

Effects of Krill-Based Product Supplementation on the Growth Performance and Immunity of Pacific White Shrimp (*Litopenaeus vannamei*): A Literature Review

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ABSTRACT

The increasing scarcity and price volatility of fish meal (FM), largely driven by overexploitation of marine fisheries, have intensified the search for sustainable and functional alternatives in shrimp aquaculture. This review synthesizes current evidence published between 2016 and 2026 to evaluate the nutritional and immunological effects of Antarctic krill (*Euphausia superba*)-based products on the growth performance and health of Pacific white shrimp (*Litopenaeus vannamei*). Relevant studies were retrieved from the Scopus and ScienceDirect databases and critically analyzed to assess the effects of krill-derived ingredients on feed utilization, growth performance, immune responses, and disease resistance. The available evidence indicates that dietary supplementation with low levels of krill meal (approximately 1–6%) consistently enhances feed attractiveness and palatability through chemosensory stimulation, leading to improved feed intake, increased weight gain, and reduced feed conversion ratio. Furthermore, krill-derived bioactive compounds, including astaxanthin, phospholipids, nucleotides, and chitin, modulate innate immune function by upregulating immune-related genes, enhancing antioxidant enzyme activities, and strengthening resistance against major shrimp

pathogens, including *Enterocytozoon hepatopenaei* (EHP) and White Spot Syndrome Virus (WSSV). Collectively, the reviewed evidence suggests that krill-based products represent promising functional feed ingredients capable of partially replacing fish meal while simultaneously improving growth performance, feed efficiency, and immunocompetence in *L. vannamei*. Nevertheless, further long-term studies are required to optimize dietary inclusion levels, evaluate economic feasibility, and assess the sustainability of large-scale commercial applications.

INTRODUCTION

The global aquaculture sector, particularly *Litopenaeus vannamei* production, is projected to reach 5.84 million metric tons (MT) in 2025, representing a 6% growth from the 5.5 million MT recorded in 2024 (Aqua Culture Asia Pacific, 2026). Despite this expansion, the industry faces significant economic pressure, as feed costs constitute 40–65% of total production expenses. This financial burden is exacerbated by a heavy reliance on fish meal (FM), the supply of which is increasingly constrained by overfishing and market instability. With FM prices surging to USD 1,825 MT⁻¹ in 2025 (Aqua Culture Asia Pacific, 2026), the urgent exploration of cost-effective, sustainable alternatives has become a priority for industrial feed formulation.

Antarctic krill (*Euphausia superba*) has emerged as a promising functional feed ingredient due to its vast biomass, estimated at 300–500 million MT (Meyer *et al.*, 2025). In 2025, historic production levels reached 624,918 MT, surpassing the 620,000 MT trigger level established under CCAMLR Conservation Measure 51-01. Over the 2015–2025 period, Norway has dominated harvest contributions (62.6%), followed by China (20.8%) and the Republic of Korea (8.4%) (CCAMLR, 2026). Nutritionally, krill meal is characterized by high protein content (up to 70.31%) and a significant lipid profile (25.16%), featuring phospholipids that offer superior bioavailability compared to triglycerides found in traditional fish oils. Furthermore, krill is enriched with astaxanthin—a potent immunomodulator—alongside free amino acids and nucleotides that serve as highly effective feeding attractants for shrimp (detailed in Table 1; Burri *et al.*, 2020; Liang *et al.*, 2024; Wei *et al.*, 2022).

Over the past decade, research focus has shifted toward the application of krill as a functional ingredient capable of enhancing specific growth rates (SGR), lowering feed conversion ratios (FCR), and enabling a reduction in FM usage by up to 75% without compromising physiological performance (Nunes *et al.*, 2024; Tran *et al.*, 2025). Consequently, this review aims to synthesize the impact of krill-based products on the performance clusters of *L. vannamei*, specifically focusing on feed palatability enhancement (Nunes *et al.*, 2024), growth optimization, and the modulation of immune responses to critical pathogens, such as White Spot Syndrome Virus (WSSV) and *Enterocytozoon hepatopenaei* (EHP) (Tor-wattanaphol *et al.*, 2026).

Although the number of studies investigating krill-derived ingredients in shrimp nutrition continues to increase, the available evidence remains fragmented, with considerable variation in the types of krill products, the levels of inclusion in feed, the experimental

conditions, and the biological responses evaluated. This heterogeneity complicates the interpretation of their overall effectiveness and limits the formulation of practical recommendations for commercial feed formulations. Therefore, this review aims to synthesise and critically evaluate the latest literature on the use of krill-based products in *Litopenaeus vannamei* feed, with a particular focus on their nutritional characteristics, mechanisms of action, effects on feed utilisation, growth performance, immune modulation, and disease resistance. Furthermore, this review identifies existing knowledge gaps and outlines priorities for future research to support the development of sustainable, high-performance shrimp feeds that reduce reliance on conventional fishmeal whilst maintaining optimal production efficiency.

METHODS

Place and Time

This literature review research was conducted from Juny to July 2026 in Semarang, Central Java, Indonesia.

Materials and Methods

This study employed a systematic qualitative literature review based on Page *et al.* (2021) to evaluate the effects of krill-based dietary products on the growth performance, feed utilization, immune responses, and disease resistance of Pacific white shrimp (*Litopenaeus vannamei*). The literature search was conducted using Scopus and ScienceDirect as the primary databases, supplemented by Google Scholar and ProQuest. Relevant studies published between 2016 and 2026 were identified using combinations of the following keywords: ("krill meal" or "krill oil" or "krill-based product" or "*Euphausia superba*") and ("*Litopenaeus vannamei*" or "*Penaeus vannamei*") and ("growth performance" or "feed efficiency" or "immunity" or "immune response" or "disease resistance" or "survival").

Studies were included when they were peer-reviewed original research articles or relevant proceedings involving dietary krill-based products in *L. vannamei* and reported at least one outcome related to growth, feed utilization, survival, immunity, antioxidant activity, or disease resistance. Review articles, non-peer-reviewed publications, studies unrelated to *L. vannamei*, and studies without sufficient information on dietary intervention or outcomes were excluded.

Data were extracted into a structured matrix covering publication year, shrimp developmental stage, krill product type, inclusion level, fish meal replacement level, experimental duration, dietary treatment, and major biological responses. The extracted evidence was synthesized descriptively and critically according to growth performance, feed efficiency, feed attractability, immune and antioxidant responses, disease resistance, and potential physiological mechanisms. Because substantial differences existed among studies in experimental design, dietary formulation, krill product composition, culture conditions, and response variables, the findings were synthesized qualitatively rather than through statistical meta-analysis. Particular emphasis was placed on identifying consistent response patterns, optimal inclusion ranges, potential mechanisms, and knowledge gaps in the application of krill-based products in *L. vannamei* aquaculture.

Data Analysis

The data analysis technique in this article uses content analysis techniques. Data analysis begins by analyzing research results from the most relevant, relevant, and quite relevant. Researchers then read the abstract of each study to provide an assessment of whether the

problems discussed are in accordance with the problems to be solved in this research. Next, note down the important and relevant parts of the research problem and end with drawing conclusions (Affandi & Diniariwisan, 2024).

RESULTS

Nutrient Content of Krill by Product (*Euphausia superba*)

The nutritional composition of krill-derived products varies depending on the species, processing method and product type. Nevertheless, various previous studies have consistently shown that krill meal and krill oil contain high levels of protein, phospholipid-rich lipids, essential fatty acids and bioactive compounds. A summary of the reported nutritional composition and functional components is presented in Table 1.

Table 1. Nutrient Profile of Krill by Product (*Euphausia superba*)

Nutrient Category	Parameter	Value Range	Source
Macro Nutrient (Meal)	Crude Protein	57.40% – 70.31%	Coelho <i>et al.</i> , 2026; Qiao <i>et al.</i> , 2026; Nunes <i>et al.</i> , 2024; Shan <i>et al.</i> , 2018; Wei <i>et al.</i> , 2022
	Crude Lipid	13.27% - 25.16%	Coelho <i>et al.</i> , 2026; Qiao <i>et al.</i> , 2026; Nunes <i>et al.</i> , 2024; Burri <i>et al.</i> , 2020a; Shan <i>et al.</i> , 2018
	Ash	12.23% – 12.76%	Coelho <i>et al.</i> , 2026; Qiao <i>et al.</i> , 2026; Nunes <i>et al.</i> , 2024
	Crude Fiber	2.41% – 3.51%	Nunes <i>et al.</i> , 2024; Torwattanaphol <i>et al.</i> 2026
Profile Fatty Acid (Oil)	Total Phospholipids	30.00% – 65.00%	Liang <i>et al.</i> , 2024; Özbay, 2026
	EPA (Eicosapentaenoic Acid)	13.80% – 20.30%	Özbay, 2026
	DHA (Docosahexaenoic Acid)	5.60% – 17.40%	Özbay, 2026
	SFA (Saturated Fatty Acid)	11.70% – 51.59%	Özbay, 2026
	MUFA (Monounsaturated Fatty Acid)	32.13% – 52.50%	Özbay, 2026
	PUFA (Polyunsaturated Fatty Acid)	9.22% – 55.17%	Özbay, 2026
Functional Compounds	Astaxanthin	9.47 mg/kg – 115.00 mg/kg	Mai <i>et al.</i> , 2025; Burri <i>et al.</i> , 2020a

Effect of Krill Meal on growth of *L. vannamei*

Several recent studies have shown that krill meal is an effective functional ingredient for enhancing the growth performance of *Litopenaeus vannamei*. As summarised in Table 2, the optimal level of krill meal inclusion in feed not only promotes growth and feed efficiency, but also allows for the replacement of fish meal in significant quantities whilst maintaining or improving production performance.

Table 2. Growth Effect of Krill Meal Diet on *L. vannamei*

Source	Species	Stadia	Control Level (KM Inclusion)	Optimal Level (KM Inclusion)	FM Replacement	Growth Effect
Tor-wattanaphol <i>et al.</i> (2026)	<i>L. vannamei</i>	Juvenile	0.0%	19.7%	75.0%	Enhanced growth performance (MBW +21.44%; WG +25.58%) with improved feed efficiency (FCR -27.22%) relative to control
Coelho <i>et al.</i> (2026)	<i>L. vannamei</i>	Juvenile	0.0%	5.0%	46.7%	Increased growth performance (FBW +5.93%; WWG +6.83%) along with improved feed efficiency (FCR -7.04%) relative to control
Nunes <i>et al.</i> (2024)	<i>L. vannamei</i>	Juvenile	0.0%	1.5%	50.0%	Moderate growth enhancement (FBW +3.83%; WWG +4.11%) compared to control
Wei <i>et al.</i> (2022)	<i>L. vannamei</i>	Juvenile	0.0%	13.3%	52.8%	Improved growth performance (FBW +20.32%; SGR +8.58%) with enhanced

Source	Species	Stadia	Control Level (KM Inclusion)	Optimal Level (KM Inclusion)	FM Replacement	Growth Effect
						feed efficiency (FCR -21.12%), Protein Efficiency Ratio (+23.04%), and Protein Retention (+25.28%) relative to control
Burri <i>et al.</i> (2020)	<i>L. vannamei</i>	Juvenile	0.0%	6.0%	62.5%	Peak Performance: Highly significant growth enhancement (FBW +27.13%; WG +54.07%; SGR +28.86%) accompanied by optimized feed efficiency (FCR -28.83%) relative to control

Immunomodulatory Effect of Krill Meal Diet on *L. Vannamei*

Several recent studies have demonstrated that krill meal is a promising functional ingredient for enhancing the immune competence of *Litopenaeus vannamei*. As summarized in Table 3, dietary krill meal supplementation can improve immune and antioxidant responses, modulate immune-related gene expression, and enhance resistance to major pathogens while allowing partial replacement of fish meal without compromising shrimp health.

Table 3. Immunomodulatory Effect of Krill Meal Diet on *L. vannamei*

Source	Species	Stadia	Control Level (KM Inclusion)	Optimal Level (KM Inclusion)	FM Replacement	Immunity Effect	Gene Expression	Challenge Test
Tor-wattanaphol <i>et al.</i> (2026)	<i>L. vannamei</i>	Juvenile	0.0%	19.7%	75.0%	Enhanced performance: THC +82%, PO +44%, Phagocytic	Primes cellular and humoral responses for	WSSV: Delayed mortality; survival increased to

Source	Species	Stadia	Control Level (KM Inclusion)	Optimal Level (KM Inclusion)	FM Replacement	Immunity Effect	Gene Expression	Challenge Test
						Activity +108%	pathogen recognition	50% (Control: 0%). EHP: Pathogen load reduced by -75%
Barreto <i>et al.</i> (2025)	<i>L. vannamei</i>	PL	0.0%	27.0%	Partial	Enhanced antioxidant capacity: CAT activity +61%	Upregulated defense genes: hmc (+1833%), lect (+1075%), gst (+187%), gpx (+339%)	Vibrio harveyi: Survival rate improved by +8.8% compared to diets without krill meal
Nunes <i>et al.</i> (2024)	<i>L. vannamei</i>	Juvenile	0.0%	1.5%	50.0%	Acts as a functional palatability enhancer and growth promoter	Citing literature showing upregulation of proPO, serine protease, and SOD at 4-6% KM	Not performed in this study
Wei <i>et al.</i> (2022)	<i>L. vannamei</i>	Juvenile	0.0%	11.9% - 17.2%	47.4% - 68.5%	Significant reduction in oxidative stress: Serum MDA -49.6%	Stable antioxidant enzymes (SOD, GR); improved lipid metabolic efficiency	WSSV: Survival Rate improvement of +48% (Control SR 35% vs Optimal SR 52%)
Shan <i>et al.</i> (2018)	<i>L. vannamei</i>	Juvenile	0.0%	10% - 20%	Partial	HP Astaxanthin +312%; improved molting synchronism for cannibalism prevention	Focused on fatty acid profile optimization (n-3 PUFA enrichment)	Not performed in this study

DISCUSSION

Within the aquaculture sector, feed management remains a pivotal yet challenging aspect of *Litopenaeus vannamei* cultivation, often accounting for approximately 50% of total production costs (Campbell *et al.*, 2026; Xu, 2025). Industrial feed formulations have traditionally relied heavily on marine-derived ingredients, particularly fish meal (FM) derived from wild-caught stocks. This dependence has necessitated a robust exploration of functional alternatives to reduce FM inclusion. Current initiatives have widely evaluated plant-based protein sources, including Soybean Meal (SBM) and Fermented Soybean Meal (FSBM) (Cherdkeattipol *et al.*, 2021; Yao *et al.*, 2020), as well as Corn Gluten Meal (CGM) and Wheat Gluten Meal (WGM) (García-Ulloa *et al.*, 2017; Ray *et al.*, 2021; Yohana *et al.*, 2023). Furthermore, the application of Single Cell Proteins (SCP)—such as *Methylococcus capsulatus* (Chen *et al.*, 2021), *Clostridium autoethanogenum* protein (CAP) (Chen *et al.*, 2025), and *Rhodobacter sphaeroides* (Liao *et al.*, 2022)—has emerged as a viable and sustainable technological frontier.

Antarctic krill (*Euphausia superba*) represents a substantial marine resource, with a biomass estimated between 300 and 536 million tons (Meyer *et al.*, 2025). Although the 2025 harvest (624,918 MT) exceeded the precautionary trigger level (620,000 MT), triggering temporary closures under CCAMLR regulations, such stringent management reinforces the long-term sustainability of the stock. With current utilization rates remaining below 1%, krill offers a more stable supply chain compared to traditional FM (CCAMLR, 2026; Meyer *et al.*, 2025). Amidst a feed crisis exacerbated by a 25% surge in FM and fish oil prices since 2021 (Tor-wattanaphol *et al.*, 2026; Villarreal, 2023), krill serves as a high-value functional intervention. Its inclusion effectively reduces the economic Fish-In Fish-Out (eFIFO) ratio, enabling intensified shrimp production while significantly lowering reliance on wild-caught marine resources (Tran *et al.*, 2025).

The strategic deployment of krill focuses on a low-inclusion dosage (1–6%), which has been demonstrated to be sufficient for enhancing feed palatability and growth performance (Burri *et al.*, 2020; Nunes *et al.*, 2024). Through synergistic formulation, krill functions as a nutritional "buffer," mitigating the sensory and performance limitations associated with high plant-based protein inclusion (e.g., SBM or CGM). Consequently, this approach allows producers to optimize cost-efficiency without compromising shrimp performance, while aligning with rigorous conservation standards (Coelho *et al.*, 2026; Tor-wattanaphol *et al.*, 2026; Tran *et al.*, 2025). Importantly, the effectiveness of low-level krill supplementation is closely associated with its ability to stimulate feeding behavior, particularly through enhanced feed attractability and palatability.

In shrimp aquaculture, "attractability" is defined as the feed's capacity to trigger the initial feeding response—comprising detection, orientation, and locomotion toward the food source—while "palatability" refers to the stimulants that initiate and sustain ingestion (Nunes *et al.*, 2006, 2022). Mechanistically, this process is mediated by cuticular chemosensory structures concentrated on the antennules, mouthparts, dactyls of the walking legs, and maxillipeds, which detect chemical signals in the aquatic environment (Eap *et al.*, 2020; Nunes *et al.*, 2022). Low-molecular-weight organic compounds, such as free amino acids (e.g., taurine, glycine, alanine, arginine), nucleotides (e.g., IMP and AMP), and betaine, serve as primary chemical triggers that bind to chemoreceptors, transmitting feeding signals to the central nervous system (Morais, 2016; Roda *et al.*, 2024). The efficacy of these signals is heavily

dependent on the raw material source; marine-derived proteins—such as krill meal, squid meal, and fish hydrolysates—exhibit significantly higher attractability compared to terrestrial or plant-based proteins due to their superior concentration of water-soluble compounds (Nunes *et al.*, 2022; Smith *et al.*, 2005). Furthermore, processing methods like enzymatic hydrolysis enhance the concentration of short-chain peptides and free amino acids, thereby optimizing palatability (Roda *et al.*, 2024; Suresh & Nates, 2011). Maintaining freshness is equally critical, as the accumulation of biogenic amines (e.g., cadaverine and putrescine) resulting from decomposition can diminish nutritional quality and inhibit feed intake (Nunes *et al.*, 2006; Roda *et al.*, 2024).

The strategic inclusion of krill meal (KM) at functional levels (0.5%–5%) is essential for consistent feeding responses. Optimizing these parameters not only promotes higher growth rates but also minimizes nutrient leaching and environmental pollution by reducing the time feed remains in the substrate (Carvalho & Nunes, 2006; Nunes *et al.*, 2022). The application of KM in juvenile *L. vannamei* consistently enhances growth performance and feed efficiency compared to FM-only control groups (Table 2). KM functions as a potent "feeding effector," with its high density of free amino acids and nucleotides acting as primary stimulants (Wei *et al.*, 2022). Significant growth improvements were reported by Burri *et al.* (2020), where 6.0% KM inclusion—replacing 62.5% of FM—yielded a 54.07% increase in Weight Gain (WG) and a 28.83% improvement in Feed Conversion Ratio (FCR). Even higher FM substitution levels were achieved by Tor-wattanaphol *et al.* (2026), who utilized 19.7% KM to replace 75.0% of FM, resulting in a 25.58% increase in WG and a 27.22% reduction in FCR.

Moreover, Wei *et al.* (2022) demonstrated that 13.3% KM inclusion (52.8% FM substitution) enhanced protein retention by 25.28% and reduced FCR by 21.12%. At lower inclusion levels, KM remains effective; Coelho *et al.* (2026) found that 5.0% KM (46.7% FM replacement) increased Wet Weight Gain (WWG) by 6.83%. Remarkably, Nunes *et al.* (2024) observed that KM levels as low as 1.5% (15 g/kg) were sufficient to induce high apparent feed intake, suggesting a threshold where diminishing returns may occur at higher concentrations. The observed variance in growth performance is closely linked to the proximate composition of the specific KM product utilized (Table 3). The substantial growth increase (54.07%) reported by Burri *et al.* (2020) is attributed to the high crude lipid content (25.00%) of the QRILL™ Aqua product, providing essential fatty acids for optimal energy metabolism. Conversely, the high-protein/low-lipid profile (70.31% crude protein, 4.86% lipid) utilized by Wei *et al.* (2022) correlates directly with superior protein retention efficiency. Ultimately, KM serves as a vital functional buffer, restoring palatability and growth performance in diets with reduced FM. As underscored by Tor-wattanaphol *et al.* (2026) and Tran *et al.* (2025), maintaining low inclusion levels is the most strategic approach to bolstering industrial aquaculture sustainability while adhering to conservation mandates.

Beyond its nutritional contribution to growth and feed efficiency, the functional role of KM may also extend to the physiological defense capacity of *L. vannamei*. This is particularly important because the immune system of *L. vannamei* relies exclusively on innate immunity, utilizing both cellular and humoral defense mechanisms (Kulkarni *et al.*, 2021; Tassanakajon *et al.*, 2018). Cellular immunity involves hemocytes in direct pathogen mitigation—facilitating encapsulation, phagocytosis, and nodulation—while humoral immunity involves the release of defensive molecules, such as prophenoloxidase (proPO), superoxide dismutase (SOD), antimicrobial peptides, and protease inhibitors (Dugassa & De Gryse, 2018; Vazquez *et al.*, 2009). Hemocytes are central to this innate framework; upon pathogen detection via Pattern Recognition Receptors (PRRs), these cells migrate to infection sites to orchestrate a systemic

immune response, reflecting a complex crosstalk between hemocytes and other systemic tissues (Jiravanichpaisal *et al.*, 2006; Söderhäll, 2016).

This intricate defense network is susceptible to external immunomodulation via functional ingredients, such as immunostimulants, probiotics, and bioactive extracts (Chiu *et al.*, 2021; Setyawan *et al.*, 2024; Yudiati *et al.*, 2026). These additives expose the shrimp's system to non-infectious Pathogen-Associated Molecular Patterns (PAMPs)—including Beta1,3-glucan, lipopolysaccharides (LPS), and peptidoglycans—thereby initiating intracellular signaling cascades and the upregulation of immune-related genes. This process triggers "immune priming," wherein the host's defense mechanism is proactively enhanced, facilitating a faster and more robust response to subsequent pathogen exposure (Chiu *et al.*, 2021; Yudiati *et al.*, 2026).

Krill meal (KM) has demonstrated significant efficacy as a natural immunostimulant in *L. vannamei* diets, outperforming traditional FM-based controls (Table 4). Beyond its role as a protein source, KM provides bioactive molecules—specifically nucleotides, chitin, phospholipids, and astaxanthin—which collectively modulate cellular immune responses and neutralize reactive oxygen species (Wei *et al.*, 2022). Tor-wattanaphol *et al.* (2026) reported that a 19.7% KM inclusion (75.0% FM substitution) provided optimal immunological protection, characterized by a substantial reduction in *Enterocytozoon hepatopenaei* (EHP) prevalence and enhanced survival rates under White Spot Syndrome Virus (WSSV) challenge tests.

Furthermore, Wei *et al.* (2022) documented significant up-regulation of immune-related genes, including proPO and lysozyme, alongside amplified activity of antioxidant enzymes (SOD and PO) in the hepatopancreas. Similar protective effects are observed in early developmental stages; Barreto *et al.* (2025) noted that incorporating KM into microfeeds for post-larvae is essential for maintaining physiological health and preventing immunodeficiency, even when substituting traditional marine proteins with soy protein concentrates.

The variability in immune response and transcriptional regulation is closely associated with the proximate composition of the KM used (Table 5). The transcriptomic modulation observed by Wei *et al.* (2022) is attributed to the high crude protein content (70.31%) of the KM source, which facilitates the synthesis of essential immune proteins and activates the proPO cascade. Conversely, the superior survival rates post-WSSV/EHP infection observed by Tor-wattanaphol *et al.* (2026) are linked to a lipid-rich profile featuring highly unsaturated fatty acids (HUFA) and stable astaxanthin. These bioactives are critical for maintaining hemocyte membrane integrity and supporting *in vivo* antiviral defenses, mirroring the nutritional retention found in freeze-dried standards (Shan *et al.*, 2018).

CONCLUSION

Antarctic krill (*Euphausia superba*) represents a strategically vital functional ingredient for the future of sustainable aquaculture. By facilitating a reduction in the economic Fish-In Fish-Out (eFIFO) ratio and serving as an effective nutritional "buffer" for plant-based and single-cell protein sources, krill meal addresses the industry's critical dependence on finite wild-caught fish meal stocks without compromising shrimp performance. Empirical evidence demonstrates that inclusion at functional levels (typically 1%–6%, with up to 19.7% in specialized applications) significantly enhances Specific Growth Rates (SGR) and minimizes Feed Conversion Ratios (FCR). This performance boost is driven by the high concentration of

low-molecular-weight organic compounds, particularly free amino acids and nucleotides, which serve as potent stimulants for feed attractability and palatability.

Beyond its role as a macronutrient provider, krill serves as a natural immunostimulant. Its bioactive constituents—notably astaxanthin, phospholipids, and chitin—induce *in vivo* immune priming. This mechanism upregulates key immune-related genes (proPO and lysozyme) and amplifies antioxidant enzyme activities (SOD and PO), thereby significantly bolstering the immunocompetence of *L. vannamei*. Consequently, krill inclusion provides a robust defense strategy against critical pathogens, including White Spot Syndrome Virus (WSSV) and Enterocytozoon hepatopenaei (EHP), leading to substantially improved survival rates.

In summary, the integration of krill-based products into feed formulations offers a dual-advantage: optimizing industrial cost-efficiency and fortifying the biological resilience of shrimp populations. Future research and industrial application should focus on standardizing krill-based inclusion protocols to maximize these synergistic benefits while ensuring compliance with global conservation mandates for Antarctic marine resources.

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