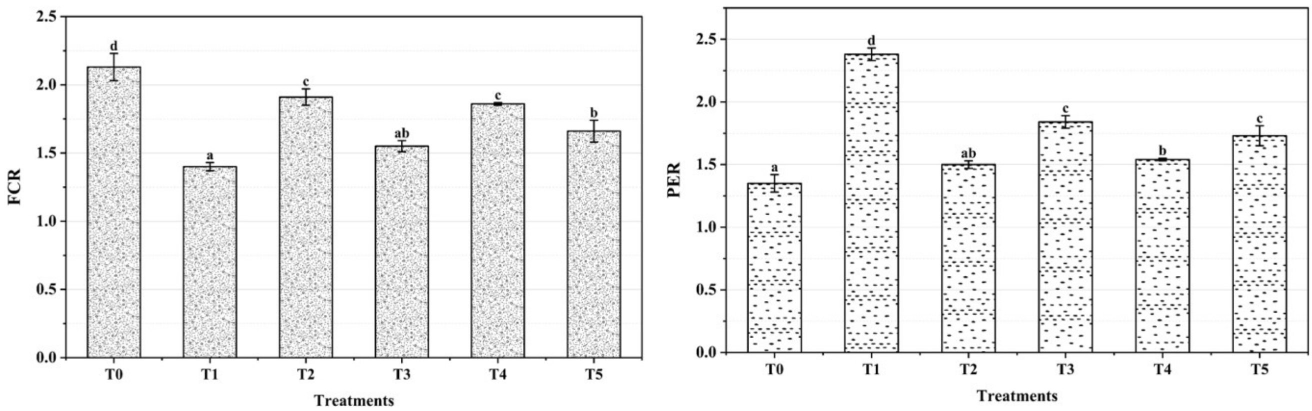


FIGURE 4 Feed utilisation of *Penaeus vannamei*. Feed conversion ratio (FCR; left) (b) protein efficiency ratio (PER; right).

3.3 Survival rate

The survival rate differed significantly among the treatments. T3 treatment recorded the highest survival rate (97.78±2.22%), followed by T1 (95.56±1.57%). Statistical analysis revealed no significant difference between the T3 and T1 treatments, indicating that both treatments were equally effective in improving the survival rate of *P. vannamei*, although the T3 treatment exhibited a slightly higher mean value. T5 treatment recorded a survival rate of 88.89±3.14%, which was considerably higher than the T0 control (71.11±1.57%) but significantly lower than the T1 and T3 treatments. T4 and T2 treatments exhibited survival rates of 84.44±1.57% and 80.00±2.72%, respectively. The lower survival rate was observed in the T0 (71.11±1.57%) control treatment (Figure 5).

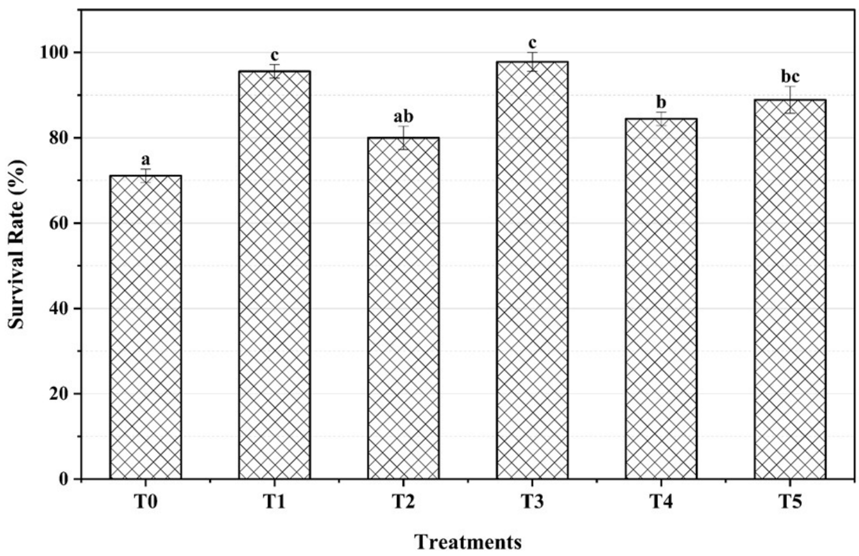


FIGURE 5 Survival rate of *Penaeus vannamei* fed different experimental diets

3.4 Physico-chemical water parameters

The physico-chemical water quality parameters recorded during the experimental period remained within the acceptable range for the culture of *P. vannamei*. Throughout the study, water temperature ranged from 27.20 to 28.96°C, while salinity varied between 19.99 and 20.97 ppt. The pH values were maintained between 7.54 and 8.16, indicating a stable culture environment. Dissolved oxygen levels ranged from 5.84 to 6.91 ppm during the experimental period, which was adequate to support shrimp growth and survival. Total alkalinity varied from 148.28 to 160.18 ppm, reflecting suitable buffering capacity of the culture water. The overall mean values recorded during the study were 27.76–28.28°C for temperature, 20.27–20.74 ppt for salinity, 7.54–8.00 for pH, 6.14–6.65 ppm for dissolved oxygen, and 149.60–155.40 ppm for total alkalinity (Table 3).

4. DISCUSSION

4.1 Growth performance

The present study clearly demonstrated that dietary supplementation with methanolic crude extracts of selected seaweeds at an inclusion level of 5 g kg^{-1} (0.5%) significantly enhanced the growth performance of *P. vannamei*, as evidenced by improvements in mean weight gain and specific growth rate (SGR). Among all treatments, T1 supplemented with *Ulva* spp. recorded the highest mean weight gain and SGR values, followed closely by the T3 treatment supplemented with *Sargassum* spp. The superior growth performance observed in the T1 treatments attributed to the presence of ulvan polysaccharides, vitamins, minerals, amino acids, and highly digestible nutrients in *Ulva* spp. Similar findings were reported by Akbary and Aminikhoei (2018), who observed significant improvement in growth performance of *Litopenaeus vannamei* fed diets supplemented with *Ulva rigida* polysaccharide extract. Their study demonstrated that dietary supplementation of *Ulva* extract positively influenced weight gain and SGR in shrimp. Mangott *et al*. (2020) reported that dietary incorporation of *Ulva lactuca* significantly improved growth performance and nutrient utilization in *L. vannamei*. Omont *et al*. (2019) similarly observed improved growth performance and SGR in shrimp fed diets supplemented with *Ulva* extract. Ge *et al*. (2019) further reported enhanced growth and better feed utilization in shrimp fed *Ulva prolifera* polysaccharides. These previous findings are positively aligned with the present study and strongly support the superior growth-promoting effect of the methanolic crude extract of *Ulva* spp. in shrimp aquaculture. In contrast, Rodríguez-González *et al*. (2014) and Qiu *et al*. (2018) reported that excessive dietary inclusion of *Ulva* meal slightly reduced growth performance due to higher fibre content and lower nutrient digestibility. These contrasting findings suggest that optimum dietary inclusion level is crucial for achieving maximum growth enhancement from *Ulva* spp. supplementation.

TABLE 3 Physico-chemical water parameters range during the experiment.

Week	Temperature (°C)	Salinity (ppt)	pH	Dissolved oxygen (ppm)	Total alkalinity (ppm)
1	27.81 – 27. 20	20.71 – 19.99	7.85 – 7.57	6.50 – 6.25	153.32 – 150.04
2	27.79 – 27.38	20.93 – 20.45	8.04 – 7.66	6.51 – 6.22	152.09 – 149.57
3	27.83 – 27.44	20.82 – 20.40	7.90 – 7.81	6.42 – 6.07	160.14 – 149.83
4	27.73 – 27.33	20.97 – 20.07	8.16 – 7.83	6.54 – 6.10	160.18 – 148.53
5	27.58 – 27.25	20.68 – 20.38	8.01 – 7.70	6.88 – 6.29	152.41 – 149.32
6	28.68 – 27.61	20.77 – 20.22	8.06 – 7.62	6.88 – 5.84	154.78 – 148.28
7	28.75 – 28.20	20.51 – 20.35	7.97 – 7.63	6.77 – 6.05	159.10 – 150.32
8	28.84 – 28.57	20.84 – 20.27	7.96 – 7.61	6.91 – 6.05	154.16 – 150.46
9	28.81 – 28.12	20.64 – 20.29	8.05 – 7.68	6.51 – 6.25	153.19 – 149.45
10	28.96 – 28.51	20.50 – 20.28	8.05 – 7.64	6.58 – 6.22	154.65 – 150.29

The T3 treatment, supplemented with the methanolic crude extract of *Sargassum* spp., also recorded significantly higher mean weight gain and SGR, remaining statistically comparable to T1 throughout the culture period. The enhanced growth performance observed in T3 was associated with the presence of fucoidan, alginate, laminarin, sulfated polysaccharides, minerals, and digestible growth-promoting compounds naturally present in *Sargassum* spp. Similar findings were reported by Abbas *et al*. (2023a), who observed significant enhancement in growth performance of *L. vannamei* fed dietary Sargassum polysaccharides. Melchor-Martínez *et al*. (2023) also reported improved growth performance in shrimp fed diets containing *Sargassum* meal. Giang *et al*. (2016) demonstrated that dietary administration of *Sargassum microcystum* polysaccharide extract significantly improved weight gain, daily growth, and SGR in white shrimp. Similarly, Lin *et al*. (2017) observed enhanced growth performance and feed utilization efficiency in shrimp fed heat-processed *Sargassum cristaefolium* diets. Sudaryono *et al*. (2018) also reported higher ADG and improved weight gain in shrimp fed *S. cristaefolium* meal. These findings strongly support the results of the present study suggest that the methanolic crude extract of *Sargassum* spp. possesses strong growth-promoting potential in shrimp aquaculture. However, Hafezieh *et al*. (2017) reported comparatively lower growth performance at higher inclusion levels of raw *Sargassum* meal or extract, indicating that excessive inclusion may reduce nutrient digestibility and feed utilization due to higher fiber content.

The T5 supplemented with the methanolic crude extract of *Gracilaria* spp. also showed a significant increase in mean weight gain and SGR compared with the control treatment. The enhanced growth performance observed in the T5 treatment was associated with the presence of polysaccharides (agar, sulfated galactans), vitamins, minerals, and digestible nutrients present in *Gracilaria* spp. Similar findings were reported by Jasmanindar *et al*. (2018a), who observed an increase in growth performance and SGR when *Gracilaria verrucosa* extract was supplemented to the diet of shrimp. The final body weight, weight gain, and SGR of shrimp also show an increase when fed with *Gracilaria* extract in another study conducted by Jasmanindar *et al*. (2018b). The growth performance of shrimp fed with *Gracilaria tenuistipitata* extract also increased, according to Liu *et al*. (2019). Tian *et al*. (2024) observed increased weight gain and SGR when *Gracilaria lichenoides* was used as a dietary supplement. Thus, previous studies result supports the current study that *Gracilaria* spp. Methanolic crude extract has significant potential for growth performance in shrimp culture. However, some studies have reported that the growth performance slightly decreased when the inclusion amount increased beyond the optimum, probably affecting nutrient digestibility and utilisation.

The T4 treatment, supplemented with the methanolic crude extract of *Cystoseira* spp. exhibited a moderate and significant increase in mean weight gain and SGR compared with the control. The enhanced growth performance observed in T4 is due to the effects of fucoidan, alginic acid, sulfated polysaccharides, minerals, and digestible compounds that are available in brown seaweeds. Similar findings were also observed in the growth performance of *L. vannamei* fed fucoidan derived from *Cystoseira indica* in the studies conducted by Patel *et al*. (2026). Similarly, the positive effect of dietary fucoidan supplementation on the growth performance of *Marsupenaeus japonicus* postlarvae was demonstrated by Traifalgar *et al*. (2010). Effect of dietary fucoidan supplementation on *P. monodon* postlarvae was also noted by Traifalgar *et al*. (2009). The observations recorded in the present study are quite consistent with the previous reports of brown seaweeds, which indicates the positive role of brown seaweeds-derived fucoidan for promotion of shrimp aquaculture growth. The difference in the growth rate was recorded as lower when compared to T1 and T3 treatments in T4, indicating the moderate growth-promoting effects of *Cystoseira* spp. Higher levels of fibers and complex polysaccharides may contribute to low digestibility and feed utilization efficiency at such incorporation level.

In terms of mean weight gain and SGR, T2 treatment supplemented with *Caulerpa* spp. exhibited only a slight improvement compared with the control treatments. However, its growth-promoting effect was lower than observed in the treatments supplemented with *Ulva* spp., *Sargassum* spp., and *Gracilaria* spp. The moderate growth performance recorded in the T2 treatment might be attributed to the presence of related to the nutritional values in *Caulerpa* spp. such as sulfated polysaccharides, minerals, amino acids, vitamins, and readily digestible nutrients, while the relatively high fibre content and presence of secondary metabolites might lower the feed digestibility and efficiency. A similar trend was reported by Puspitasari *et al*. (2019), Nasmia *et al*. (2022), Yuniati *et al*. (2024), and Liang *et al*. (2025), who observed moderate to slight improvements in growth performance in other groups where the performance remained close to control in several treatments with higher incorporation levels. However, the weight gain and SGR showed improvement in Putra *et al*. (2019), Zhang *et al*. (2023), and Lee *et al*. (2023) on shrimp fed *Caulerpa* with processed or fermented methods. Thus, inclusion level, processing of the biomass, and species variation can be contributing factors to the growth-promoting capability. Based on the present study, the methanolic crude extract of *Caulerpa* spp. exhibited only a moderate growth-promoting effect, with performance value remaining relatively close to the control group.

4.2 Feed utilisation

The superior feed utilization observed in the T1 treatment was associated with the presence of ulvan, sulfated polysaccharides, vitamins, minerals, and antioxidant compounds in *Ulva* species, which enhance digestion and nutrient absorption. Similar findings were reported by Akbary and Aminikhoei (2018), who observed reduced FCR and improved growth in *L. vannamei* fed polysaccharide extract of *U. rigida*. Omont *et al*. (2019) also reported improved FCR and digestive enzyme activity in shrimp fed *Ulva* extract diets, while Mangott *et al*. (2020) observed enhanced nutrient utilization in shrimp fed *U. lactuca* meal. Ge *et al*. (2019) reported improved feed conversion and growth in shrimp fed *U. prolifera* polysaccharide extract, whereas Klongklaew *et al*. (2021) observed improved FCR and growth performance using hot water crude extract of *Ulva intestinalis*. Rodríguez-González *et al*. (2014) and Qiu *et al*. (2018) further reported satisfactory feed utilization with moderate inclusion of *Ulva* meal in shrimp diets.

The T3 treatment, supplemented with *Sargassum* crude extract, also exhibited significantly improved feed utilization compared with the control group, as evidenced by its lower feed conversion ratio (FCR; 1.55±0.04) and higher protein efficiency ratio (PER; 1.84±0.05). Similar findings were reported by Abbas *et al*. (2023a), who observed enhanced growth performance and feed utilization in shrimp fed *Sargassum* polysaccharide extract. A reduced FCR value was observed by Hafezieh *et al*. (2017) of *Sargassum ilicifolium* powder supplemented diet. Whereas noticeably improved feed conversion was observed by Giang *et al*. (2016) in a crude polysaccharide extract of *S. microcystum*-supplemented diet of shrimp. In FCR and PER, improved values of shrimp were seen by Patel *et al*. (2026) fed with fucoidan extracted from *Sargassum johnstonii*. Also, PER were improved by Lin *et al*. (2017), and Sudaryono *et al*. (2018) by feeding *S. cristaefolium* meal and processed seaweed feed respectively in the diet of shrimp. These improvements values might be due to the presence of fucoidan and other bioactive polysaccharides that enhance digestion efficiency and nutrient utilization.

Feed utilization efficiency also showed a positive response in the *Gracilaria* crude extract treatment (T5) compared to the control. The FCR and PER values of T5 treatment were 1.66 ± 0.08 and 1.73 ± 0.08, respectively. These results were similar to previous findings reported by Jasmanindar *et al*. (2018a, 2018b), where they found reduced FCR and enhanced growth when shrimp were fed on *G. verrucosa* extract. Liu *et al*. (2019) reported improved growth performance and enhanced feed utilization in shrimp fed *G. tenuistipitata* extract, while Tian *et al*. (2024) observed increased feed efficiency when shrimp fed on *G. lichenoides* meal. Similarly, Niu *et al*. (2019) also found low FCR and high PER in shrimp fed diets containing macroalgae, including *Gracilaria* species. Rodríguez-González *et al*. (2014) also observed improved protein utilization efficiency and feed conversion in shrimp fed diets supplemented with *Gracilaria* meal.

A moderate improvement in feed utilization efficiency was observed in the T2 treatment, supplemented with *Caulerpa* crude extract, as FCR (1.91±0.06) and PER (1.50±0.03). The findings of previous researchers, Nasmia *et al*. (2022) indicated a good effect of *Caulerpa* meal in shrimp diet on growth and reduced FCR. Feeding *Penaeus monodon* on sea grape powder could improve feed conversion (Putra *et al*. 2019). There was also improved antioxidant activity and feed efficiency of shrimp when fed a diet containing *Caulerpa lentillifera* (Liang *et al*. 2025). Improved growth and nutrient utilization in shrimp fed on fermented *Caulerpa microphysa* by-product was also achieved (Lee *et al*. 2023). However, Puspitasari *et al*. (2019) observed a lower effect of the inclusion of high levels of *Caulerpa racemosa* meal on FCR and PER.

FCR (1.86±0.01) and PER (1.54±0.01) were intermediate for *Cystoseira* crude extract treatment (T4). Similar findings were reported by Patel *et al*. (2026), who observed improved FCR and PER values of shrimp supplemented with fucoidan extracted from *C. indica*. Dietary supplementation with fucoidan derived from brown seaweeds has been reported to improved feed efficiency and protein utilization by *P. monodon* and *Marsupenaeus japonicus* (Traifalgar *et al*. 2009, 2010). The enhanced feed utilization efficiency observed in these studies might be due to sulfated polysaccharides and antioxidant compounds present in it that improve nutrient digestibility and metabolic activity.

Overall, the present study demonstrated that dietary supplementation with seaweed crude extracts significantly improved feed utilization efficiency in shrimp, with *Ulva* crude extract producing the best results followed by *Sargassum* and *Gracilaria* crude extracts. The improvements in FCR and PER observed in the present study were associated with bioactive compounds such as ulvan, fucoidan, sulfated polysaccharides, minerals, vitamins, and antioxidants that enhance digestive enzyme activity, nutrient absorption, gut health, and protein utilization efficiency in shrimp culture.

4.3 Survival rate

The higher survival rate observed in T3 treatment is consistent with several previous studies on *Sargassum* spp. Patel *et al*. (2025) reported survival up to 98.33% in shrimp fed *S. johnstonii* extract, while Victoriano-Blancia *et al*. (2022), and Huang *et al*. (2006) also observed improved survival in shrimp supplemented with *Sargassum* polysaccharides. Similarly, Melchor-Martínez *et al*. (2023), Hafezieh *et al*. (2017), Lin *et al*. (2017), and Sudaryono *et al*. (2018) reported survival ranging from 80–100% in shrimp fed *Sargassum*-based diets. Abbas *et al*. (2023b) and Giang *et al*. (2016) also demonstrated positive effects of *Sargassum* polysaccharides on shrimp survival and health. These findings strongly support the superior performance of T3 treatment observed in the present study.

The significantly higher survival observed in T1 treatment is supported by previous studies on *Ulva* spp. Akbary and Aminikhoei (2018) reported 100% survival in shrimp fed *U. rigida* extract, while Serrano and Declarador (2014), Ge *et al*. (2019), Omont *et al*. (2019), Mangott *et al*. (2020), and Klongklaew *et al*. (2021), also reported improved survival in shrimp supplemented with *Ulva* extracts or meal. Qiu *et al*. (2018) and Rodríguez-González *et al*. (2014) observed moderate to high survival in shrimp fed *Ulva* meal diets. Vargas-Cardenas *et al*. (2023) and Ashour *et al*. (2024) further demonstrated that seaweed supplementation improved shrimp survival and physiological health. These reports are consistent with the high survival obtained in T1.

The relatively high survival rate observed in the T5 treatment is consistent with the findings of previous studies on *Gracilaria* spp. Jasmanindar *et al*. (2018a) and (2018b), Liu *et al*. (2019), Niu *et al*. (2019), and Tian *et al*. (2024) all reported increased survival and enhanced physiological functions in shrimp when fed on a *Gracilaria* based diet. Similarly, Rodríguez-González *et al*. (2014) observed survival between 77.77–94.44% when shrimp were fed on *Gracilaria parvispora* meal. These findings further support the beneficial role of *Gracilaria* crude extract in this study. The moderate survival observed in T4 conforms with findings of similar studies with *Cystoseira* species. Patel *et al*. (2026) found better survival rates in shrimp fed diet supplemented with fucoidan of *C. indica* while Traifalgar *et al*. (2010) and Traifalgar *et al*. (2009) showed improved survival rates in crustaceans fed diets supplemented with fucoidan. It suggests that brown seaweeds rich in fucoidan have a beneficial effect on the survival rate and health of shrimp.

The survival rate recorded in the T2 treatment supplemented with *Caulerpa* spp crude extract. Supplement was moderately low compared with other seaweeds supplemented feeds but high from control feeds. High survival of shrimp was also obtained by Puspitasari *et al*. (2019), Putra *et al*. (2019), Nasmia *et al*. (2022), Zhang *et al*. (2023), and Yuniati *et al*. (2024) in shrimp fed on *Caulerpa* feed. However, several studies have indicated that higher dietary inclusion levels of *Caulerpa* may be associated with reduced growth performance and lower survival rates, which may explain the comparatively lower survival observed in the T2 treatment in the present study. Overall, the present study demonstrated that dietary supplementation of seaweed crude extracts significantly improved shrimp survival compared to the control treatment, with *Sargassum* and *Ulva* extracts showing the most promising effects for enhancing survival and overall shrimp health.

4.4 Physico-chemical water parameters

The temperature range maintained during the study may have supported normal metabolic activity and feed intake in shrimp. Previous studies have reported that temperatures between 27 and 32°C are considered optimal for the culture of *P. vannamei* and contribute to improved growth performance and physiological performance (Boyd and Tucker 1998; Van Wyk and Scarpa 1999). Similarly, the stable salinity maintained for osmotic stress supported normal physiological functioning, as *P. vannamei* performs well under moderate salinity conditions (Bray *et al*. 1994).

The stable pH conditions maintained during the experimental period may also have contributed to better shrimp health and pond stability. Appropriate pH levels are important for metabolic processes, nutrient availability, and reduction of toxic effects of dissolved compounds in aquaculture systems. Boyd (2001) reported that pH values between 7.5 and 8.5 are suitable for shrimp culture, whereas sudden fluctuations may negatively affect survival and growth.

Adequate dissolved oxygen levels may have further supported normal respiration, feed utilization, and immune function in shrimp. Low dissolved oxygen concentrations are known to suppress feeding activity, reduce growth, and increase susceptibility to disease. According to Fast and Lester (1992), dissolved oxygen levels above 5 ppm are generally considered suitable for penaeid shrimp culture. Similarly, appropriate alkalinity may have helped maintain buffering capacity and pH stability, thereby reducing environmental stress and supporting biological productivity within the culture system (Van Wyk and Scarpa 1999).

5 | CONCLUSIONS

Present investigation finding of different seaweed crude extract supplement with at 5 g kg^{-1} in in shrimp feed give the batter growth rate, feed utilisation and survival. Among the five species, *Ulva* spp. higher growth rate, followed by *Sargassum* spp. In terms of the survival rate, the highest survival observed at the end of the experiment in *Sargassum* spp. fed diet. This finding suggested that marine macroalga are the potential to provide good results for sustainable aquaculture practices.

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ETHICAL APPROVAL

All applicable international, national and/or institutional guidelines for the care and use of animals were followed in this study.

CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHORS' CONTRIBUTION

RVC: Conceptualization, Methodology, Data analysis, Writing — original draft. NHJ: Conceptualization, Methodology, Writing — review & editing. DCT: Methodology. VKS: Formal analysis. JMT: Writing — original draft. BDS: Writing — review & editing.

AI USE DECLARATION

ChatGPT v5 was used for targeted polish tasks, including improving sentence clarity, enhancing transitions between paragraphs, and refining wording for precision and readability.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available within this article.

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