

Review Articles

Development Dilemma of *Litopenaeus vannamei* Industry in China, Current Countermeasures Taken and Its Implications for the World Shrimp Aquaculture Industry

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This study focuses on the *Litopenaeus vannamei* shrimp, exploring its development, dilemmas, and challenges in China's industry alongside countermeasures implemented by Chinese authorities and agencies. Since its introduction to China in 1988, *L. vannamei*, known for its high economic value and adaptability, has become China's leading mariculture shrimp species and one of the most significant globally. The thriving *L. vannamei* industry has boosted economic gains and job creation in China's marine fisheries, supplied high-quality protein to consumers, and fostered socio-economic growth. Additionally, China's experiences and lessons in the *L. vannamei* industry serve as valuable references for other shrimp-farming nations, promoting global industry health. Despite its success, the industry faces challenges, including germplasm resource scarcity, feed ingredient shortages, disease management, and wastewater treatment. To address these issues, China has initiated various strategies, including germplasm resource conservation, the development of low-fishmeal protein feeds, disease monitoring, and wastewater management, aiming for the industry's green and sustainable evolution. This paper asserts that China's initiatives in advancing the *L. vannamei* industry offer significant inspiration globally, particularly in two main areas: Firstly, through effective policy support, China has fostered research and development of new shrimp varieties suited to its aquaculture conditions, enhancing germplasm quality and breeding efficiency. Secondly, China has actively disseminated its innovations, outcomes, and experiences globally, hosting various aquaculture training sessions and seminars. These initiatives offer technical support and platforms for international dialogue, fostering cooperation and exchange among shrimp farming nations. Moreover, China's dedication to advancing artificial culture technology for *L. vannamei*—through collaborative and continuous research across breeding, nutrition, disease management, and sustainability—has led to significant industry advancements. These contributions not only extend the industry chain but also position China as a leader and model for global shrimp aquaculture innovation. Through this study, we aim to offer insights and practical advice by analyzing the challenges and responses within China's *L. vannamei* industry. We hope these findings will serve as valuable references for enhancing the global shrimp aquaculture industry and aid other nations in their aquaculture endeavors.

INTRODUCTION

The Pacific white shrimp, *Litopenaeus vannamei*, belongs to the Arthropoda, Crustacea, Malacostraca, Decapoda, *Pe-*

naeidae family.¹ Originating from the Pacific coast of Latin America, it thrives in the tropical waters from the Gulf of Mexico to Tumbes, Peru, with a significant population near Ecuador. Known for its broad salinity tolerance, rapid growth, strong environmental adaptability, and high meat

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quality, *L. vannamei* is now among the most critical marine cultured shrimp species worldwide. *L. vannamei* was introduced to China in 1988, and its larval cultivation was completed under laboratory conditions in 1992.^{2,3} Over three decades, it has emerged as China's leading marine shrimp species, sparking a global aquaculture boom thanks to advancements in breeding technology and large-scale cultivation. FAO data from 2022 shows that 47 countries cultivate *L. vannamei*, reaching a total production of 6.82 million tonnes. Notably, eight countries, including China, India, Ecuador, Indonesia, Vietnam, Thailand, Mexico, and Brazil, have productions exceeding 100,000 tonnes, with China leading globally at 2.09 million tonnes.⁴ This thriving industry not only enhances China's marine fisheries' economic benefits and employment but also provides Chinese consumers with a valuable protein source. Despite its growth, the *L. vannamei* industry confronts several challenges, including germplasm resource depletion, feed shortages, disease outbreaks, and environmental concerns from wastewater discharge. These issues compromise shrimp quality and yield, endangering both sustainability and ecological health. To address these challenges, the Chinese government, along with research institutes and businesses, has initiated comprehensive measures. Efforts include enhancing germplasm resource conservation, advancing the use of efficient, low-fishmeal protein feeds, establishing disease monitoring and early warning systems, and implementing standards for wastewater discharge and recycling. These actions aim to steer the *L. vannamei* industry towards greener and more sustainable development. The development of the *L. vannamei* industry in China is not only crucial for the country's aquaculture but also significantly influences the global shrimp farming sector. China's achievements and insights offer valuable lessons to other nations, fostering a healthier worldwide shrimp aquaculture environment. Additionally, as this industry continues to evolve, it will enhance the global aquatic market with increased supply and variety, catering to diverse consumer needs and bolstering international trade and cooperation.

OVERVIEW OF THE DEVELOPMENT OF THE *L. VANNAMEI* INDUSTRY IN CHINA

(A) SEEDLING AND NEW AQUATIC VARIETIES OF *L. VANNAMEI*

Healthy seed production of *L. vannamei* is the cornerstone of its industry in China. Following its introduction, significant advancements in industrialized seedling production were achieved between 2000-2001,⁵ marking a transition from reliance on foreign shrimp species. Today, China boasts extensive, standardized facilities for *L. vannamei* seedling production, achieving an annual output of approximately 138.6837 billion seedlings,⁶ sufficient to meet domestic aquaculture needs. Additionally, China has enhanced the breeding of *L. vannamei* using both traditional and modern methods, leading to new varieties tailored to various cultivation conditions and market demands. These

efforts have significantly improved the species' growth rates, disease resistance, and overall quality.

As of July 2023, the National Original Seed and Good Seed Validation Committee of China's Ministry of Agriculture and Rural Affairs has approved 283 new aquatic varieties, with shrimp varieties comprising 32 of these, or 11.3%. Notably, 13 of these shrimp varieties are *L. vannamei*, making up 40.6% of the new shrimp approvals. Apart from the "SPF Vannamei shrimp" introduced from Hawaii, USA, in 2001, the remaining 12 varieties have been developed domestically. Further details are provided in [Table 1](#).

(B) OVERVIEW OF *L. VANNAMEI* CULTURED IN THE WORLD

In 2022, China maintained its global leadership in *L. vannamei* production, reaching 2,098,600 tonnes across both seawater and freshwater environments. This accounted for 5.89% of China's total marine aquaculture output of 22.757 million tonnes for the year. Remarkably, since 2001, when production was just 87,800 tonnes, there has been a significant growth to over 2 million tonnes by 2022—nearly 24 times the initial figure.^{6,7}

L. vannamei aquaculture, central to the industry, has diversified across China through innovation and adaptation, leading to various cultivation methods such as pond, shed, high-level pond, factory recycled water, mulch, and weir aquaculture. This diversification has achieved scaled, intensified, and efficient production. As of now, the cultivation area spans 163,396 hectares across coastal provinces like Shandong, Guangdong, and others, with inland regions also participating. Despite a 8.23% reduction in mariculture area in 2022, productivity and efficiency gains indicate a shift towards more intensive aquaculture practices. Notably, in Shandong Province alone, while the aquaculture space shrank by 18.61%, production surged by 15.62%.⁶

In terms of global production pattern, China, Ecuador, India, Indonesia and Vietnam have accounted for more than 80% of the total production of *L. vannamei* in the world for many years. In the past 20 years, most of the aquaculture output of the five major producing countries showed an annual growth trend ([Figure 1](#)), which generally reflects the development trend of the global shrimp aquaculture industry. The growth rate and amplitude of production vary among different countries ([Figure 2](#)). China and Ecuador are relatively significant and stable, while the production of Vietnam and Indonesia has certain volatility and shows an overall growth trend.

In the global regional distribution, Asia occupies the dominant position of *L. vannamei* culture. According to the annual Global Shrimp Aquaculture Production Survey and Forecast report from the Global Seafood Alliance (Darryl, 2023), shrimp production in Asia is projected to decline by slightly over 3 percent in 2023, the first annual decrease in a decade, these numbers are based on a lower estimate for China (about 1.06 million tonnes) in 2023. However, for a long time, China has been focusing on the innovative application of greenhouses and recirculating aquaculture system technology to accumulate strength for sustainable industrial development. Shrimp production in Latin Amer-

Table 1. Introduction of new varieties of *L. vannamei*

Name of new aquatic variety	Registration number	Breeding unit	Target trait	Breeding technique
SPF <i>Litopenaeus vannamei</i>	GS-03-001-2002	Hainan Fisheries Research Institute.	Introduced variety	--
Kehai No. 1	GS-01-006-2010	Institute of Oceanology, Chinese Academy of Sciences; Northwest A&F University; Hainan Dongfang Zhongke Marine Biological Breeding Co., LTD.	Growth rate	Family selection
Zhongke No. 1	GS-01-007-2010	South China Sea Institute of Oceanology, Chinese Academy of Sciences; Zhanjiang Donghai Island Dongfang Industrial Co., Ltd ; Zhanjiang Haimao Aquatic Biotechnology Co., LTD; Guangdong Guangken aquatic products development Co., LTD.	Growth rate	Population selection + Family selection
Zhongxing No. 1	GS-01-008-2010	Sun Yat-Sen University; Guangdong Hengxing Feed Industry Co., LTD.	Resistance to WSSV	Family selection
Guihai No. 1	GS-01-001-2012	Guangxi Zhuang Autonomous region Fisheries Research Institute.	Growth rate / Surviving rate	Family selection
Renhai No. 1	GS-02-007-2014	Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences; Qingdao Higene Aquabreeding Technology CO., LTD.	Growth rate / Surviving rate	Family selection + Cross breeding
Guangtai No. 1	GS-01-003-2016	Institute of Oceanology, Chinese Academy of Sciences; Northwest A&F University; Hainan Guangtai Marine Breeding Co., LTD.	Growth rate / Surviving rate	Family selection
Haixingnong No. 2	GS-01-004-2016	Guangdong Haixingnong Group Co., LTD; Guangdong Haid Group Co., LTD; Sun Yat-Sen University ; Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences.	Growth rate / Surviving rate	Family selection
Zhengjinyang No. 1	GS-01-006-2017	South China Sea Institute of Oceanology , Chinese Academy of Sciences; Maoming Jinyang tropical Tropical Seafood aquaculture Co., LTD.	Low temperature resistant / Low salt tolerance / Surviving rate / Growth rate	Family selection
Xinghai No. 1	GS-01-007-2017	Guangdong Ocean University; Zhanjiang Dehai Industrial Co., LTD; Zhanjiang Guoxing aquatic Technology Co., LTD.	Surviving rate / Weight	Family selection
Haixingnong No. 3	GS-01-007-2022	Zhanjiang Haixingnong Marine Biotechnology Co., LTD; Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences; Sun Yat-Sen University; Guangdong Haixingnong Group Co., LTD.	Weight / Surviving rate	Family selection
Bohai No. 1	GS-02-006-2022	Bohai Sea Aquaculture Breeding (Hainan) Co., LTD; Institute of Oceanology, Chinese Academy of Sciences; Bohai Aquatic Products Co., LTD.	Growth rate / High salt tolerance	Family selection + Cross breeding
Haimao No. 1	GS-02-007-2022	Haimao seed industry Technology Group Co., LTD; South China Sea Institute of Oceanology , Chinese Academy of Sciences; Guangdong Jinjiao aquaculture seed technology Co., LTD; Qingdao Excellence Ocean Group Co., LTD	Anti- <i>Vibrio Harveyi</i> / Growth rate	Family selection + Cross breeding

(Source: Ministry of Agriculture and Rural Affairs of China, 2023)

ica is the other major global producing region after Asia, among which Ecuador produces the highest in the region, having already become the second country to produce 1 million tonnes of shrimp aquaculture in 2021, and is expected to reach 1.5 million tonnes in 2023 and 2024. The industry in Ecuador has benefitted very significantly from

major investments in genetic improvement, particularly automatic feeders and mechanical aeration, the recent development of a huge export market in China. Meanwhile, Ecuador and India are also reported to have the industry's lowest production costs. In the future, with significant advances in genetic improvement, feeds and feeding, aquacul-

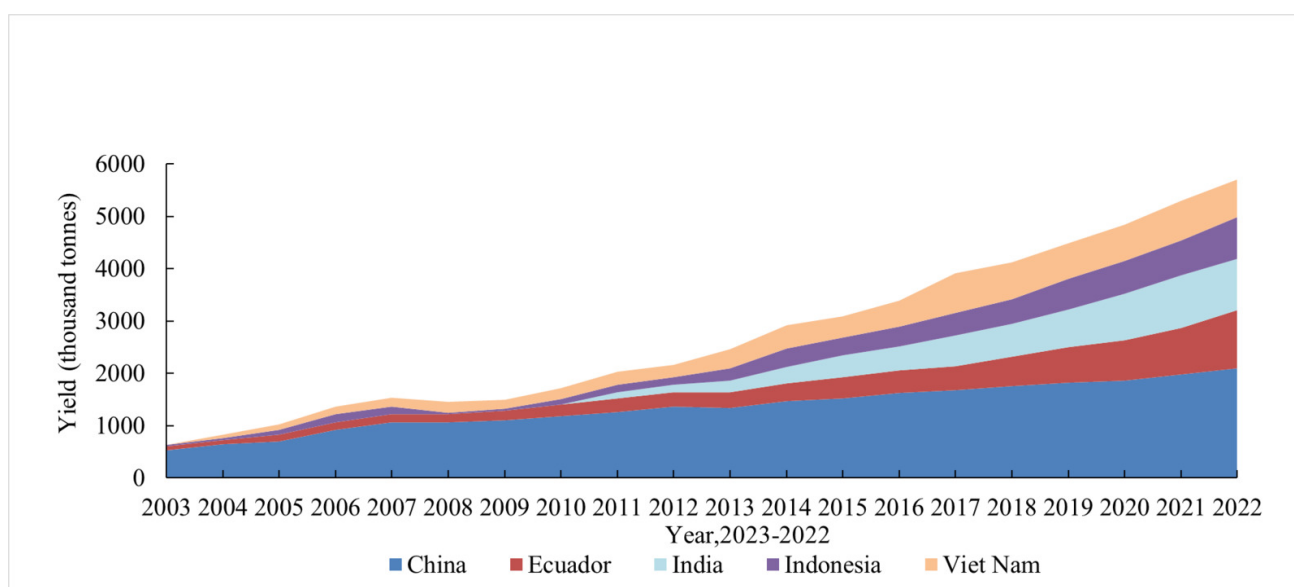


Figure 1. The trend of production in 5 major producing countries of *L. vannamei*

(Source: FAO.2024.Global aquaculture production Quantity (1950-2022), https://www.fao.org/fishery/statistics-query/zh/aquaculture/aquaculture_quantity)

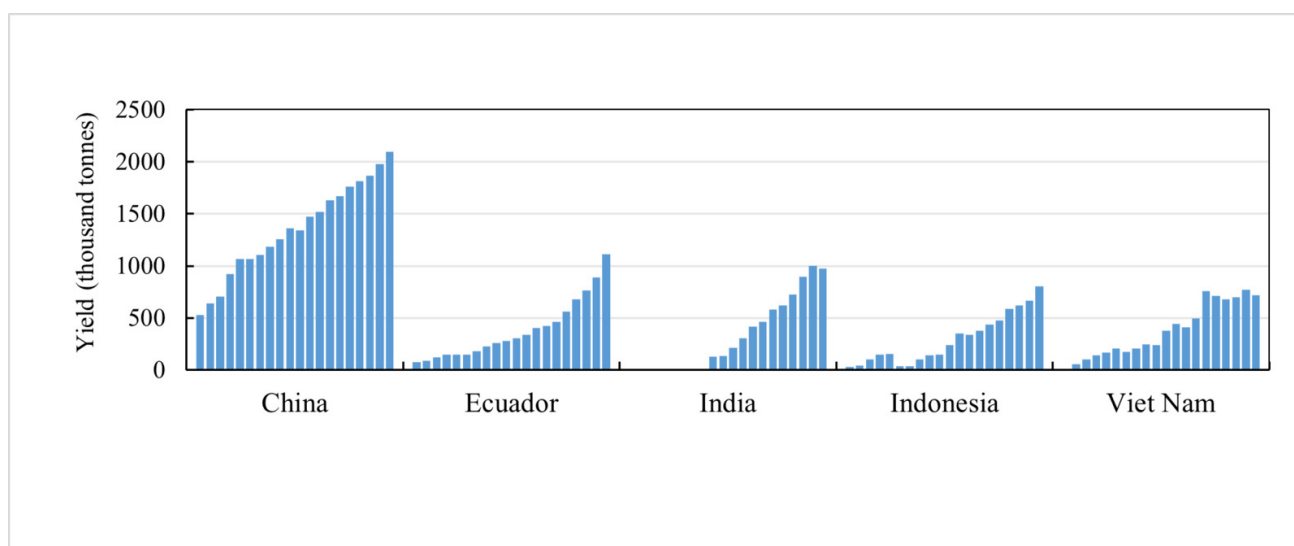


Figure 2. Yield trend analysis of aquaculture *L. vannamei* in 5 major producing countries,2003-2022

(Source: FAO.2024.Global aquaculture production Quantity (1950-2022), https://www.fao.org/fishery/statistics-query/zh/aquaculture/aquaculture_quantity)

ture and production technologies, the shrimp farming industry still has significant potential.

(C) DISEASE SITUATION OF *L. VANNAMEI*

Disease is the main problem and bottleneck constraining the development of the *L. vannamei* industry in China. The introduction of *L. vannamei* has alleviated the plight of White spot syndrome virus (WSSV) infection of *Fenneropenaeus chinensis*, but with the prolongation of the aquaculture time and the expansion of the scale, the disease problem of *L. vannamei* has become more and more serious. In recent years, the common shrimp diseases in China are: Infection with *Enterocytozoon hepatopenaei* (EHP), White spot disease (WSD), Infection with Infectious hypodermal

and hematopoietic necrosis (IHHN), Infection with Decapod iridescent virus 1, Acute hepatopancreatic necrosis disease (AHPND), Infectious myonecrosis (IMN), Shrimp post-larva bacterial vitrified syndrome (BVS) and other diseases, which had caused huge losses to the aquaculture industry.

In the case of AHPND, losses are estimated to be more than US\$1 billion per year, causing incalculable losses to the shrimp aquaculture industry. The disease was once known as Early mortality syndrome (EMS). Since 2009, it has been outbreak in China, Vietnam, Malaysia, Thailand, Mexico and other countries⁸⁻¹² and has rapidly swept through the global staple areas of *L. vannamei*. Due to its wide and rapid spread, short course of disease and high mortality rate, resulted in high pond discharge rates of aquaculture.

To combat diseases in *L. vannamei*, China has implemented multiple strategies, including enhanced pathogen monitoring, seedling health improvement, aquaculture management optimization, and judicious medication and immune enhancer use. Despite these efforts, the outcomes have been less than satisfactory, leaving disease control in *L. vannamei* as a pressing issue.

(D) DEEP PROCESSING OF *L. VANNAMEI*

Developing deep-processed products represents an advancement and expansion of the *L. vannamei* industry. As China's aquaculture production grows and market demand diversifies, the variety of shrimp deep-processed products has expanded significantly. Offerings now include frozen shrimp, shrimp meat, cooked shrimp, seasoned shrimp, shrimp sauce, dried smoked products, instant foods, snack foods, and prepared dishes, catering to the varied tastes and health preferences of consumers.

Deep-processed *L. vannamei* products enjoy popularity and competitive edge in both domestic and international markets. Frozen shrimp dominate exports, constituting about 80% of the total, while high-value processed products like boiled shelled shrimp, tempura, and sushi shrimp make up another 16%. These exports primarily serve to fulfill supermarket demands and tempura processing needs abroad. Notably, the share of processed shrimp exports has grown, with frozen shrimp experiencing the most rapid increase, reaching 217,000 tonnes in 2018.¹³

THE PREDICAMENT FACED BY THE DEVELOPMENT OF *L. VANNAMEI* INDUSTRY IN CHINA

In 2023, the *L. vannamei* industry faces significant challenges globally and in China, marked by sluggish consumption, low prices, and financial losses for producers. These issues stem from complex factors beyond mere supply-demand imbalances. Notably, while prices for other shrimp species in China have increased, those for *L. vannamei* have decreased. Addressing this requires enhancing breeding efficiency to ensure the industry's stable and sustainable growth. Despite significant advancements in seed production, aquaculture technology, nutrition, feed, disease prevention, control, and deep processing, China's *L. vannamei* industry confronts several critical challenges in key areas:

(A) GERMPLASM RESOURCES DEGRADATION

With *L. vannamei*'s introduction to China, the need for quality shrimp seeds surged, heavily depending on foreign germplasm imports due to historical gaps in local breeding innovation. This reliance has led to genetic homogeneity, risking inbreeding decline as a narrow gene pool from few parent stocks dominates production. This not only diminishes genetic diversity and adaptability but also elevates the costs associated with cultivating superior seedlings.¹⁴

The reliance on imported shrimp species, which have varied genetic backgrounds, has constrained breeding ad-

vancements. The predominantly hybrid offspring from seed technology abroad are suitable for immediate needs but offer limited long-term genetic diversity for breeding. This situation, compounded by inadequate selection criteria and complex biological traits of shrimp, such as small egg size and high genomic complexity, results in inefficient breeding practices. Consequently, the overall quality and survivability of seedlings remain low, struggling to fulfill the market's diverse requirements.

(B) THE SHORTAGE AND DEPENDENCE ON FEED INGREDIENTS

Feed constitutes the largest cost in *L. vannamei* farming, heavily reliant on imported fishmeal and soybean. Challenges like raw material shortages, price volatility, and supply instability impact feed quality and cost. Consequently, identifying alternative fishmeal sources has become critical for the industry's sustainability and a focal point in nutrition research. Understanding *L. vannamei*'s response to fishmeal alternatives, including animal, plant, and microbial proteins, is essential for effective substitution and enhancing feed efficiency.¹⁵

Much of the research into fishmeal substitution in shrimp feed is still focused on testing various alternatives and determining appropriate substitution ratios, with insufficient exploration of the underlying mechanisms. This gap in understanding shrimp's nutritional needs and response mechanisms to alternative feeds hinders the development of optimized formulations. Consequently, the industry faces low feed utilization rates, contributing to resource wastage and environmental pollution.

(C) THE FREQUENCY OF DISEASES AND THE DIFFICULTY OF PREVENTION AND CONTROL

Disease is the primary barrier to the development of *L. vannamei* aquaculture in China, with numerous diseases impacting the industry. Recent years have seen a high incidence of both endemic and imported diseases. Factors such as variable seedling quality, environmental pollution, outdated breeding techniques, and insufficient disease detection have further exacerbated these issues.

Basic strategies have been accumulated for the treatment of bacterial diseases in shrimp, while the treatment of viral diseases is often helpless. Currently, China relies on biosecurity measures, complementary animal protection products, drugs and immune enhancers for disease control and prevention of *L. vannamei*. However, the effects of these methods are not ideal, and there are problems such as poor specific control, high initial investment, insufficient level of prevention and control level, resulting in drug residues and immune suppression. The zoonotic risk of the shrimp pathogen itself is minimal. Therefore, it is necessary to ensure the quality of shrimp and food safety while preventing the outbreak of disease. Since July 2020, China's Ministry of Agriculture and Rural Affairs (MARD) has stipulated that feed manufacturers are prohibited from producing commercial feeds containing growth-promoting drugs (a class of antibiotics) feed additives (except for traditional Chinese

medicines). The arrival of the antibiotic-free era has put forward higher requirements for the prevention and control of aquatic diseases in *L. vannamei*, and better regulates the development of aquaculture.¹⁶

(D) THE INADEQUACY OF THE DISCHARGE AND TREATMENT OF AQUACULTURE WASTEWATER

In China, traditional aquaculture practices like pond and small shed workshop cultures dominate *L. vannamei* breeding. These methods struggle with controlling environmental factors, leading to inefficient water use and significant wastewater discharge. The released water, rich in organic matter, nitrogen, and phosphorus, heavily pollutes surrounding ecosystems, jeopardizing water and soil quality, disturbing ecological balance, and challenging the industry's sustainability.

China's shrimp aquaculture is characterized by a mix of small-scale retail households and larger enterprises, resulting in fragmented production that hampers industry growth. This fragmentation prevents economies of scale and significant investment in infrastructure, leading to a lack of stability and difficulty in adopting modern, intelligent farming practices. The industry largely relies on traditional methods, with an urgent need to increase the adoption of advanced technologies and factory breeding modes.¹³ Consequently, this structure also affects waste management, contributing to inadequate wastewater treatment and environmental challenges.

(E) ENVIRONMENTAL IMPACT OF *L. VANNAMEI* BREEDING

Shrimp farming may bring many adverse effects to the environment, including resource consumption, deterioration of water quality, disease spread, habitat damage and reduced biodiversity, etc. Especially for industrialized shrimp farming, its consumption of water resources is huge. Regular water changes to ensure water quality result in water consumption far exceeding that of pond farming. The influence of water eutrophication is the most significant in shrimp culture. Highly intensive aquaculture leads to the increase of nitrogen and phosphorus concentrations in water and serious eutrophication, which seriously affects the growth environment of shrimp. It is reported that the breeding density of the industrialized breeding mode of *L. vannamei* is 16 times that of pond breeding.¹⁷ Excessive feeding of feed and low conversion rate are among the reasons causing water eutrophication, which may result in the rampant growth of algae in ponds and deterioration of water quality. Improper breeding methods will have negative impacts and shocks on the surrounding ecosystem.

During the aquaculture process, high concentrations of ammonia nitrogen ($\text{NH}_3\text{-N}$) and nitrite nitrogen ($\text{NO}_2\text{-N}$) will affect the physiology, health and production efficiency of shrimp, causing the shrimp to lose appetite or even die, forming a vicious cycle in the shrimp ponds.¹⁸ If supervision or operation is improper, excessive or abusive use of drugs will occur during the cleaning of ponds and water disinfection, and the residual drugs will damage the surround-

ing water environment. Improper treatment of aquaculture wastewater directly discharged, will pollute the nearby sea areas, poison marine organisms, and even cause red tides, resulting in a large number of biological deaths. Meanwhile, various viruses and pathogenic bacteria carried in the wastewater will endanger other crustacean aquatic organisms, causing them to be infected or die, and destroying the ecological balance of the external water.

COUNTERMEASURES TAKEN BY CHINA IN PROMOTING THE DEVELOPMENT OF THE *L. VANNAMEI* INDUSTRY

To address the challenges faced by China's shrimp aquaculture industry and to steer it towards transformation, upgrading, and green sustainable development, the Chinese government, scientific research institutes, and enterprises have initiated several active measures:

(A) STRENGTHEN THE PROTECTION AND UTILIZATION OF GERMPLASM RESOURCES

To address the challenges in the *L. vannamei* industry, the Chinese government has intensified policy support, fostering the establishment of marine fishery germplasm resource banks, including for *L. vannamei*. This involves collecting and preserving diverse shrimp strains to bolster genetic breeding and germplasm improvement. The government has also promoted shrimp breeding innovation, leading to significant advancements through the dedicated efforts of scientists and technologists. Breakthroughs in breeding, seedling production, and germplasm resource utilization have been achieved, resulting in new shrimp varieties that meet varying environmental and market demands. Techniques such as traditional breeding, multi-trait hybrid breeding, and molecular breeding have enhanced shrimp growth, disease resistance, and quality. These efforts have increased genetic diversity and adaptability, establishing a foundation for the sustainable development of the *L. vannamei* industry.

China has long adhered to the combination of industry, university and research, guiding scientific research institutes to closely integrate with enterprises. For example, the team of the Yellow Sea Fisheries Research Institute organized the establishment of the first joint breeding center of *L. vannamei* in China. In 2023, the expert Advisory Committee of the National Shrimp Joint breeding platform, composed of five academicians leading the top scientific research team, was established to provide technical advice and guidance on the construction and operation of the platform. The "last kilometer" of the new species of *L. vannamei* from the laboratory to industrialization will be opened. At the same time, we should join with various scientific research institutes and breeding enterprises to form a breeding alliance, and build an innovative system of "enterprise leading + N scientific research institutes + several leading enterprises + existing extension system". Promote cross-disciplinary, cross-departmental and cross-regional joint research, work together to break through the bottle-

neck of key theories and core technologies in shrimp breeding, and effectively improve the core species supply rate of *L. vannamei*. Get rid of dependence on foreign seed sources, optimize commercial breeding system, cultivate independent varieties and breeding system, and improve the coverage rate and market influence of *L. vannamei*.

Breeding enterprises in China are increasingly adopting the “integration of breeding, propagation, and promotion” model. This approach positions enterprises at the forefront, facilitating the transfer of breeding elements, technology, and talent from scientific research institutions to businesses. Through a system that encourages the sharing of achievements and aligns interests, these enterprises have developed a comprehensive seed industry framework that spans breeding, propagation, and the promotion of superior varieties. This strategy has enhanced their core competitiveness and market presence. As a result, several seed companies have secured core technologies and intellectual property rights, aligning with the “integration of breeding, propagation, and promotion” criteria and receiving government evaluation.

In 2021 and 2022, around 300,000 pairs of shrimp were imported, but forecasts for 2023 and 2024 suggest a decrease in imports and an increase in the share of domestic superior species to over 30%. The new *L. vannamei* varieties developed in China are demonstrating superior growth rates, meat yield, stress and disease resistance, marking significant advancements in the industry’s development.

(B) RESEARCH AND APPLICATION OF HIGH EFFICIENCY COMPOUND FEED

The Chinese government has significantly bolstered R&D efforts in the aquaculture sector by providing financial support and fostering collaborations between universities, research institutions, and enterprises. These partnerships have achieved substantial progress and breakthroughs across various fronts. Key achievements include the development of an aquatic animal nutrition demand database, advancements in understanding nutrition metabolism mechanisms, and the exploration of new non-grain protein sources such as microbial, insect, animal, and plant proteins. Furthermore, strides have been made in the research and development of feed processing machinery and technologies essential for feed production. These efforts have led to continuous improvements in feed output and quality. Notably, China’s production of aquatic feed surged from 750,000 tonnes in 1991 to over 22 million tonnes in 2018, marking a thirtyfold increase and accounting for more than half of the global output.¹⁹

In the breeding of *L. vannamei*, the shift from relying on fresh, wild-caught, and mixed fish feed to predominantly using compound feeds marks a significant advancement. Tailoring feed formulations to the shrimp’s various growth stages and specific cultivation conditions has proven more effective. Liang et al.²⁰ developed specialized feeds for parent shrimp that substitute fresh feed, substantially reducing disease risk and pathogen transmission. During the shrimp cultivation phase, the focus is on creating compound feeds characterized by low fishmeal and protein con-

tent, which are adaptable to coarser diets. Modern feeds increasingly utilize alternative protein sources like fermented plant proteins, insect proteins, and microbial proteins, enabling a reduction of fishmeal content from 25% to approximately 5% without compromising the shrimp’s growth or health.²¹ These innovations significantly lower feed costs and reliance on external sources, enhance feed efficiency and farming productivity, and diminish resource wastage and environmental impact, contributing to the aquaculture sector’s green and sustainable development in China.

(C) ESTABLISH DISEASE MONITORING AND EARLY WARNING SYSTEMS TO IMPLEMENT COMPREHENSIVE DISEASE PREVENTION AND CONTROL

The Ministry of Agriculture and Rural Affairs (MARD) has been diligently overseeing the “National Aquatic Animal Disease Surveillance Program” to monitor aquatic diseases across China, enhancing disease risk assessments, monitoring, early warnings, and emergency responses. In 2022, MARD and the National Aquatic Technology Extension Terminal launched the “Guidelines for Prevention and Control of Aquatic Animal Diseases (Trial)” and established a comprehensive aquatic seedling quarantine system. This initiative lays down detailed protocols for early diagnosis, disease prevention, monitoring, and emergency actions, creating a multi-tiered disease detection and early warning framework alongside an integrated disease prevention and control technology system. In efforts to advance comprehensive disease management in shrimp, strategies encompassing biological, immune, and ecological controls are being applied across seedling rearing, farming, feed, and environmental management. A significant focus is on minimizing medication use to boost shrimp health and immunity, thereby reducing disease risks and losses.

Crustaceans are notably the most economically impacted by diseases in China, with 2021 estimates showing a loss of 17.2 billion yuan due to diseases, representing 31.9% of total aquaculture disease-related economic losses. Of this, *L. vannamei* accounted for losses of 5.7 billion yuan. The emphasis is thus on enhancing disease monitoring and early warning systems to timely address shrimp disease outbreaks and offer evidence-based prevention and control measures. Supported by government initiatives, grassroots technical promotion, research institutions, and enterprises, resources like aquatic microbial strain banks and disease-related databases are being enriched. Significant advancements have been made in drug pharmacokinetics and safety assessments, with the development and application of new fishery medications derived from Chinese herbs. The Yellow Sea Fisheries Research Institute of the Chinese Academy of Fisheries Sciences has developed an aquatic disease remote consultation system and early warning platform, facilitating real-time disease information sharing and diagnoses across locations. This system aids experts in providing scientific disease management guidance to farmers, reduces mortality rates, and spreads the latest disease prevention knowledge. It also allows researchers to promptly respond to disease occurrences on farms, enhancing the role of scientific research in supporting industrial development and

establishing a new paradigm of research serving production directly.

(D) ACCELERATE THE DEVELOPMENT OF COMPREHENSIVE UTILIZATION AND DEEP PROCESSING OF *L. VANNAMEI*

The *L. vannamei* processing industry, leveraging its status as a high-quality ocean protein source, caters to consumer preferences for nutrition and flavor. It addresses challenges in cold chain storage, seasoning, and sterilization to offer products like pre-cooked dishes, ready-to-eat foods, and seasonings. Enhanced by efficient logistics, these products swiftly reach the consumer market. Efforts are also directed towards expanding product functionality and target demographics, incorporating Chinese herbs, enzymes, and biological enzymes to develop functional foods with defined structure-activity relationships.

With the industry's growth, domestic research institutions and enterprises are focusing on the comprehensive utilization and deep processing of *L. vannamei*, setting industry standards, and innovating high-value products to augment product value and economic returns, thereby enriching and extending the industrial chain. Governmental support aims to alleviate the capital challenges faced by innovative enterprises, diversifying financing options through policy-based financial assistance and guarantees. Concurrently, there is a push to enhance research and development investment, especially in essential equipment, aiming to elevate the processing industry's mechanization, intelligence, and automation levels.

(E) VARIOUS INITIATIVES TO REDUCE THE ENVIRONMENTAL IMPACT OF SHRIMP BREEDING

The development of the aquaculture industry should take into account ecological, social and economic goals. Local governments and fishery departments need to promote appropriate breeding models based on local conditions. Pond breeding has a small environmental impact but occupies a large area, has a low output, is difficult to monitor, and it is hard to guarantee the quality and safety of aquatic products. Unilaterally emphasizing the environmental impact and adopting the pond breeding model may cause insufficient supply of aquaculture production. In the process of industrialized breeding, it is advocated to adopt recirculating aquaculture to improve the utilization efficiency of water resources, introduce and use aquaculture wastewater treatment devices, strengthen supervision and management, and achieve the standard discharge and recycling of breeding wastewater. Furthermore, by improving the feed composition based on the needs of shrimps, enhancing the guidance on breeding techniques and feeding strategies, standardizing the processes, and improving the scientific and standardized level of precise feeding, the aquaculture pollution caused by a large amount of remaining feed can be effectively prevented.

The government should strictly monitor and manage sewage discharge, control the concentration and total amount of discharge, reduce the load of marine pollution,

and create an excellent environment for shrimp breeding. During the breeding process, facilities and equipment such as water storage tanks, filtration tanks, and water treatment should be equipped to reduce the impact of external environmental pollutants. Shrimp farmers and enterprises should be familiar with water quality control techniques, use drugs scientifically, and strictly prohibit the abuse of prohibited drugs. It is encouraged and advocated that the breeding wastewater be discharged after reaching the standard, effectively control the generation and leakage of internal pollutants, and enhance the environmental protection awareness of shrimp farmers. By increasing the scientific research investment in the industrialized breeding of *L. vannamei*, developing and applying more efficient and environmentally friendly breeding technologies and equipment, vigorously promoting the polyculture models of fish, shrimp, crabs, shellfish, and applying technologies such as micro-ecological regulation, a better breeding ecosystem can be constructed. This promotes industrial development and achieves the effects of cleaning the bottom substrate, improving the water quality and reducing the adverse impact on the environment.

THE INSPIRATION TO THE WORLD *L. VANNAMEI* INDUSTRY BROUGHT BY CHINA'S PROMOTION OF SHRIMP INDUSTRY DEVELOPMENT

The collective efforts of the Chinese government, universities, research institutes, enterprises, and farmers have significantly advanced the *L. vannamei* industry, offering valuable insights for global shrimp aquaculture development. Through strategic policy guidance and support, dedicated research into new shrimp varieties has led to remarkable achievements:

Firstly, through good policy guidance and support of the Chinese government, scientific research institutions and enterprises devoted themselves to the research and development of new varieties, successfully bred a number of new varieties of *L. vannamei* adapted to China's aquaculture environment. For example, the collaboration between the Institute of Oceanography of the Chinese Academy of Sciences and Bohai Aquatic Breeding (Hainan) Co., Ltd. resulted in the development of "Bohai 1", a variety notable for its high salt tolerance and rapid growth. Haimao Seed Industry Science and Technology Group Co. Ltd., in partnership with the South China Sea Institute of Oceanography of the Chinese Academy of Sciences, created "Haimao No. 1", distinguished by its resistance to bacterial diseases and accelerated growth. With the technical support of the Yellow Sea Fisheries Research Institute of the Chinese Academy of Fishery Sciences, the industry saw the creation of "Renhai No. 1" and "Haixingnong No. 3", varieties that enhance survival rates and are adaptable to both seawater and inland brackish water aquaculture environments. These innovations in shrimp breeding underscore the pivotal role of new varieties in strengthening the seed industry

and bolstering the cultivation of *L. vannamei*, underscoring the importance of collaborative development efforts.

Secondly, China has actively opened and shared our innovative technologies, excellent achievements and experience and practices to the world, and has opened many international and domestic aquaculture training courses and seminars. For example, the 2018 Technical Training Course Program for Developing Countries - Southeast Asian Mariculture Technology Training Course, and the Ministry of Agriculture and Rural Development's 2019 Sailing to the Sea Talent Training Project -Maritime Silk Road Training Course on Mariculture, FAO Workshop on Emergency Preparedness and Response and Contingency Planning, Regional Workshop for OIE National Focal Points for Aquatic Animals, International Workshop on Aquaculture Biosecurity, not only to share successful experience, but also to jointly tackle technical problems, inspire everyone, help to improve the knowledge and technical level of practitioners and farmers, enhance the breeding efficiency of the entire industry, and provide technical services, demonstration and promotion for healthy shrimp farming, disease prevention and control industries. The Chinese government has taken the lead in establishing industry norms and formulated several national, provincial, ministerial, and local standards for *L. vannamei* seedling breeding, dry shrimp, frozen shrimp processing, etc., regulating the behavior and process of various industries, and constantly integrating technical standards for all links of the industrial chain. Jointly promote the development of *L. vannamei* industry in the direction of scale, innovation, systematization and health, and promote the green and sustainable development of the industry.

In addition, China has actively promoted the research and development of artificial breeding technology for *L. vannamei*. Through joint efforts and years of technical research, breakthroughs have been made in key areas such as shrimp breeding, aquaculture, feed nutrition, disease prevention and control, energy saving and emission reduction (recycled aquaculture), and intensive processing of *L. vannamei*. It has greatly promoted the transformation and development of *L. vannamei* industry, which has the longest industrial chain and the largest aquaculture scale. Through the integration, support, integration, application, and promotion of the whole artificial breeding technology, the efficiency of aquaculture has been continuously improved, benefiting most areas of the country, inland areas, saline-alkali areas, plateau, and more than 30 provinces and municipalities. This has helped China become the world's largest shrimp producer. The inspiration of these measures to the world shrimp aquaculture industry is that the support and guidance of the government, the close cooperation between scientific research institutions and enterprises, as well as the promotion and application of artificial aquaculture technology, are important factors in promoting the rapid development of the shrimp aquaculture industry. These strategies highlight the importance of government support, collaboration between research entities and businesses, and the application of advanced aquaculture technologies in fostering the shrimp aquaculture sector's

growth. By adopting similar measures, countries conducive to *L. vannamei* farming can enhance their shrimp farming efficiency and scale, contributing to the industry's overall prosperity.

The world population is projected to reach 9.7 billion by 2050, up by 1.7 billion compared with 2022. Based on an estimated per capita level of 20.7kg in 2022, the total supply of aquatic animal food will need to increase by 36 million tonnes (fresh weight equivalent), representing a 22 percent rise.⁴ This alteration will significantly impact the supply and demand of *L. vannamei*. Sustainable aquaculture will tend to be intensified and expanded to meet the global demand for aquatic products while ensuring equitable distribution of benefits. In the future, the global and Chinese shrimp industry will continue to develop, benefiting from continuous innovation and optimization in aspects such as new variety cultivation, efficient feed research and development, disease prevention, and aquaculture technology. The breeding efficiency and product quality of shrimp will be further enhanced. Meanwhile, throughout the entire process of breeding, attention is paid to environmental protection, ecological security, and sustainable development to meet regulatory requirements. As an important driving force for the industry, China will profoundly influence the global *L. vannamei* industry in terms of innovation in breeding technology and in-depth market development.

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DATA ACCESSIBILITY

The datasets generated and/or analyzed during the current study are available from the corresponding authors on reasonable request.

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CONFLICT OF INTEREST STATEMENT

The authors declare that this article was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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