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Impact of Composite Regulation Technology on the Ecology, Growth, and Immunity of *Litopenaeus vannamei* in High-Position Pond Aquaculture

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Abstract

To explore the optimization effects of fixed aquatic water treatment materials combined with immunomodulatory agents on the ecosystem and farming efficiency of *Litopenaeus vannamei* in high-water-level ponds, this study established experimental ponds (with fixed aquatic water treatment materials and feed supplemented with chitosan oligosaccharides) and control ponds (no fixed water treatment materials applied, fed with basal feed only). Through a comparative trial over a complete farming cycle, the study systematically analyzed changes in plankton community structure and diversity, water physicochemical factors, shrimp growth performance, immune indicators, and muscle nutritional composition. The results showed that in the experimental group, diatoms (*Ditylum brightwellii* and *Skeletonema*) dominated the plankton community, while the density of harmful blue-green algae (*Oscillatoria* and *Trichodesmium*) significantly decreased, and planktonic animal diversity improved in the later stages. Among the water physicochemical indicators, the experimental group exhibited a 50% reduction in nitrite levels by the later stages, significantly higher than the 33.33% reduction in the control group. Total ammonia nitrogen levels remained lower than those in the control group, with a smaller increase in the later stages. Total phosphorus levels were significantly lower in the experimental group after 80 days, and the later-stage decline in chemical oxygen demand was 11.65% higher than that in the control group. Shrimp body weight increased significantly by 13.23%, while hepatosomatic index, musculosomatic index, and immune enzyme (acid phosphatase and total antioxidant substances) activity also improved markedly. The content of unsaturated fatty acids (linoleic acid and oleic acid) in the muscles significantly increased. The study demonstrated that the combined application of fixed aquatic water treatment materials and chitosan oligosaccharide preparations can optimize the farming water environment, enhance shrimp growth performance and quality, and provide technical support for the ecological cultivation of *Litopenaeus vannamei*.

Keywords: *Litopenaeus vannamei*; immobilized materials; chitosan oligosaccharide; plankton community; growth performance; immune indicators

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1. Introduction

The intensive farming approach of *Litopenaeus vannamei* (*L. vannamei*), one of the highest-yielding economic shrimp species in the world, not only boosts output but also encounters problems such as declining water quality, ecological imbalance, and frequent

disease outbreaks [1]. Eutrophication is caused by the buildup of nutrients like nitrogen and phosphorus in aquaculture water bodies. When harmful algae, like blue-green algae, proliferate, they can set off a chain reaction of rapid oxygen depletion and toxin release, which directly affects the shrimp's quality and survival rate [2]. Shrimp immunity decreases under high-density farming circumstances, making them vulnerable to diseases, limiting the industry's long-term development [3]. Furthermore, in recent years, physical–biological synergistic regulation technology has become a research hotspot for improving aquaculture ecology both domestically and internationally. Through adsorption, ion exchange, and carrier functions, immobilized water treatment materials can effectively remove nitrogen, phosphorus, and other pollutants from water while also offering attachment sites for beneficial microorganisms [4,5]; as a natural immune enhancer, chitosan oligosaccharides can activate the shrimp immune system, improve intestinal microbial balance, and improve their growth performance and disease resistance [6,7]. Sarker et al. [3] found that a solid-phase composite biological filter medium can effectively reduce concentrations of ammonia nitrogen, phosphorus, and organic matter in aquaculture water. It also stabilizes the physical and chemical environment and enhances shrimp growth. Nabaterega et al. [8] indicated that a biological filtration and ecological filter media system can improve the micro-ecological structure of water, inhibit the growth of harmful organisms, and enhance the water's self-purification capacity. The mechanisms by which they interact with one another in terms of water quality, plankton, and shrimp still need to be carefully investigated, and systematic research on the overall regulatory effects of their combined application in the South American white shrimp farming system has not yet been established. The structure of the plankton community in the aquaculture water, the shrimp's growth performance, and the nutritional indicators of the shrimp are the three dimensions in which this study reveals the synergistic regulatory effects of immobilized materials and chitosan oligosaccharides through comparative experiments between test ponds and control ponds.

2. Materials and Methods

2.1. Objects of the Experiment

The Pacific white shrimp larvae utilized in the experiment were first-generation specific pathogen-free (SPF) larvae sourced from a local, reputable hatchery. Their initial body length ranged from 0.8 to 1.0 cm. After reaching an average body length of 5 cm and an average weight of 1.7 g, they were stocked in separate ponds. All experimental shrimp larvae originated from the same batch, demonstrating uniform size, absence of disease and limb defects, and exhibiting exceptional health and vitality.

2.2. Experimental Design

The experiment was conducted in a high-level pond designated for *L. vannamei* shrimp farming and lasted for 110 days. Six identical ponds, each covering an area of 2 ha and with a water depth ranging from 1.5 to 1.7 m, were selected. These ponds featured flat bottoms, uniform aeration equipment, and consistent water inlet and outlet systems. The six ponds were randomly divided into two treatment groups, with three replicate ponds in each group (n = 3). The experimental group received immobilized water treatment material at a rate of 40 kg/hm^2 and was supplemented with 0.05‰ chitosan oligosaccharide in their feed. In contrast, the control group was not given any immobilized water treatment material and was fed a basal diet devoid of immune additives. The stocking density of each group was 225,000 nos/ha. Prior to stocking, the physicochemical baseline indicators of the shrimp pond water were collected and measured simultaneously. The initial levels of ammonia nitrogen (0.01 ± 0.003 mg/L), nitrite (0.006 ± 0.001 mg/L), total phospho-

rus (0.08 ± 0.01 mg/L), and COD (4.2 ± 0.4 mg/L) were found to be statistically similar between the two groups of ponds ($p > 0.05$).

2.3. Management of Aquaculture

In the experiment, a uniform batch of *L. vannamei* postlarvae was introduced into six ponds. After the nursery phase, the seedstock was distributed into separate rearing ponds, maintaining a stocking density of 225,000 nos/ha. The shrimp were stocked in separate ponds after reaching a body length of 5 cm. The water temperature was 24–32 °C, the salinity was 18–22‰, the pH was 7.8–8.6, and oxygenation was carried out continuously for 24 h a day. The control group was not administered any water quality treatment materials, and the feed provided was a standard formulation containing a crude protein content of 38%. The aquaculture management measures for both groups were entirely the same. The experimental immobilised water-quality treatment medium consists of a super-energy carbon-source filler that includes three water-quality components. The outer layer consisted of a three-dimensional spherical shell, which offered a uniform, stable, and relatively independent environment for the core components of the filler. The middle layer consisted of a composite polymer material that served as a microbial carrier for the MBBR filler, providing a fixed structure. The chitosaccharide additive utilized in the experiment was a fully water-soluble functional material derived from biomass refining technology. It comprises 24.5% chitosaccharides, exhibits a degree of polymerization ranging from 2 to 8, and has a degree of deacetylation exceeding 95%. It is satisfactory. The control group received no water quality treatments, and the diet consisted of a basic formulation with a crude protein content of 38%. The management measures for aquaculture in both groups were aligned, involving feeding at four specific times throughout the day: 6:00, 10:00, 16:00, and 18:00. The feeding amount was calibrated to range from 3% to 5% of the shrimp's body weight. At the outset, only water was introduced.

2.4. Sample Collection and Measurement

2.4.1. Water Sample Collection and Measurement

During the trial period, water samples were collected every 15 days before water replacement in the afternoon. A total of five time points were established, corresponding to 50 days, 65 days, 80 days, 95 days, and 110 days of cultivation. The sampling intervals were standardized to 15 days. Water samples were collected using a diagonal sampling method, with two sampling points selected from each pond. Using an organic glass water sampler, 500 mL of water from the upper and lower layers of each sample point was collected. The two water samples from the same pond were mixed evenly to represent the water quality of that pond. The samples were stored in a refrigerated room at 3–4 °C away from direct sunlight, and measurements were completed as soon as possible. Five physicochemical indicators of the water were identified: the N-(1-naphthyl) ethylenediamine spectrophotometric method for determining nitrite, Nessler's reagent spectrophotometric method for measuring ammonia nitrogen, and the molybdenum-antimony anti-spectrophotometric method for assessing inorganic phosphorus and reactive phosphate.

2.4.2. Collection and Analysis of Phytoplankton Samples

Phytoplankton samples were collected concurrently at the five water sampling intervals. To collect quantitative samples, 30–40 litres of water were sieved using a 25 μm plankton net with a mesh size of 0.064 mm (200 mesh). Utilized a 5% formaldehyde solution for fixation, maintaining a sample-to-fixative ratio of 100:1. Consolidate the sample to a final volume ranging from 100 to 1000 mL following a 24-h sedimentation interval. Thereafter, measure the density of phytoplankton and zooplankton cells (cells/L). Furthermore, use the Shannon–Wiener index to calculate the plankton diversity index. To examine the

composition of the dominating species, a qualitative sample was collected using the tow-net method. The Shannon–Wiener diversity index was chosen to assess community diversity, using the following formula:

$$H' = -\sum i = 1SP\ i\ lnP\ i,$$

where S is the number of species (at the genus level) and P i = Ni/N (Ni is the density of the i-th species and N is the total density). Qualitative data are merely used in order to gain better knowledge of species richness, while quantitative data serve as the foundation of the calculations.

2.4.3. Collection and Analysis of Shrimp Samples

At the end of the farming period, which lasted 110 days, a random selection of 30 shrimp was made from each pond to assess growth indicators. The body length was measured using a vernier calliper with an accuracy of 0.01 cm, and the body weight was determined with an electronic balance that has an accuracy of 0.01 g. Additionally, recorded the weights of the hepatopancreas and muscle. Subsequently, calculated the hepatosomatic index using the formula

$$\text{hepatosomatic index} = \text{hepatopancreas weight/body weight} \times 100\%$$

and the condition factor with the formula

$$\text{condition factor} = \text{body weight/body length}^3 \times 100\%$$

The Nanjing Jiancheng Biotechnology Institute provided a specialised detection kit to examine 30 g of homogenised hepatopancreas tissue. Hepatopancreas tissue used for the assessment of immune enzyme activity, and after preparing tissue homogenate, the indicators were tested using a commercially available kit, strictly following the kit instructions: acid phosphatase (ACP) and alkaline phosphatase (AKP) were measured by colorimetric method; glutathione peroxidase (GPX) and Total antioxidant capacity (T-AOC) were measured by ultraviolet spectrophotometry; and malondialdehyde (MDA) was measured by the thiobarbituric acid method. A sample of 100 g of muscle tissue was utilised to analyse routine nutritional components, including moisture, ash, and crude protein, as well as the composition of amino acids and fatty acids. Amino acids are quantified via high-performance liquid chromatography (HPLC), while fatty acids are analysed using gas chromatography–mass spectrometry (GC-MS).

2.5. Data Analysis

Statistical data analysis was conducted utilizing SPSS 20.0 software. Multiple comparisons were performed using Bonferroni correction and were uniformly expressed as "mean ± standard deviation (Mean ± SD, n = 3)". All tables indicated the number of replicates (n = 3). $p < 0.05$ indicated a significant difference between groups, and $p > 0.05$ indicated no significant difference.

3. Results

3.1. The Impact of Composite Regulation Technology on the Physicochemical Properties of Aquaculture Water

3.1.1. Variation in Nitrite Levels

Figure 1 shows variability in nitrite concentration for both the control and experimental groups. In the first phase, both groups exhibited small changes (control: 0.03 mg/L, experimental: 0.02 mg/L).

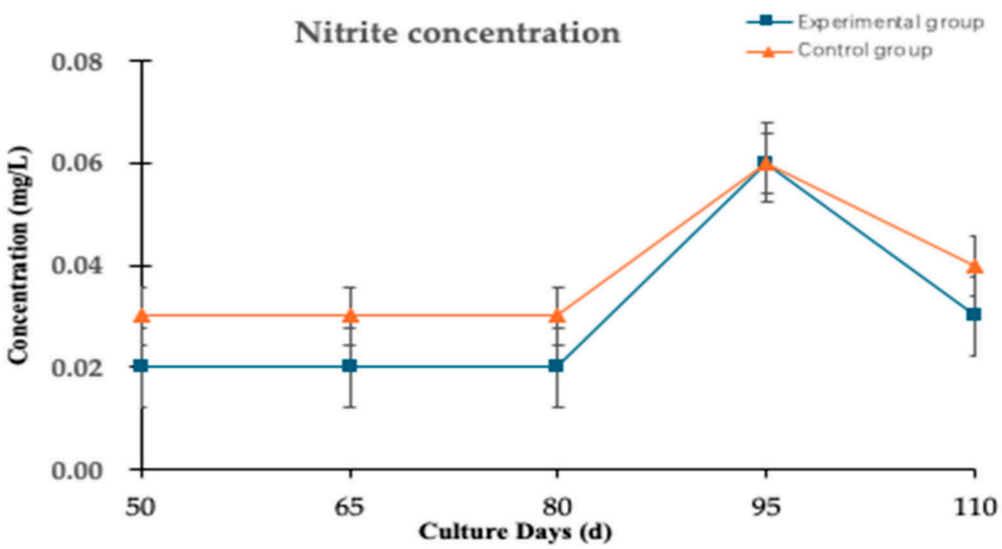

Figure 1. Variations in Nitrite concentration in the water of experimental and control ponds.

3.1.2. Variations in Ammonia Nitrogen

The variations in ammonia nitrogen concentration observed in both the control group and the experimental group are illustrated in Figure 2, demonstrating a wave-like fluctuation over the entire duration of the study. The ammonia nitrogen concentration in the experimental group increased on culture day 65, whereas the control group decreased. On culture day 80, the experimental group showed a decrease in concentration, and the control group's concentration increased. On culture day 95, the concentrations in both the experimental and control groups were nearly equal; however, the experimental group showed a slightly higher concentration. On culture day 110, the control group showed a slightly higher concentration than the experimental group.

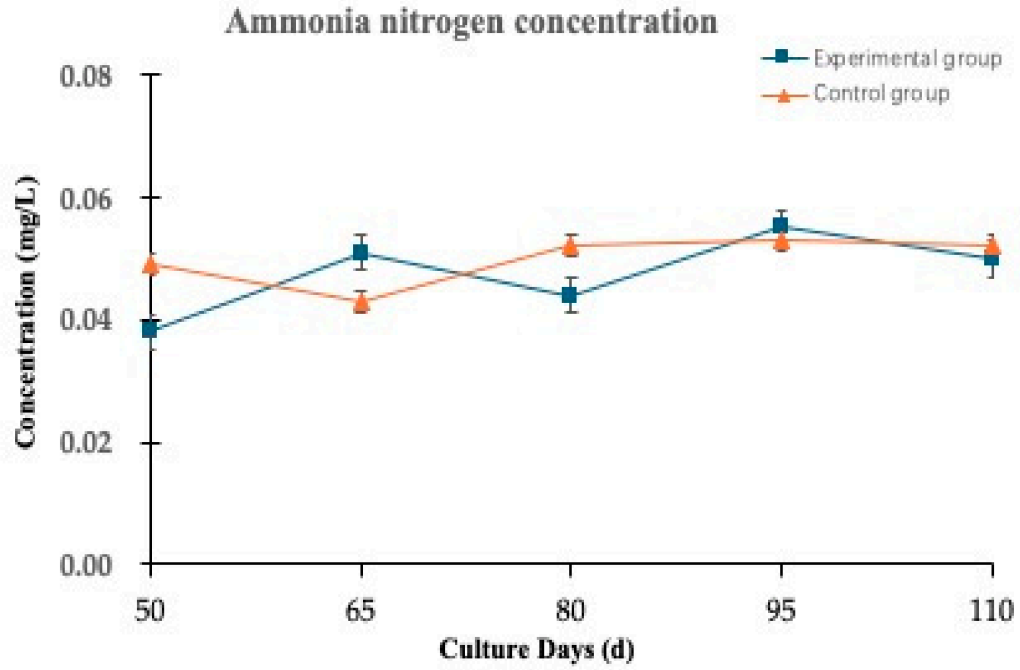

Figure 2. Changes in ammonia nitrogen concentration in the water during the culture.

3.1.3. Variations in Inorganic Phosphorus and Total Phosphorus Concentrations

The variations in inorganic phosphate concentrations within both the control and experimental groups are illustrated in Figure 3. The experimental group exhibited an initial increase followed by a decline, peaking at 2.58 mg/L at the 80-day mark. In contrast, the control group showed a continuous decrease, initially achieving a maximum.

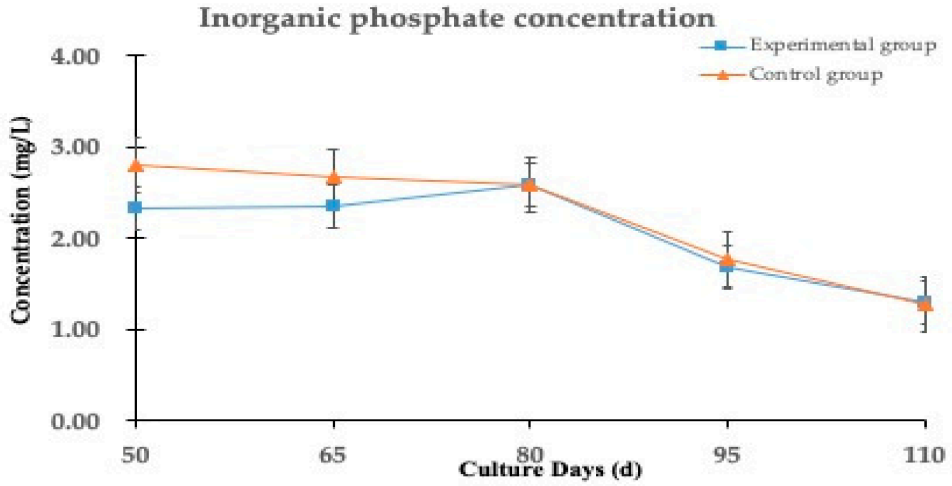

Figure 3. Variations in inorganic phosphorus concentration in the water of the experimental pond and control pond.

The variations in total phosphorus concentration within both the control and experimental groups are illustrated in Figure 4. On day 50, the experimental group recorded a concentration of 2.61 mg/L, surpassing the control group, which measured 2.10 mg/L. This trend culminated in a peak concentration of 4.44 mg/L on day 65.

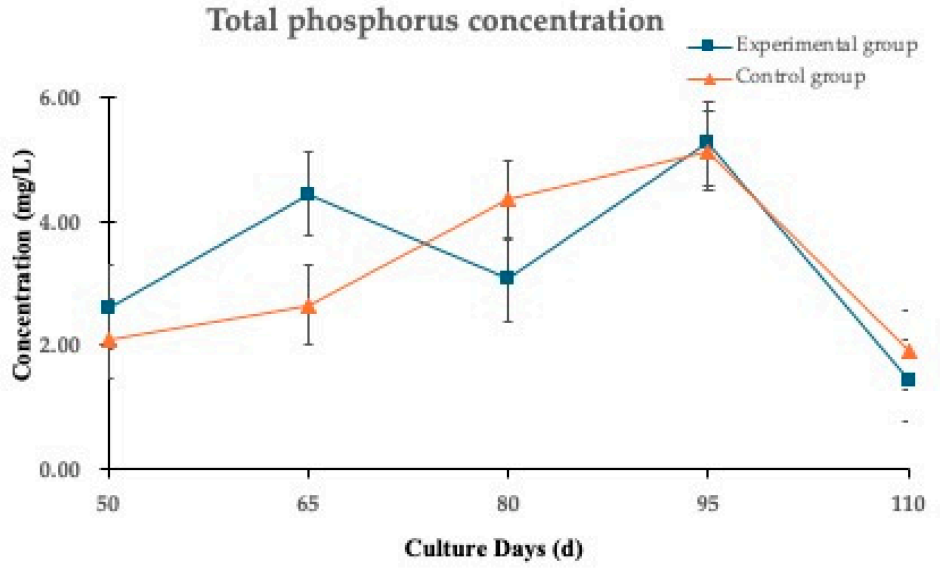

Figure 4. Changes in total phosphorus concentration in the water of the experimental pond and control ponds.

3.1.4. Variations in Chemical Oxygen Demand (COD) Concentration

The variations in COD concentration for both the control group and the experimental group are illustrated in Figure 5. From day 50 to day 80, the experimental group exhibited a significantly higher concentration (maximum 32 mg/L) compared to the control group (maximum 25.1 mg/L), with $p < 0.05$.

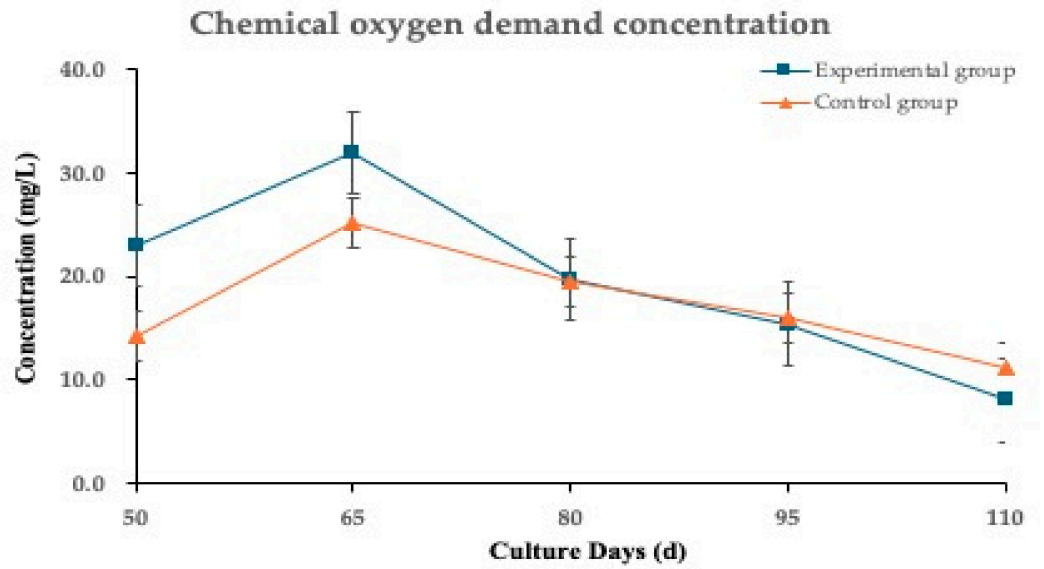

Figure 5. Variations in Chemical Oxygen Demand Concentration in the Experimental and Control Ponds.

3.2. Composite Regulation Technology Impact on Phytoplankton Community Composition

3.2.1. Phytoplankton

After a cultivation period of 50 days, the predominant species observed in both experimental groups were primarily harmful cyanobacteria, particularly *Microcystis aeruginosa*, with cell densities recorded at 186,700 cells/L in the experimental group and 133,300 cells/L in the control group. These densities were found to be 23 times and 256 times greater than those of diatoms (Cyclotella and Chaetoceros), respectively. On days 65 (P1) and 80, the primary species in the experimental group transitioned to diatoms, notably Cyclotella (26,700 cells/L) and Chaetoceros (600,000 cells/m^3), whereas the control group continued to exhibit a minor presence of *Microcystis aeruginosa*. On day 95, both groups exhibited the presence of Aphanizomenon (cyanobacteria), with the density in the control group (416,700 cells/L) being twice that observed in the experimental group. On day 110, the experimental group exhibited a predominance of diatoms (Chaetoceros and Cyclotella), with no presence of Aphanizomenon observed. In contrast, the control group maintained a density of 133,300 cells/L of Aphanizomenon (Tables 1 and 2). The diversity index of phytoplankton in the experimental group exhibited a consistent upward trend, whereas the control group displayed variations and maintained a generally low level. The control group showed fluctuations and was generally low. Except for 50 days and 80 days, the planktonic biodiversity index of the experimental group was significantly higher than that of the control group at other time points ($p < 0.05$). The prevalence of diatoms within the experimental group can increase dissolved oxygen levels in the aquatic environment through the process of photosynthesis, while also mitigating the risk of eutrophication by absorption of nitrogen and phosphorus. Furthermore, the decrease in cyanobacteria, particularly from the genus Microcystis, can lead to a reduction in the consumption of dissolved oxygen.

Table 1. Quantitative Determination Results of Phytoplankton Cell Count.

Group	Culture Time (d)	Species Name	Density (Cell/L)	Diversity Index H′
Experimental group	50	*Trichodesmium thiebauti* *Chaetoceros knipowitschi* *Thalassiosira* sp. *Coscinodiscus oculus-iridis*	186,567 ± 11,200 40,000 ± 3200 33,333 ± 2800 6667 ± 900	0.92 ± 0.04
Control group	50	*Trichodesmium thiebauti* *Thalassiosira* sp. *Coscinodiscus oculus-iridis*	133,333 ± 9300 33,333 ± 2700 13,333 ± 1600	0.78 ± 0.03
Experimental group	65	*Thalassionema nitzschiodes* *Coscinodiscus oculus-iridis*	26,667 ± 2400 13,333 ± 1500	1.05 ± 0.05 [a]
Control group	65	*Trichodesmium thiebauti* *Thalassionema nitzschiodes*	213,333 ± 12,800 13,333 ± 1400	0.51 ± 0.03 [b]
Experimental group	80	*Thalassiosira* sp. *Phormidium* sp.	600,000 ± 30,000 133,333 ± 8600	1.82 ± 0.06
Control group	80	*Thalassiosira* sp. *Phormidium* sp.	433,333 ± 22,500 200,000 ± 13,200	1.56 ± 0.05
Experimental group	95	*Oscillatoria* sp. *Thalassionema nitzschiodes* *Coscinodiscus argus* *Coscinodiscus jonesianus*	208,333 ± 13,500 83,333 ± 6100 25,000 ± 2100 25,000 ± 2000	1.95 ± 0.07 [a]
Control group	95	*Oscillatoria* sp. *Coscinodiscus jonesianus* *Coscinodiscus argus* *Nitzschia lorenziana* *Coscinodiscus oculus-iridis*	416,667 ± 21,800 25,000 ± 1900 16,667 ± 1800 8333 ± 1100 8333 ± 1000	1.23 ± 0.04 [b]
Experimental group	110	*Thalassiosira* sp. *Thalassionema nitzschiodes* *Nitzschia* sp. *Coscinodiscus argus*	16,667 ± 1700 16,667 ± 1600 8333 ± 1000 8333 ± 950	2.10 ± 0.07 [a]
Control group	110	*Oscillatoria* sp. *Coscinodiscus argus* *Coscinodiscus jonesianus*	133,333 ± 8900 8333 ± 900 8333 ± 920	0.85 ± 0.04 [b]

Note: For data from the same sampling time point, different letters in the superscript indicate significant differences ($p < 0.05$); the same letter or no letter indicates that the difference is not significant.

Table 2. Qualitative Determination Results of Phytoplankton Cell Count.

Group	Culture Time (d)	Species Name	Count (Number)
Experimental group	50	-	-
Control group	50	-	-
Experimental group	65	-	-
Control group	65	-	-
Experimental group	80	*Aphanizomenon* sp. *Oscillatoria* sp. *Coscinodiscus* sp. *Coscinodiscus oculus-iridis*	192 45 4 2
Control group	80	*Pyrophacus horologicum* *Coscinodiscus adiatus* *Pleurosigma falx*	3 2 1
Experimental group	95	*Thalassionema nitzschiodes* *Oscillatoria* sp. *Thalassiosira* sp.	6 5 2
Control group	95	*Melosira granulata* *Oscillatoria* sp. *Pleurosigma naviculaceum*	15 10 1
Experimental group	110	*Thalassiosira* sp. *Coscinodiscus jonesianus*	2 1
Control group	110	*Oscillatoria* sp.	4

Note: Density is not calculated for qualitative samples; this indicates that no testing was conducted.

3.2.2. Zooplankton

Copepods (the genus *Acartia*, *Pseudodiaptomus*, and *Paracalanus*) dominated both zooplankton populations. On day 50, the experimental group had a higher density (367 individuals/m^3) compared to the control group (267 individuals/m^3). Between days 65 and 95, the control group's density was 3.03 times (303 individuals/m^3 vs. 100 individuals/m^3), 1.98 times (593 individuals/m^3 vs. 300 individuals/m^3), and 2.88 times (720 individuals/m^3 vs. 250 individuals/m^3) higher than the experimental group. On day 110, both groups' densities peaked, with the experimental group having a slightly greater density (800 individuals/m^3) than the control group (725 individuals/m^3), as well as an increase in species (two new copepod species) (Tables 3 and 4). In the initial phase of the culture, the zooplankton diversity index did not differ significantly between the two groups ($p > 0.05$). During the later phase of culture (80 d–110 d), the experimental group had a significantly higher zooplankton diversity index (2.8–3.2) compared to the control group (1.9–2.3) ($p < 0.05$). This indicates that the adopted combined regulatory technique improves the living conditions for zooplankton, promotes community diversity, and provides shrimp with a more abundant source of natural food.

Table 3. Quantitative Determination Results of Zooplankton Population Density.

Group	Culture Time (d)	Filtration Volume (L)	Species Name	Quantity	Population Density (ind/L)	Sum of Densities (ind/L)
Experimental group	50	30	*Hemicyclops larva* *Acartia larva* *Paracalanus aculeatus* *nauplius*	6 3 1 1	200 ± 18 100 ± 11 33 ± 6 33 ± 6	367 ± 29
Control group	50 65	30	*Hemicyclops larva* *Acartia larva* *nauplius*	4 3 1	133 ± 14 100 ± 11 33 ± 6	267 ± 24
Experimental group	65 65	30	*Acartia larva*	1	33 ± 7	33 ± 7
Control group	65 80	30	*Acartia larva* *nauplius*	2 1	67 ± 10 33 ± 7	100 ± 13
Experimental group	80 80	30	Nauplius larva	2	67 ± 9	67 ± 9
Control group	95	30	Nauplius larva	4	133 ± 15	133 ± 15
Experimental group	95 95	40	*Acartia* sp. Nauplius larva *Pseudodiaptomus annandalei* Nauplius larva (copepoda)	3 2 2 1	75 ± 8 50 ± 7 50 ± 7 25 ± 5	200 ± 22
Control group	95 110	40	*Acartia* sp. *Nauplius larva* *Pseudodiaptomus poplesia* *Pseudodiaptomus annandalei*	13 5 3 2	325 ± 31 125 ± 16 75 ± 9 50 ± 7	575 ± 46
Experimental group	110 110	40	*Acartia* sp. *Pseudodiaptomus poplesia* *Pseudodiaptomus annandalei* Nauplius larva (copepoda) Nauplius larva *Eurytemora pacific*	19 4 4 3 1 1	475 ± 42 100 ± 12 100 ± 12 75 ± 9 25 ± 5 25 ± 5	800 ± 63
Control group		40	*Acartia* sp. *Pseudodiaptomus poplesia* Nauplius larva	15 12 2	375 ± 36 300 ± 28 50 ± 7	725 ± 58

Table 4. Qualitative Assessment Results of Zooplankton (Late Culture Period).

Group	Culture Time (d)	Species Name	Quantity (Pieces)
Experimental group	50	-	-
Control group	50	-	-
Experimental group	65	-	-
Control group	65	-	-
Experimental group	80	*Pseudodiaptomus poplesia*	4
		Nauplius larva	1
Control group	80	Nauplius larva	5
		Pseudodiaptomus poplesia	2
Experimental group	95	*Acartia* sp.	24
		Seudiaptomus annandalei	16
Control group	95	*Acartia* sp.	11
		Nauplius larva	3
Experimental group	110	*Acartia* sp.	16
		Pseudodiaptomus poplesia	8
		Nauplius larva	6
		Nauplius larva(copepoda)	2
		Seudiaptomus annandalei	1
Control group	110	*Acartia* sp.	10
		Nauplius larva	7
		Pseudodiaptomus poplesia	5

Note: Density is not calculated for qualitative samples; this indicates that no testing was conducted.

3.3. Impact on the Development and Immune Functionality of L. vannamei

3.3.1. Growth Indicators

The experimental group exhibited a body weight increase of 13.23% ($p < 0.05$) compared to the control group (Table 5). Additionally, both the liver-to-body ratio and muscle-to-body ratio were significantly higher in the experimental group, with increases of 4.19% and 14.59%, respectively, compared to the control group.

Table 5. Growth Performance Indicators of *Litopenaeus vannamei*.

Growth Performance Indicators	Experimental Group	Control Group
Final body weight FW (g)	20.18 ± 3.75^{a}	17.82 ± 3.25^{b}
Final body length FL (cm)	13.36 ± 0.73	12.96 ± 0.85
Hepatopancreas HPW (g)	1.15 ± 0.27^{a}	0.97 ± 0.21^{b}
Muscle weight MW (g)	9.93 ± 1.67	9.23 ± 1.59
Liver body ratio HI	0.06 ± 0.01^{a}	0.05 ± 0.01^{b}
Body ratio AMR	0.55 ± 0.66^{a}	0.48 ± 0.22^{b}
Plumpness CF	0.83 ± 0.05	0.82 ± 0.12

Note: Different letters in the superscript of data from the same peer indicate significant differences ($p < 0.05$). The same letter or no letter indicates that the difference is not significant.

3.3.2. Immune and Digestive Physiological Indicators

The activity of acid phosphatase, total antioxidants, and malondialdehyde in the hepatopancreas of shrimp in the experimental group was significantly higher compared to the control group ($p < 0.05$). Conversely, the activities of alkaline phosphatase and glutathione peroxidase did not differ significantly from those in the control group ($p > 0.05$). Additionally, the concentration of malondialdehyde was significantly higher in the experimental group than in the control group ($p < 0.05$) (Table 6).

Table 6. Immune Enzyme Activity in the Hepatopancreas of *L. vannamei.*

Immune Enzyme Activity	Experimental Group	Control Group
Acid phosphatase ACP (μmol/min/g)	2.59 ± 0.40 [a]	1.53 ± 0.12 [b]
Alkaline phosphatase AKP (μmol/min/g)	7.26 ± 1.47	7.32 ± 2.59
Glutathione peroxidase GPx (nmol/min/g)	947.95 ± 326.89	723.48 ± 632.66
Total antioxidant capacityT-AOC (μmol Trolox/g)	17.11 ± 1.17 [a]	10.84 ± 1.03 [b]
MalondialdehydeMDA (nmol/g)	92.06 ± 20.06 [a]	53.6 ± 4.36 [b]

Note: Different letters in the superscript of data from the same peer indicate significant differences ($p < 0.05$). The same letter or no letter indicates that the difference is not significant.

3.4. Impact on the Nutritional Composition of Muscle in L. vannamei

The nutritional composition of muscle in *L. vannamei* showed no significant changes in moisture (75.53–76.20%), ash (0.27–0.28%), and crude protein content (20.70–21.90%) between the two groups of shrimp (Table 7). As shown in Table 8, a total of 17 amino acids were detected in the muscle tissue of *L. vannamei* from both groups. Glutamic acid (Glu) was the most abundant, followed by glycine (Gly), arginine (Arg), and aspartic acid (Asp), while the levels of cystine (Cys), methionine (Met), and histidine (His) were relatively low. Although the total amino acid (TAA), essential amino acid (EAA), and umami-related amino acid (DAA) contents in the experimental group were higher than those in the control group, the differences were not statistically significant ($p > 0.05$).

Table 7. Typical Nutritional Components of *L. vannamei* Muscle.

Nutritional Components	Experimental Group	Control Group
Moisture	75.53 ± 0.4	76.20 ± 0.36
Ash	0.28 ± 0.04	0.27 ± 0.03
Crude protein	21.90 ± 1.47	20.70 ± 0.46

Table 8. Amino Acid Composition and Content of Muscle in *L. vannamei*. Unit: g/100 g.

Amino Acid Composition	Experimental Group	Control Group
Aspartic acid (Asp)	1.82 ± 0.03	1.83 ± 0.08
Threonine (Thr)	0.67 ± 0.01	0.69 ± 0.04
Serine (Ser)	0.64 ± 0.02	0.65 ± 0.05
Glutamic acid (Glu)	2.93 ± 0.05	2.86 ± 0.15
Glycine (Gly)	1.79 ± 0.02	1.95 ± 0.13
Alanine (Ala)	1.06 ± 0.02	1.03 ± 0.02
Cystine (Cys)	0.08 ± 0.02	0.07 ± 0.01
Valine (Val)	0.83 ± 0.02	0.85 ± 0.05
Methionine (Met)	0.32 ± 0.09	0.32 ± 0.09
Isoleucine (IIe)	0.75 ± 0.01	0.76 ± 0.04
Leucine (Leu)	1.38 ± 0.03	1.39 ± 0.05
Tyrosine (Tyr)	0.56 ± 0.01	0.57 ± 0.02
Phenylalanine (Phe)	0.81 ± 0.01	0.81 ± 0.04
Lysine (Lys)	1.53 ± 0.03	1.54 ± 0.06
Histidine (His)	0.35 ± 0.01	0.35 ± 0.01
Arginine (Arg)	1.89 ± 0.04	1.86 ± 0.09
Proline (Pro)	1.17 ± 0.03 [a]	1.00 ± 0.04 [b]
Total amino acid TAA	18.58 ± 0.19	18.52 ± 0.7
Essential amino acids EAA	6.36 ± 0.18	6.29 ± 0.04
Semi-non-essential Amino acids HEAA	2.22 ± 0.10	2.24 ± 0.05
Umami amino acids DAA	7.66 ± 0.37	7.60 ± 0.09
Non-essential amino acids NEAA	12.29 ± 0.17	12.16 ± 0.53
EAA/TAA/%	37.84 ± 0.35	37.37 ± 0.32
EAA/NEAA/%	63.95 ± 0.97	62.64 ± 0.80

Note: Different letters in the superscript of data from the same peer indicate significant differences ($p < 0.05$). The same letter or no letter indicates that the difference is not significant.

Table 9 indicates that a total of 23 fatty acids were identified in the muscle samples from both groups of *L. vannamei*. The experimental group exhibited a minimal concentration of capric acid, whereas the control group showed no detectable levels of it. Palmitic acid and stearic acid constituted the primary saturated fatty acids, whereas oleic acid, linoleic acid, and tetracosic acid represented the principal monounsaturated fatty acids. The experimental group exhibited higher concentrations of palmitic acid at 7.09% and stearic acid at 6.4%, in contrast to the control group, which recorded levels of 6.15% and 5.5%, respectively. The concentrations of EPA and DHA were higher in comparison to the control group; however, the observed differences did not reach statistical significance ($p > 0.05$). Nevertheless, the contents of linoleic acid (6.22%) and oleic acid (4.43%) were significantly higher than those of the control group (5.42% and 3.78%, respectively). The concentrations of eicosapentaenoic acid (EPA), eicosadienoic acid (EDA), dicosic acid, and tetracosic acid were substantially higher in comparison to the control group ($p < 0.05$).

Table 9. Fatty Acid Composition and Content of Muscle in *L. vannamei.*

Fatty Acid Composition		Experimental Group	Control Group
			unit:%
Bitter	C8:0	Not detected (<0.00005)	Not detected (<0.00005)
Capric acid	C10:0	0.01 ± 0.01	Not detected (<0.00005)
Undecanoic acid	C11:0	Not detected (<0.00005)	Not detected (<0.00005)
Lauric acid	C12:0	Not detected (<0.00005)	Not detected (<0.00005)
Tridecanoic acid	C13:0	Not detected (<0.00005)	Not detected (<0.00005)
Myristic acid	C14:0	0.08 ± 0.01	0.07 ± 0.01
Myristoleic acid	C14:1	Not detected (<0.00005)	Not detected (<0.00005)
Pentadecanoic acid	C15:0	0.08 ± 0.01	0.07 ± 0.01
Pentadecenoic acid	C15:1	Not detected (<0.00005)	Not detected (<0.00005)
Palmitic acid	C16:0	7.09 ± 0.59	6.15 ± 0.28
Palmitoleic acid	C16:1	0.26 ± 0.02	0.26 ± 0.02
Heptadecanol	C17:0	0.40 ± 0.04	0.36 ± 0.02
Heptadecanoic acid	C17:1	Not detected (<0.00005)	Not detected (<0.00005)
Stearic acid	C18:0	6.40 ± 0.7	5.50 ± 0.14
Trans oleic acid	C18:1n9t	Not detected (<0.00005)	Not detected (<0.00005)
Oleic acid	C18:1n9c	4.43 ± 0.32	3.78 ± 0.22
Trans-linoleic acid	C18:2n6t	Not detected (<0.00005)	Not detected (<0.00005)
Linoleic acid	C18:2n6c	6.22 ± 0.41	5.42 ± 0.15
Arachidonic acid	C20:0	0.36 ± 0.03	0.29 ± 0.01
γ-Alpha-linolenic acid	C18:3n6	Not detected (<0.00005)	Not detected (<0.00005)
Eicosenoic acid	C18:3n3	0.21 ± 0.02	0.17 ± 0.01
α-Alpha-linolenic acid	C20:1	0.49 ± 0.06	0.43 ± 0.02
Twenty-one carbonic acid	C21:0	0.08 ± 0.01	0.07 ± 0.00
Eicosadienoic acid	C20:2	0.63 ± 0.03	0.55 ± 0.02
Dodecanediol	C22:0	0.46 ± 0.03	0.36 ± 0.05
Eicosatrienoic acid	C20:3n6	0.03 ± 0.01	0.03 ± 0.01
Erucic acid	C20:3n3	0.02 ± 0.00	0.01 ± 0.00
Eicosatrienoic acid	C22:1n9	0.05 ± 0.01	0.03 ± 0.00
Arachidonic acid ARA	C20:4n6	1.31 ± 0.04	1.23 ± 0.05
Trichocarbonate	C23:0	0.16 ± 0.02	0.14 ± 0.00
Dodecadienoic acid	C22:2	0.01 ± 0.00	0.01 ± 0.00
Twenty-four carbonic acid	C20:5n3	4.73 ± 0.19	4.32 ± 0.12
Eicosapentaenoic acid EPA	C24:0	0.34 ± 0.03	0.32 ± 0.02
Ticosatenoic acid	C24:1	0.13 ± 0.01	0.10 ± 0.02
Methyl docosahexaenoate DHA	C22:6n3	6.37 ± 0.39	5.87 ± 0.22
Saturated fatty acids SFA		14.41 ± 1.35	12.44 ± 0.44
Unsaturated fatty acids UFA		25.93 ± 1.43	23.11 ± 0.79

4. Discussion

4.1. Regulation Mechanism of Composite Regulation Technology on Physicochemical Factors in Aquaculture Water

The stability of physicochemical factors is crucial for the healthy growth of shrimp. In this study, composite regulation technology effectively regulated nitrite, ammonia nitrogen, total phosphorus, and COD in the water. The experimental group showed

better reduction in nitrite and control of ammonia nitrogen in the later stages than the control group. It has been further confirmed that the composite biological filter medium can effectively reduce phosphorus loads and organic pollution in water, demonstrating excellent in situ purification performance for aquaculture water [3]. This is related to the nitrogen conversion effect of immobilized microorganisms and the synergistic effect of chitosan oligosaccharide in reducing nitrogen excretion, consistent with the research of Zhang et al. [9]. After 80 days, the total phosphorus concentration in the experimental group was significantly lower than that in the control group, and the COD reduction was even greater in the later stages, effectively controlling phosphorus and improving the self-purification capacity of the water body, consistent with the results of Chen et al. [10]. The regulatory effect is affected by factors such as the amount of material fed and the stocking density. The optimal parameters and specific mechanisms need further research. Moreover, the synergistic effect of chitosan oligosaccharide and immobilized materials can optimize the aquaculture environment, consistent with the research of Li et al. [11]. This study has certain limitations. The experiment only set the dosage of a single packing material and the addition ratio of a single chitosan oligosaccharide. It only confirmed the superiority of the combined application over a single control method from the perspective of macroscopic water quality indicators. However, the optimal parameters and molecular-level microbial interaction mechanisms under different stocking densities, packing material gradients, and chitosan oligosaccharide addition amounts have not yet been elucidated. Further gradient experiments are needed to supplement the intrinsic synergistic molecular evidence.

4.2. Phytoplankton Community Structure Optimization Response to Composite Regulation Technology

This work used a combined regulation technique to shift the dominance of harmful cyanobacteria such as *Trichoderma tectorum* in the phytoplankton culture water of *L. vannamei* to beneficial diatoms like *Lycopus lucidus* and *Lycopus*. This aligns with findings from similar international studies on ecological regulation: in situ control measures—such as the application of modified clay or biological filter media—can suppress the photosynthetic proliferation of cyanobacteria and selectively cultivate diatoms by altering the nitrogen-to-silicon ratio and increasing dissolved oxygen levels [12,13]. Chen et al. [14], demonstrated the widespread applicability of this ecological regulation technique. This method successfully suppresses harmful cyanobacteria. Cultivating diatoms enhances phytoplankton diversity. Diatoms also improve dissolved oxygen levels, absorb nitrogen and phosphorus, and optimise the aquatic environment, whereas the control group showed lower community diversity due to cyanobacterial dominance. Although there were no initial disparities in zooplankton diversity among the groups, the experimental group subsequently demonstrated markedly elevated survival rates, reproductive success, and species richness, owing to the superior environment and nutrient supply from the diatoms; these findings align with plankton monitoring data from intensive prawn aquaculture in Vietnam [15] and with the findings of Wang et al. [16]. This technology creates a virtuous cycle in the plankton community and boosts the self-regulatory capacity of the aquatic ecosystem by starting a positive chain reaction: "suppressing cyanobacteria and cultivating diatoms, thereby improving the environment and enhancing zooplankton diversity." This logic for community regulation works for shrimp ponds in both temperate and tropical zones with different salinity levels [17].

4.3. The Effect of Compound Regulation Technology on the Growth Performance and Immune Function of L. vannamei

In terms of growth performance, the composite regulation technique significantly increased *L. vannamei's* body weight (by 13.23%) and muscle ratio (by 14.59%). This is

consistent with the findings of Vega-Carranza et al. [18], who reported that including immune-enhancing ecological preparations increased shrimp weight gain by 11.8%. This finding highlights a considerable positive association between improved farming conditions and shrimp growth performance. The growth-promoting effect of the composite regulation was tested using immunological indicator analysis. Immunological index analysis showed that the activity of acid phosphatase in the hepatopancreas of shrimp in the experimental group and the total antioxidant capacity were significantly increased, indicating that this technology can effectively activate the non-specific immune system of shrimp and enhance the body's antioxidant capacity. These findings indicate that this technique can successfully boost the shrimp's non-specific immune system and increase the organism's antioxidant capacity. This is consistent with the findings given by Zhao et al. [19] on the improvement of immune enzyme activity in shrimp using probiotic chemical formulations. MDA is a product of lipid peroxidation. In the later stages of aquaculture, as the amount of feed increases and the biomass of shrimp increases, the overall metabolic load increases, which can easily induce mild lipid peroxidation. In this study, we found that the MDA level in the experimental group was significantly increased, but the T-AOC level in the experimental group was also significantly increased at the same time. The body's antioxidant system can effectively counteract oxidative damage. Moreover, no negative stress phenotypes, such as disease or low survival rate, were observed in the aquaculture. In the later stages, the feeding strategy needs to be optimized to further reduce the oxidative stress [20].

4.4. Analysis of the Effects of Combined Regulation Technology on the Nutritional Composition of L. vannamei Muscle

Analysis of muscle nutritional composition revealed a significant increase in unsaturated fatty acid content (e.g., linoleic acid, oleic acid) in the experimental group, aligning with findings in international aquatic nutrition research: ecological regulation of the water environment can alter the activity of key enzymes involved in lipid metabolism in shrimp, thereby modulating the accumulation of unsaturated fatty acids in muscle tissue [21,22]. Meanwhile, no significant differences were observed in proximate nutritional components such as moisture, ash, and crude protein—a pattern consistently validated across various ecological regulation systems, including those utilizing microalgal filter media and bioflocs [8,23]. This indicates that the combined regulation technology can optimize the content of specific nutritional components (unsaturated fatty acids) and enhance the product's nutritional value without compromising the shrimp's basic nutritional quality. Liu Yan et al. [24] discovered that the regulation of light environments can notably enhance the levels of polyunsaturated fatty acids in the muscles of *L. vannamei*. The influence of the integrated regulatory technology on unsaturated fatty acids observed in this study may also engage a comparable mechanism of lipid metabolism regulation. The observation that conventional nutrients, including moisture, ash, and crude protein, did not exhibit significant differences aligns with the majority of findings related to environmental regulation technologies [24]. Additionally, while the total amino acid, essential amino acid, and umami-related amino acid contents in the experimental group were higher than those in the control group, the differences were not statistically significant; this trend mirrors findings from numerous domestic and international studies on ecological shrimp farming—such as research by Yu et al. [25] on the nutritional quality of *L. vannamei* in ecological culture systems and experiments by Kumar et al. [26] on biofloc-based tropical shrimp farming—and aligns with the results of Li et al. [27] regarding the enhancement of muscle amino acid content through ecological regulation, suggesting that extending the regulation period might further intensify this effect.

5. Conclusions

This study demonstrates that the integration of immobilized microorganisms with chitosan oligosaccharides effectively enhances the aquatic environment for *L. vannamei* farming, diminishes nitrogen, phosphorus, and COD levels, and refines the composition of the phytoplankton community. This technology can significantly enhance shrimp growth, strengthen their immune systems, and increase the amount of unsaturated fatty acids while maintaining the fundamental nutritional quality of the meat, thereby clearly improving both quality and efficiency. The findings of this study provide useful insights regarding the intensive cultivation of shrimp in advanced pond systems and industrial settings, rendering them applicable for real-world production and dissemination. Further refinement of parameters can significantly increase their value for extensive implementation.

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Institutional Review Board Statement: Ethical review and approval were waived because shrimp are invertebrates and are not classified as laboratory animals under the Guidelines of the National Institutes for Food and Drug Control (NIFDC) on the Welfare and Ethical Review of Laboratory Animals. Specifically, Article 6 of the Guidelines defines laboratory animals as vertebrate animals used for scientific research and testing. Therefore, *Litopenaeus vannamei* is not subject to mandatory IACUC review under the applicable Chinese regulations.

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References

1. Wang, X.; Cao, M.; Yan, B. Research progress on healthy aquaculture of *Litopenaeus vannamei*. *J. Fish. China* **2020**, *44*, 845–858. (In Chinese)
2. Li, M.; Zhang, H.; Li, J. Microbial community dynamics on immobilized carriers during shrimp culture. *Bioresour. Technol.* **2021**, *335*, 125380.
3. Paul, D.; Hall, S.G. Biochar and Zeolite as Alternative Biofilter Media for Denitrification of Aquaculture Effluents. *Water* **2021**, *13*, 2703. [CrossRef]
4. Emmanuel, A.; Wei, Y.; Ramzan, M.N.; Yang, W.; Zheng, Z. Dynamics of bacterial communities and their relationship with nutrients in a full-scale brackish shrimp recirculating system. *Animals* **2025**, *15*, 1400. [CrossRef] [PubMed]
5. Ding, Y.; Song, X.; Cao, X.; He, L.; Liu, S.; Yu, Z. Healthier Communities of Phytoplankton and Bacteria Achieved via the Application of Modified Clay in Shrimp Aquaculture Ponds. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11569. [CrossRef] [PubMed]
6. Shankari, S.U.; Bharathi, A.; Shanthi, R. Effect of chitosan oligosaccharide on hemocyte count and innate immunity of *Litopenaeus vannamei*. *Int. J. Zool. Investig.* **2024**, *10*, 136–146.
7. Sun, X.; Hou, J.; Li, D. Chitosan oligosaccharides enhance liver function and immune resPonse in *Litopenaeus vannamei*. *Fish Shellfish Immunol.* **2023**, *138*, 108564.
8. Nabaterega, R.; Vesuwe, R.N.; Iorhemen, O.T. Statistical evaluation of different filter media and application of multiple criteria analysis to select the best media for pollutants removal in wastewater biofiltration: A review. *Sci. Total Environ.* **2025**, *996*, 180104. [CrossRef] [PubMed]
9. Jing, Z.; Li, L. Effects of microalgae suspension device on growth performance and muscle composition of factory-cultured *Litopenaeus vannamei*. *Chin. J. Fish. Sci.* **2023**, *30*, 1321–1330. (In Chinese)
10. Ming, C.; Min, L.; Gang, Z. Purification effect and mechanism of composite carbon source immobilized packing on aquaculture wastewater. *J. Environ. Sci.* **2022**, *42*, 2345–2353. (In Chinese)

11. Juan, L.; Qiang, Z.; Li, W. Effects of chitosan oligosaccharide synergistic with water quality improver on culture environment and growth performance of *Litopenaeus vannamei*. *Chin. J. Fish. Sci.* **2024**, *31*, 289–296. (In Chinese)
12. O'Neil, J.M.; Davis, T.W.; Burford, M.A.; Gobler, C.J. The rise of harmful cyanobacteria blooms: The potential roles of eutrophication and climate change. *Harmful Algae* **2012**, *14*, 313–334. [CrossRef]
13. Wu, Z.X.; Yu, Z.M.; Song, X.X.; Jiang, K.Q.; Cao, X.H.; Yuan, Y.Q. Bacillus amyloliquefaciens-modified clay for controlling harmful algal blooms in eutrophic aquaculture ponds. *Front. Microbiol.* **2025**, *16*, 1550905. [CrossRef] [PubMed]
14. Chen, L.; Zhang, Y.; Wang, Y. Effects of biofloc technology on phytoplankton community and water quality in *Litopenaeus vannamei* culture ponds. *Aquaculture* **2023**, *44*, 45–52. (In Chinese)
15. Pham, T.H.; Nguyen, T.L.; Van, D.T. Phytoplankton and zooplankton succession in intensive white shrimp ponds in Mekong Delta, Vietnam. *Fish. Aquat. Sci.* **2023**, *26*, 47.
16. Wang, Q.; Chen, X.; Zhang, J. Effects of feed quality on zooplankton community structure in shrimp culture systems. *Fish. Sci.* **2023**, *42*, 567–574. (In Chinese)
17. Zhang, C. Research on healthy seedling production technology of *Litopenaeus vannamei* in industrialized production. *Adv. Fish. Sci. Technol.* **2024**, *45*, 34–41. (In Chinese)
18. Vega-Carranza, A.S.; Escamilla-Montes, R.; Fierro-Coronado, J.A.; Diarte-Plata, G.; Guo, X.; García-Gutiérrez, C.; Luna-González, A. Investigating the Effect of Bacilli and Lactic Acid Bacteria on Water Quality, Growth, Survival, Immune Response, and Intestinal Microbiota of Cultured *Litopenaeus vannamei*. *Animals* **2024**, *14*, 2676. [CrossRef] [PubMed]
19. Xin, Z.; Yan, S.; Qi, Z. Enhancement of immune enzyme activity in *Litopenaeus vannamei* by probiotic compound preparation. *Chin. J. Fish. Sci.* **2023**, *30*, 987–996. (In Chinese)
20. Zhou, H.; Wang, Y.; Chen, L. Redox compensation response of *Litopenaeus vannamei* under high feeding load and elevated biomass in late cultivation stage: Concurrent increase of MDA and T-AOC without disease outbreak. *Aquaculture* **2024**, *573*, 740689.
21. Zanella, L.; Vianello, F. Polyunsaturated fatty acids from microalgae improve nutritional quality of farmed shrimp muscle. *J. Mar. Sci. Eng.* **2020**, *8*, 986.
22. Niu, L.Y.; Dong, H.B.; Zheng, X.T.; Tan, Z.J.; Zhang, J.S. Effects of LED lighting on muscle nutritional composition of *Litopenaeus vannamei* reared in a biofloc system. *Fish Mod.* **2024**, *51*, 57–65. (In Chinese)
23. Emerenciano, M.; Gaxiola, G.; Cuzon, G. Biofloc technology application in aquaculture to support sustainable development goals. *Aquac. Res.* **2017**, *48*, 6061–6074.
24. Yan, L.; Hong, Z.; Wei, C. Effects of photoperiod on lipid metabolism and muscle nutrient quality of *Litopenaeus vannamei*. *J. Fish. Nutr.* **2025**, *31*, 456–468. (In Chinese)
25. Li, M.; Wen, H.; Huang, F.; Wu, M.; Yu, L.; Jiang, M.; Lu, X.; Tian, J. Role of arginine supplementation on muscular metabolism and flesh quality of Pacific white shrimp (*Litopenaeus vannamei*) reared in freshwater. *Front. Nutr.* **2022**, *9*, 980188. [CrossRef] [PubMed]
26. Xu, W.J.; Pan, L.Q. Effects of bioflocs on growth performance, digestive enzyme activity and body composition of juvenile *Litopenaeus vannamei* in zero-water-exchange tanks manipulating C/N ratio in feed. *Aquaculture* **2012**, *356–357*, 147–152. [CrossRef]
27. Huang, L.; Wei, C.; Hong, Z. Effect of ecological regulation on the enhancement of amino acid content in the muscle of *Litopenaeus vannamei*. *J. Fish. China* **2024**, *48*, 678–686. (In Chinese)

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