

Chitosan from shrimp by-products as potential feed additive for improving shrimp farming efficiency in Vietnam, towards a more sustainable and circular economy

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ARTICLE INFO	ABSTRACT
Research Paper Received: January 23, 2025 Revised: April 22, 2025 Accepted: May 08, 2025 Keywords Chitosan Circular economy Shrimp by-products Sustainable aquaculture *Corresponding author Tran Van Ty Email: vantytran103@gmail.com	Shrimp farming in Vietnam, particularly in intensive systems, faces many challenges: disease outbreaks, environmental stress, feed quality issues, and water management, leading to high mortality and reduced efficiency. Chitosan, a natural biopolymer derived from crustaceans like shrimp and crab, offers a sustainable solution. With antimicrobial, immune-boosting, and growth-enhancing properties, chitosan has been shown to improve shrimp health by boosting immunity, reducing oxidative stress, and supporting growth, while also increasing feed efficiency and water quality. The purpose of this paper is to review the current knowledge on the potential application of chitosan in shrimp farming, particularly in Vietnam, and its role in addressing the challenges of sustainability, disease prevention, and feed efficiency in the shrimp aquaculture industry. Vietnam, as a global leader in shrimp production, possesses large quantities of shrimp by-products from processing plants and molted shells at farms, provides an abundant resource for chitosan production, creating a closed-loop solution within the shrimp industry itself. Converting this waste into chitosan supports circular economy goals and reduces reliance on antibiotics. Integrating shrimp-derived chitosan could foster a more sustainable and resilient shrimp farming industry, benefiting both the economy and the environment.

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1. Introduction

1.1. Vietnam's shrimp industry overview

The shrimp industry is a cornerstone of Vietnam's economy, particularly in the

Mekong Delta, where shrimp farming provides a livelihood for millions of people. Shrimp farming areas have expanded by an average of 5% annually, while production has grown by 8.4% per year, driven largely by improvements

in whiteleg shrimp (*Litopenaeus vannamei*) productivity. Vietnam is now among the world's top five shrimp-exporting countries, with whiteleg shrimp dominating the export market and achieving an average growth rate of 7% per year (SI, 2024; VASEP, 2024).

1.2. Disease management crisis

The management of shrimp health in intensive farming systems is a significant challenge due to their high vulnerability to diseases and environmental stress. At the most critical level, diseases like early mortality syndrome (EMS) can devastate entire populations, leading to almost 100% mortality and causing global losses of up to \$9 billion annually - about 15% of the world's shellfish production (Schryver et al., 2014). This issue is compounded in super-intensive farming environments, where 100 - 300 shrimp per square meter promote the growth of harmful pathogens such as bacteria and algae due to ineffective feed management (Nguyen, 2020). Furthermore, shrimp's inability to regulate their own body temperature makes them highly sensitive to even small environmental fluctuations. For instance, minor changes in pH, temperature shifts of 2 - 5°C, or salinity variations of 5% can cause significant stress, particularly in species like tiger prawns (Ta & Huynh, 2017; Phuong, 2021). Adding to this, shrimp lack an adaptive immune system, leaving them with very limited natural defenses (Tepbac, 2018).

1.3. Supply of raw materials for shrimp feed

The reliance on imported feed ingredients in Vietnam is significant, with approximately 70 - 80% of essential materials, such as fishmeal and soybean, sourced from abroad (WB, 2022). This dependency makes the shrimp industry vulnerable to supply chain disruptions and cost

increases. For example, between 2021 and 2022, the price of imported fishmeal rose by 6.4%, contributing to a 10 - 17% increase in production expenses (Hong, 2022; WB, 2022). These rising costs have eroded Vietnam's competitiveness, especially compared to shrimp exporters like India and Ecuador, where production costs are 30% lower (Trung, 2021).

To address this, plant-based proteins have been proposed as an alternative to fishmeal. However, this shift presents challenges that can negatively impact shrimp health and performance. Plant-based proteins often contain anti-nutritional factors (ANFs), such as protease inhibitors and phytic acid, which reduce feed efficiency, ultimately impairing shrimp growth (Gatlin et al., 2007; Glencross et al., 2007). They are also prone to mycotoxin contamination, like aflatoxins, which suppress immunity and cause organ damage (Hasan & Goncalves, 2017). Additionally, amino acid imbalances and low digestibility in plant proteins can further limit growth, reduce feed intake, and increase stress from oxidative damage (Richard et al., 2011; Tacon & Metian, 2015). Natural farming practices, which prioritize strict environmental controls and minimize antibiotic use, are emerging as key strategies to enhance shrimp health and ensure production sustainability (Xia & Yue, 2010).

1.4. Understanding chitosan

Chitosan is a biopolymer derived from chitin, the second most abundant polymer, primarily extracted from the exoskeletons of crustaceans like shrimp and crabs. The industrial production of chitosan involves the deacetylation of chitin by removing most of the acetyl groups from chitin, converting N-acetyl-d-glucosamine into β -1,4-d-glucosamine (Malerba & Cerana, 2018).

Chitosan is biodegradable, biocompatible and non-toxic, making it environmentally safe and suitable for various applications. Additionally, it possesses diverse functionalities, including antimicrobial, antioxidant, immunostimulant, and heavy metal-binding properties (Malerba & Cerana, 2018). These features make chitosan a highly valuable ingredient across numerous sectors, including food production, pharmaceuticals, and agriculture. In Vietnam, there is an abundant supply of chitosan sourced from shrimp processing by-products and molted shells from farms (Trang & Pham, 2012). Leveraging these resources not only adds value to the shrimp industry but also promotes sustainability by converting waste into a valuable biopolymer.

In aquaculture, chitosan is widely used as a feed additive to enhance shrimp's health and aquatic environment. It strengthens shrimp immunity, reduces disease outbreaks with its antimicrobial properties, and helps shrimp better handle environmental stress (Wang et al., 2017). Additionally, chitosan enhances nutrient absorption, supports gut health, promotes molting, and improves the stability of feed pellets in water, leading to greater feed efficiency. Environmentally, chitosan improves water quality by binding to and removing harmful substances like phytoplankton, organic matter, and heavy metals, resulting in cleaner, more stable water conditions in shrimp ponds (Lertsutthiwong et al., 2009). These combined effects make chitosan a valuable compound for sustainable shrimp farming.

2. Chitosan as a Functional Ingredient for Shrimp Feed

Chitosan, as a highly versatile biopolymer, varies in physicochemical and biological

properties such as degree of deacetylation (DD), molecular weight (MW), viscosity, and solubility (Pellis et al., 2022), influencing its bioactivity in aquaculture. Chitosan can be formulated as powder or liquid, and may require acidic solvents (e.g., acetic acid) for complete dissolution when used in feed applications. Therefore, selecting the appropriate form of chitosan and tailoring its properties to specific aquaculture targets are essential for maximizing its functional performance in shrimp farming.

2.1. Chitosan as an antimicrobial, immunostimulant for disease prevention and treatment

Chitosan acts as a strong natural antibacterial agent that helps shrimp combat common diseases without heavy reliance on antibiotics. First, it interacts with the negatively charged cell walls of bacteria, causing leakage and cell wall damage (Xing et al., 2015). It also forms a film on the bacterial surface, inhibiting their metabolism and nutrient exchange (Flegel, 1998). Additionally, chitosan creates chelation to specific metal ions, destabilizing the bacterial cell wall and suppressing growth. Finally, it acts as a DNA binder, preventing protein synthesis and halting bacterial replication (Xing et al., 2015).

Chitosan effectively inhibits *Vibrio* species bacteria, including *Vibrio alginolyticus* (Anas et al., 2005) and *Vibrio parahaemolyticus* (Schryver et al., 2014), which are associated with Hepatopancreatic Necrosis, and *Vibrio mediterranei* (Ruangpan, 1998), which causes Luminescent Disease. In severe cases, these pathogens can lead to mortality rates of up to 100% in shrimp (Ruangpan, 1998). By reducing pathogen prevalence, chitosan helps lower the need for antibiotics, improving shrimp health and survival (Flegel, 1998; Schryver et al., 2014).

Chitosan also boosts the shrimp's immune system, strengthening their ability to combat biotic stress. It stimulates the production of hemocytes, the primary immune cells in shrimp. Hemocytes perform key functions such as phagocytosis (engulfing pathogens), nodulation (aggregating to trap bacteria), and encapsulation (surrounding larger invaders), strengthening the shrimp's overall immune response (Wang & Chen, 2005). In the humoral immune response, hemocytes release enzymes like transglutaminase (Tgase) and prophenoloxidase (ProPO), which promote coagulation and pathogen killing through the melanization reaction, while also releasing antimicrobial peptides to inhibit or kill pathogens (Cerenius & Söderhäll, 2012; Tassanakajon et al., 2017).

By activating both cellular and humoral immune responses, chitosan significantly enhances shrimp resistance to pathogens, particularly *Vibrio* species, thereby reducing reliance on antibiotics and promoting healthier aquaculture stocks. In the study by Wang & Chen (2005), whiteleg shrimp were injected with 2 and 4 µg/g of chitosan and subsequently challenged with *V. alginolyticus* at a dose of 2×10^6 cfu/shrimp. Chitosan-treated shrimp showed significantly higher survival rates than controls, with enhanced immune responses, including total hemocyte count, and respiratory burst. This indicates that increasing chitosan up to 4 µg/g optimizes antimicrobial defenses and enhances shrimp resistance to infection.

2.2. Chitosan as an antioxidant for environmental adaptation

Chitosan plays a crucial role in reducing oxidative stress in shrimp by acting on free radicals that cause cellular damage. It works through two main mechanisms. First, chitosan

enhances the activity of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and glutathione S-transferase (GST), as well as non-enzymatic antioxidants like glutathione (GSH), which help neutralize excess reactive oxygen species (ROS) (Niu et al., 2013). Second, chitosan directly scavenges free radicals through its amino and hydroxyl groups, protecting cells from oxidative damage (Wang et al., 2012). These combined actions allow chitosan to help maintain the health of shrimp cells (Table 1).

By alleviating oxidative stress, chitosan shields shrimp from free radical-induced damage, including genetic mutations, lipid peroxidation, and protein degradation. Shrimp treated with chitosan shows enhanced antioxidant capacity, reduced oxidative damage, and improved survival rates under stress (Rahimnejad et al., 2018). This highlights chitosan as a valuable tool for boosting shrimp resilience in aquaculture systems.

Studies have shown that dietary chitosan can greatly enhance disease resistance and stress resilience in whiteleg shrimp. Chen et al. (2020) found that chitosan at 1.0 g/kg increased SOD activity by 15%, indicating stronger antioxidant defenses and less oxidative damage, leading to a 4.7% increase in survival rates under ammonia stress. Expanding on these findings, Brol et al. (2021) explored dietary chitosan at 1, 3, and 5 g/kg under saline stress, revealing that 1 g/kg was the optimal dose. This concentration maintained SOD and GST activity at baseline, increased CAT activity in the gills by 12%, and stabilized GSH levels in the hepatopancreas. Although higher concentrations offered benefits, they showed diminishing returns without added advantages over 1 g/kg. Overall, these findings collectively establish chitosan as a powerful and sustainable supplement for boosting antioxidant defenses and improving disease resistance in shrimp aquaculture.

Table 1. Chitosan on stress and disease resistance in shrimp species

Object	Stress Resistance		Disease Resistance	
	Whiteleg shrimp	Whiteleg shrimp	Whiteleg shrimp	Whiteleg shrimp
Condition	Ammonia stress add NH ₄ Cl 2.15 mg/L	Salinity stress Sal30 (sea water) → Sal5 (sea water + fresh water)	<i>Vibrio</i> <i>alginolyticus</i> (infectious disease)	<i>Vibrio</i> <i>parahaemolyticus</i> (EMS/AHPND disease)
Chitosan property	Water-soluble chitosan	From shrimp shell DD ≈ 90% MW = 125 kDa	DD ≈ 90%	MW = 544 kDa DD = 95%
Best dosage	0.1%	1 - 3%	4%	0.025%
References	(Chen et al., 2020)	(Brol et al., 2021)	(Cheng et al., 2021)	(Liang et al., 2020)

2.3. Chitosan as a growth promoter

Chitosan promotes shrimp growth by improving both nutrition digestion, adsorption and facilitating the molting process. It enhances enzyme production and nutrient absorption, leading to better feed use efficiency (Ekaputri et al., 2018). At the same time, chitosan supports molting by accelerating the breakdown of the old exoskeleton and aiding the formation of a new, stronger one (Zhang et al., 2014). These combined effects enhance shrimp growth, feed efficiency, and overall performance in aquaculture systems.

2.3.1. Nutrient digestion and absorption

The hepatopancreas, the vital digestive organ in shrimp, plays a critical role in nutrient absorption, storage, and overall health. However, plant-based proteins or fishmeal alternatives can compromise its function, causing inflammation, structural damage, and reduced efficiency in nutrient utilization (Rahimnejad et al., 2018). Chitosan enhances hepatopancreas health by

stimulating the proliferation of embryonic cells and resorptive cells, essential for nutrient absorption and storage, while strengthening hepatopancreatic tubules and the basal membrane (Rahimnejad et al., 2018). These benefits optimize digestion, nutrient utilization, and organ function, making chitosan a crucial component in supporting low-fishmeal diets for sustainable shrimp farming.

Chitosan enhances nutrient digestion and absorption by increasing the activity of digestive enzymes like protease and trypsin (Liu et al., 2019; Tseng et al., 2021). These enzymes help break down proteins more effectively, leading to improved nutrient availability. Chitosan also improves intestinal histology by increasing fold height, which expands the surface area for nutrient absorption (Rahimnejad et al., 2018). The effectiveness of chitosan as a growth-promoting agent in shrimp aquaculture is well-supported by various studies, which consistently highlight its benefits in enhancing growth performance, specific growth rate in shrimp (Table 2).

Table 2. Effects of Chitosan on promoting growth in shrimp species

No.	Chitosan Properties	Year	Object	References
1	DD $\geq$ 75% Optimal dosage: 2.13 - 2.67 g/kg	2011	Whiteleg shrimp	(Niu et al., 2011)
2	DD $\geq$ 75% Optimal dosage: 0.1 - 0.2%	2015	Giant Tiger Prawn	(Niu et al., 2015)
3	Nano chitosan particles Optimal dosage: 1 mL/kg	2020	Giant Tiger Prawn	(Abdel-Warith et al., 2020)
4	From <i>Daphnia similis</i> source Optimal dosage: 0.4%	2021	Whiteleg shrimp	(Tseng et al., 2021)

In the 23-day investigation by Niu et al. (2011), whiteleg shrimp was fed a diet containing 2 g/kg chitosan showed a significant 39% increase in weight gain compared to the control, accompanied by a 7.5% boost in specific growth rate. The study concluded that chitosan at 2.13 - 2.67 g/kg were optimal for achieving balanced growth and nutrient absorption. Further validation from Tseng et al. (2021) in their 56-day study on whiteleg shrimp showed that shrimp fed 0.4% chitosan exhibited an 8.8% higher specific growth rate and a 22% increase in weight gain. Collectively, these highlight chitosan's potential to enhance shrimp digestion and growth, establishing it as a valuable and sustainable supplement to shrimp farming.

2.3.2. Molting process stimulation

Molting is a vital process for shrimp growth, requiring sufficient chitin and nutrients stored in the hepatopancreas. In natural environments, shrimp obtain enough chitin from sources like small shrimps and crabs. However, in intensive farming systems, high stocking densities limit chitin availability from feed, and self-synthesis

alone is insufficient. Chitosan offers a solution by supplying chitin while promoting efficient molting and stronger shells, making it essential for sustainable shrimp farming (BFM, 2024).

Chitosan aids in the shrimp growth promotion by facilitating both the breakdown of the old exoskeleton and the formation of the new one (Zhang et al., 2014). During the pre-molt stage, chitosan boosts CHT6 enzyme expression, aiding in hydrolyzing the old exoskeleton for easier shedding (Zhang et al., 2014). During molt and post-molt stages, chitosan boosts CHT3 enzyme activity to hydrolyze chitin into monomers and enhances chitin synthase activity to polymerize them, building a stronger new exoskeleton.

In the study by Tseng et al. (2021), optimal chitosan supplementation at 0.4% in whiteleg shrimp led to a significant increase in molting enzyme activity, with 1,200% and 335.7% increases in CHT3 and CHT6, respectively. Similarly, in research by Attasart et al. (2005), adding chitosan at 100 ppm (with DD = 85%) in whiteleg shrimp enhanced shell formation, increasing shell weight by 13.7% and chitin content by 0.81%. These findings show that

chitosan enhances molting efficiency and exoskeleton strength, thereby improving shrimp performance in aquaculture systems (Zhang et al., 2014).

Chitosan, chitin, and shrimp head meal each have distinct benefits and limitations in shrimp farming. Chitosan presents a promising solution, such as enhancing growth performance and boosting molting enzyme activity (Zhang et al., 2014; Tseng et al., 2021). In contrast, chitin mainly serves as a chitin source, offering little support for molting enzymes and limited applicability due to its water insolubility (Attasart et al., 2005). Shrimp head meal also have some limitations, including poor feed stability and low digestibility due to high fiber and ash content (approximately 10 and 35%, respectively), which lowers nutrient absorption and feed efficiency (Cavalheiro et al., 2007). Overall, chitosan offers a superior solution over chitin and shrimp head meal, making it the preferred choice for aquaculture systems.

2.4. Chitosan in reducing waste and protecting water quality

2.4.1. Chitosan as a feed additive to improve feed pellet durability

The durability of feed pellets in water is crucial in aquaculture as it prevents disintegration, ensuring that nutrients remain intact and available for shrimp consumption. This minimizes water pollution, and improves the overall efficiency of feeding practices (BFM, 2024). Chitosan improves the feed stability by forming a protective film around pellets. When dissolved in dilute acid, its amino and hydroxyl groups become activated, forming cross-linking bonds with feed polymers, creating a tight and durable network (Dezfooli et al., 2022). This network strengthens the pellet structure,

maintaining feed integrity longer in water (Jaroensaensuai et al., 2022).

In the study by Jaroensaensuai et al. (2022), the integration of chitosan into an egg yolk-chitosan composite demonstrated exceptional improvements in the durability and nutrient retention of shrimp feed pellets. The fortified feed maintained 85 - 87% of its dry mass after 6 h in seawater, significantly outperforming uncoated pellets, which disintegrated much faster. By preserving feed integrity, chitosan helps minimize waste, maintain water quality, and ensure more efficient nutrient delivery to shrimp.

2.4.2. Chitosan as a green chemical for water quality improvement

Intensive shrimp farming in Vietnam presents significant challenges to maintaining water quality in aquaculture ponds. Conventional chemical disinfectants can disrupt the natural microbial balance and increase the risk of disease outbreaks (Nguyen & Tran, 2019; Do et al., 2023). Chitosan acts as a sustainable flocculant, effectively aggregating organic matter, such as uneaten feed, without harming beneficial microbes. The resulting sludge can be repurposed as organic fertilizer, promoting waste management and reducing the environmental impact of shrimp farming (Lertsutthiwong et al., 2009).

Chitosan's efficiency as a flocculant stems from its cationic polymer structure. It binds to negatively charged particles via electrostatic interactions, forming flocs that are easily removed from water (Lertsutthiwong et al., 2009). Additionally, chitosan performs chelation, where its amino groups bind to heavy metal ions, capturing them for efficient removal (Zubair et

al., 2020). Through these combined mechanisms, chitosan neutralizes pollutants and enhances water quality effectively.

Lertsutthiwong et al. (2009) demonstrated that 40 mg/L chitosan achieved 85% flocculation efficiency in outdoor shrimp tanks over a 28-day period. This approach effectively reduced nitrogenous waste buildup, and promoted shrimp health. Similarly, Ruswahyuni et al. (2010) applied 200 ppm liquid chitosan in semi-traditional whiteleg shrimp ponds in Indonesia. Over three months, chitosan reduced total suspended solids by 48.5% (0.68 to 0.35 mg/L),

improving water clarity. These studies underscore chitosan's role in enhancing water quality and supporting sustainable aquaculture.

3. Research on Using Chitosan in Aquaculture in Vietnam

Several studies have explored the applications of chitosan in Vietnam's aquaculture sector, particularly for enhancing immunity, growth, and disease resistance, highlighting its potential to improve both yield and sustainability in aquaculture practices (Table 3).

Table 3. Some studies on the use of chitosan in Vietnam Aquaculture

No.	Article	Year	Object	References
1	Research on the Development and Assessment of Immune-Stimulating Effects Against Liver and Kidney Disease in Striped Catfish (<i>Pangasianodon hypophthalmus</i>) Using Oligochitosan and Oligo β -Glucan	2015	Pangasius (<i>Pangasianodon hypophthalmus</i>)	(Nguyen et al., 2015)
2	Effect of Oligochitosan and Oligo- β -Glucan Supplementation on Growth, Immunity, and Disease Resistance of Striped Catfish (<i>Pangasianodon hypophthalmus</i>)	2017	Pangasius (<i>Pangasianodon hypophthalmus</i>)	(Nguyen et al., 2017)
3	Effects of dietary chitin supplementation on the resistance of Whiteleg shrimp (<i>Litopenaeid vannamei</i>) to <i>Vibrio parahaemolyticus</i>	2019	Pangasius (<i>Pangasianodon hypophthalmus</i>)	(Bui & Nguyen, 2019)
4	Effect of dietary chitosan on non-specific immune parameters of striped catfish (<i>Pangasianodon hypophthalmus</i>)	2020	Whiteleg shrimp	(Tran et al., 2020)

Chitosan has been effectively applied in aquaculture systems in some regions of Vietnam, with studies underscoring its diverse benefits. In the study by Nguyen et al. (2015), catfish were fed diets supplemented with 0, 50, 100, and 200 mg/kg of oligochitosan for 45 days before being challenged with *Edwardsiella ictaluri*, a bacterium causing enteric septicemia and high mortality rates. The results revealed that fish receiving 100 mg/kg oligochitosan had a survival rate 436% higher than the positive control (47.62 vs. 8.89%), with significant boosts in both humoral and cellular immune responses. Supporting this, Bui & Nguyen (2019) investigated chitosan at higher concentrations (0, 1, 5, and 10 g/kg) over a 4-week period. Their findings indicated that fish fed 1 g/kg chitosan showed substantial immune improvements, including higher blood cell counts and lysozyme activity. When exposed to *E. ictaluri*, these fish exhibited the lowest mortality rate at 43.3%, a 27.8% reduction compared to the 60% observed in controls. These studies affirm chitosan as powerful immunostimulants, enhancing disease resilience and sustainability in Vietnam's aquaculture, benefiting not only striped catfish but also shrimp and other cultured species.

4. Chitosan from Shrimp By-Products in Vietnam

Vietnam, a major shrimp producer, generates significant shrimp by-products, including shells, heads, and processing waste, often discarded or underutilized. However, with growing sustainability awareness, these by-products are increasingly recognized as valuable resources, particularly for chitosan production.

According to a study by Trang & Pham (2012), the shrimp processing industry in Vietnam generates approximately 200,000 metric tons

of by-products each year. This includes shrimp shells, which constitute a major portion of the waste, and can be collected in large quantities from processing plants. For instance, intensive shrimp farming systems can generate up to 280 kg of shrimp shells per 1,500 m² pond per harvest (Pham et al., 2021). These shrimp shells, which are primarily composed of chitin, are an excellent raw material for chitosan production.

In recent years, the rapid expansion of Vietnam's shrimp industry has significantly increased the volume of by-products, with estimates suggesting an annual output of 325,000 tons, and projections reaching over 450,000 tons by 2025 - equivalent to more than 1,000 tons of waste discarded daily (MOIT, 2024). If not properly managed or utilized, these by-products pose a serious environmental concern. However, they are increasingly recognized as a valuable resource, rich in protein, chitin, and astaxanthin, which can be used to produce high-value compounds such as feed additives, fertilizers, and biopolymers.

Among these, chitosan stands out as a promising solution to enhance shrimp health, digestion, and disease resistance. It supports the adoption of low fishmeal diets while decreasing dependency on antibiotics and imported additives, making shrimp farming more sustainable and cost-effective. Leveraging shrimp by-products for chitosan production also strengthens Vietnam's circular economy, turning waste into valuable resources and reducing pollution in coastal areas (Nguyen et al., 2023). With eco-friendly production methods like enzymatic degradation, chitosan not only promotes environmental sustainability but also creates economic value, reinforcing Vietnam's role as a leader in sustainable aquaculture.

5. Conclusions

Chitosan emerges as a promising multifunctional additive that addresses several critical challenges in shrimp aquaculture. Its antimicrobial and immunostimulant properties help mitigate disease outbreaks and reduce dependence on antibiotics, thereby supporting healthier and more resilient shrimp populations. Additionally, chitosan plays a key role in alleviating oxidative stress, enhancing digestive efficiency, and stimulating molting, all of which contribute to improved shrimp growth performance and survival rates.

From a feed technology perspective, chitosan improves pellet durability and nutrient retention, while also contributing to water quality improvement through its flocculating and metal-binding capabilities. These characteristics make it an ideal additive for advancing feed efficiency and environmental sustainability in high-density shrimp farming systems.

Importantly, Vietnam holds significant potential for localized chitosan production, given its abundant shrimp by-products, including shells and molted exoskeletons, which can be converted into high-value chitosan using eco-friendly extraction methods. This not only adds economic value to what would otherwise be waste, but also supports a circular economy model that aligns with global trends in sustainable aquaculture.

Overall, integrating shrimp-derived chitosan into farming practices offers a comprehensive solution, enhancing shrimp health, improving production efficiency, reducing environmental footprint, and creating value from waste. As such, chitosan not only benefits shrimp and farmers but also positions Vietnam's shrimp industry

as a frontrunner in sustainable and responsible aquaculture development.

Conflict of interest

We hereby declare that this is our original research work. The data and results presented in this article are entirely truthful and have never been published in any previous research work by anyone.

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