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Probiotics as antibiotic-sparing interventions in South and East Asian freshwater aquaculture: Evidence, environmental implications and a roadmap for precision application

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ABSTRACT

Freshwater aquaculture underpins aquatic-food security in Asia, but production intensification can increase disease pressure and encourage poorly supervised antimicrobial use. This structured narrative review evaluates probiotics as antibiotic-sparing interventions in South and East Asian freshwater aquaculture, with emphasis on host performance, disease resistance, microbial mechanisms, water quality, antimicrobial-resistance (AMR) risk, and implementation constraints. Peer-reviewed studies and institutional sources published mainly since 2000 were synthesized; 12 primary studies published during 2014-2025 contained sufficient study-level information for descriptive analysis. Bangladesh and China each contributed four studies (33.3%), India three (25.0%), and Malaysia one (8.3%). Nine studies were *in vivo* and three involved *in vitro* screening or genomic characterization. Feed and water administration each accounted for four of the nine *in vivo* studies, whereas one used immersion. Growth or feed-utilization outcomes were measured in 77.8% of *in vivo* studies, immune responses in 66.7%, gut microbiota or intestinal morphology in 55.6%, and disease resistance and water quality each in 44.4%; only 11.1% included formal economic assessment. *Bacillus* was the most frequently studied genus, while lactic-acid bacteria provided complementary functions in adhesion, acidification, bacteriocin production, and competitive exclusion. Across studies, probiotics were associated with improved growth, innate immunity, survival after bacterial challenge, intestinal condition, and selected water-quality variables. Nevertheless, responses were strain-, host-, dose-, formulation-, route-, and environment-specific. Evidence remains geographically concentrated, short-term, and dominated by bacterial challenge models. Probiotics should therefore be regarded as components of integrated health management rather than universal substitutes for therapy. Future progress requires farm-scale trials, harmonized reporting, whole-genome safety screening, confirmation of viable dose and colonization, environmental fate assessment, and region-specific precision formulations aligned with One Health antimicrobial stewardship.

Introduction

Aquaculture is now among the rapidly expanding industries that provide global food security, livelihood, and economic development, especially in Asia whereby production is highly concentrated (Verdegem et al. 2023). Fish is also a preferred and culturally important food in the region, and its consumption is shaped by socioeconomic factors (Rahman et al. 2024). As the capture fisheries have reached their maximum sustainable levels, there has been a need to have increased aquaculture systems to serve the increased demand of aquatic protein. Nevertheless, the strengthening has also brought a rise in the number of infected diseases that cause significant economic loss and decreased productivity (Leung and Bates 2013).

To mitigate disease outbreaks, antibiotics and chemotherapeutics have been widely used in aquaculture practices. Even though they are effective in the short run, their overuse and lack of regulation have caused environmental pollution, disruption of aquatic microbiota, fish product residue accumulation, and

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the development of antimicrobial resistance (AMR) (Chen et al. 2015; Xiong et al. 2015; Rigos and Kogiannou 2023).

The extensive antibiotic application in the Asian aquaculture systems is potentially harmful to the ecosystem and human health. The food chain can transfer antibiotic-resistant bacteria and resistance genes to human pathogens, which is a contributor to the global AMR crisis (Tomova et al. 2015; Watts et al. 2017). Also, the presence of antibiotic residues in aquatic products may lead to allergic reactions, chronic toxicity, and trade restrictions because of food safety issues (Liu et al. 2017; Lulijwa et al. 2020).

Environmentally, the release of antibiotics into water bodies has been known to disrupt the microbial balance and impact on the non-target organisms, including algae and cyanobacteria (Rico et al. 2012; Thiang et al. 2021). These combined effects demonstrate the necessity of finding alternative ways of introducing antibiotics in aquaculture, which are sustainable and eco-friendly.

The history of probiotics has evolved from ancient, unintentional fermentation to a rigorous science, formally beginning with Metchnikoff's 1907 "probiotic principle" that linked microbial consumption to longevity. Today, this legacy is applied in aquaculture as a sustainable alternative to antibiotics, where specific strains are utilized to enhance growth, boost immunity, and maintain water quality through systematic administration (Fig. 1; Gogineni et al. 2013; Rahayu et al. 2024).

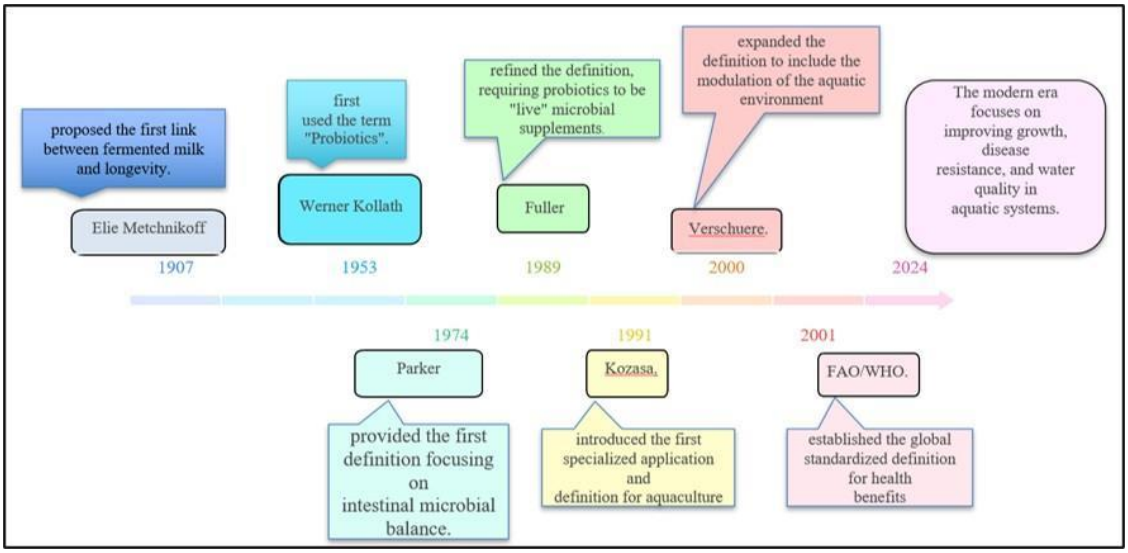


Fig. 1. Evolution of probiotics from 1907 to 2024 (Gogineni et al. 2013; Rahayu et al. 2024).

Probiotics have attracted a lot of interest as a potential substitute for antibiotics in aquaculture. Probiotics have various functions, such as improving gut health, boosting immune response, preventing the activity of pathogenic microorganisms, and preserving water quality (Balcázar et al. 2006; Nayak 2010) and are defined as live microorganisms that, when given in sufficient amounts, confer a health benefit to the host (Reid et al. 2019).

An increasing body of literature in Asia has shown the positive impact of probiotics on growth performance, disease resistance, and survival of aquatic life (Hasan and Banerjee 2020; Gaffar et al. 2023). Bangladeshi, Chinese, and Indian studies have investigated the use of probiotics in the gut microbiome regulation, water quality and disease control (Hossain et al. 2023; Hlordzi et al. 2020; Akhter et al. 2015).

Different probiotic genera that have been utilized in aquaculture include *Bacillus*, *Lactobacillus*, *Pediococcus* and *Saccharomyces* have antimicrobial, enzymatic, and immunostimulatory effects (Mohamed et al. 2025; Diwan et al. 2022). Table 1 shows the available studies on probiotics usage in Asian freshwater aquaculture.

Table 1. Characteristics, research focus and principal findings of probiotic studies in Asian aquaculture.

Study	Location	Study Focus	Probiotic Strain /Formulation	Host Species / System	Dose, Administration & Duration
Hossain et al. (2013)	Bangladesh (Khulna)	Experimental assessment of probiotic effects on shrimp growth and survival	Not reported	Shrimp aquaculture	Not reported
Saini et al. (2014)	India	Controlled feeding and pathogen-challenge experiment	Commercial mixture (*Bacillus*, *Lactobacillus*, *Arthrobacter* spp.)	*Labeo rohita*	0, 2, 3, 4, 5 g/kg diet; feed administration for 60 days
Akhter et al. (2015)	South Asia (Bangladesh & India)	Review of probiotic and prebiotic roles in fish health	Various bacterial, yeast, and microbial probiotic groups	Fish and shellfish aquaculture	Not applicable
Maji et al. (2016)	India	Isolation and in vitro screening of freshwater fish probiotics	*Lactobacillus*, *Pediococcus*, *Weissella*, *Enterococcus* isolates	Five freshwater carp species	In vitro screening (Dose/duration N/A)
Shefat (2018)	Bangladesh	Review of commercial probiotic use in shrimp farming	Commercial probiotic products	Shrimp aquaculture	Not applicable
Yi et al. (2018)	China	Feeding and bacterial-challenge experiment	*Bacillus velezensis JW*	*Carassius auratus*	10^7 and 10^9 CFU/g feed for 4 weeks

Study	Location	Study Focus	Probiotic Strain /Formulation	Host Species / System	Dose, Administration & Duration
Zhang et al. (2019)	China	Feeding, growth, immunity, and challenge experiment	*Bacillus velezensis LF01*	*Oreochromis niloticus*	1×10^9 CFU/g feed; continuous or 3-wk interval for 9 weeks
Hasan and Banerjee (2020)	India	Review of probiotics as growth, immunity, and gut health mediators	Multiple probiotic genera and formulations	Freshwater fish aquaculture	Not applicable
Chowdhury and Roy (2020/2021)	Bangladesh (Sylhet)	Cage-feeding experiment and multistrain dose optimization	Commercial multistrain (LAB, *B. subtilis, B. licheniformis*, yeasts, fungi, vitamins, enzymes)	*Pangasianodon hypophthalmus*	0.10%, 0.15%, 0.20%, 0.25% of diet; feed administration in cages for 12 weeks
Govindaraj et al. (2021)	India	Isolation, in vitro screening, mucus-adhesion, Artemia carrier testing	*Limosilactobacillus fermentum* URLP18 and other LAB	Isolates from five freshwater fish species	In vitro & Artemia carrier test (Dose/duration N/A)
Zhu et al. (2021)	China	Immersion, immune response, water quality, challenge experiment	*Bacillus velezensis CPA1-1*	*Macrobrachium nipponense*	10^5, 10^6, 10^7 CFU/mL; immersion for 20 days
Salma et al. (2022)	Bangladesh (Rajshahi, Bagmara, Durgapur, Puthia)	Field assessment of aqua-chemicals and probiotics as sustainable inputs	Commercial aqua-chemicals and probiotic products	Freshwater aquaculture farms	Not reported
Sam-on et al. (2023)	Malaysia	Whole-genome sequencing and genome-based characterization	*Bacillus velezensis FS26*	*Macrobrachium rosenbergii* isolate	Genome screening (Dose/duration N/A)
Hossain et al. (2023)	Bangladesh (Mymensingh, Rajshahi, Jashore, Cumilla)	Assessment of probiotic status, challenges, and future potential	Commercial and farm-level probiotic products	Freshwater aquaculture systems	Not reported
Gaffar et al. (2023)	Bangladesh	Aquarium and pond evaluation of commercial/lab probiotics	Two commercial products and lab formulation (*B. subtilis*, *L. buchneri*, *L. plantarum*)	*Mystus cavasius*	1 mL/L initially & alternate days; 8 wks (aquaria) / 16 wks (ponds)
Qiu et al. (2023)	China	Biofloc, water quality, growth, immunity, microbiota experiment	*Bacillus subtilis* and effective-microorganism consortium	*Macrobrachium rosenbergii*	10^9 CFU/mL every 6 days; water/biofloc administration for 60 days
Gao et al. (2024)	China (Jiangsu)	Isolation and comprehensive screening of marine candidate probiotics	*B. subtilis P8/P29/P30*, *B. velezensis P12*, *Prestia flexa P21*, *Cytobacillus firmus P23*	Shrimp, water, sediment isolates; safety evaluated in *Ctenopharyngodon idella*	In vitro & safety assessment (Production dose N/A)
Asha et al. (2024)	Bangladesh	Biofloc experiment comparing commercial probiotic formulations	*Bacillus* spp.; *Bacillus*+LAB+*Nitrosomonas*+*Nitrobacter*; *Bacillus*+enzymes	*Oreochromis niloticus*	1 L activated formulation / 200-L tank every 15 days for 90 days
Rasul et al. (2025)	Bangladesh (Mymensingh, Trishal, Phulpur, Muktagacha)	Field assessment of probiotics and chemicals in disease management	Commercial probiotics, chemicals, and disease-management products	Freshwater aquaculture farms	Not reported
Ferdous et al. (2025)	Bangladesh	Water-applied probiotic experiment on growth, physiology, tissue	*B. subtilis*, *B. thuringiensis*, *L. plantarum*, *L. buchneri*	*Labeo rohita*	0.5 and 1.0 mL/L; water administration for 60 days
Halder et al. (2026)	Bangladesh	Comparative assessment of probiotic vs antibiotic gut microbiota changes	Probiotic and antibiotic treatments	Freshwater aquaculture species	Not reported

LAB, lactic acid bacteria; CFU, colony-forming units; N/A, not applicable.

Regardless of the already conducted studies, there are still several major gaps in the use of probiotics within the Asian freshwater aquaculture. To begin with, the majority of research is centered on bacterial probiotics, whereas other microbial communities, including fungi (mycobiome) and viruses (virome), although also being important to aquatic ecosystems, are underexplored.

Second, little is known of the intricate interactions between probiotics and host organisms as well as dynamic environmental factors. Three-way interaction is an important factor that affects probiotic efficacy but has not been well defined.

Third, most of the studies are performed in controlled laboratory circumstances, and little research is done at the field level to validate the effectiveness of probiotics in practical farming systems. Also, the dependence on foreign probiotic preparations points to the absence of geographically and host-specific strains that could be used in local aquaculture.

Lastly, the mechanistic understanding of the way probiotics provide their benefits on molecular and genomic level is still in development, which hinders their use in a specific and efficient manner. While extensive literature highlights probiotics as sustainable alternatives to antibiotics, this review uniquely bridges major gaps by providing a synthesized evaluation focused specifically on Asian freshwater aquaculture systems. Most existing reviews focus broadly on commercial marine systems or generalized global freshwater models. This synthesis specifically contextualizes the unique eco-aquaculture practices of Asian freshwater systems, addressing regional strain selection, indigenous pond dynamics, and low-cost farm-level administration. Unlike previous publications that evaluate fish growth, mucosal immunity, or water quality in isolation, this review synthesizes the host-microbiome-environment interaction matrix as an interdependent system, highlighting how probiotic strains simultaneously modulate gut microbiota, water

biofiltration (breakdown), and disease resilience. This review explicitly connects probiotic application in Asian freshwater farming by detailing how replacing prophylactic antibiotics directly mitigates the environmental spread of antimicrobial resistance (AMR) genes into aquatic food webs and human clinical pathways.

Materials and methods

Review design and literature collection

This study used a structured narrative-review design on the use of probiotics in Asian freshwater aquaculture. Peer-reviewed journals, reports, and institutional publications were searched to gather relevant literature. The databases like Web of Science, Scopus, Google Scholar, and FAO repositories were taken into consideration to find scientific articles on the topics of probiotics, aquaculture practices, the use of antibiotics, and management of fish health. The literature search involved the use of keywords such as probiotics in aquaculture, Asian freshwater aquaculture, fish diseases, antibiotic resistance in aquaculture, and microbial bioremediation in fish farming. Studies published since 2000 were given priority over older foundational studies but where needed, older studies were accommodated to give a historical perspective (e.g., Ringø and Gatesoupe 1998; Sahu et al. 2008).

Eligibility criteria

Studies were eligible when they (i) addressed freshwater aquaculture in Asia; (ii) evaluated probiotic administration through feed, water, or immersion; (iii) reported growth, feed utilization, immunity, disease resistance, gut condition, survival, or water-quality outcomes; and (iv) provided experimental, observational, or clearly described review evidence. Marine-only reports, studies without an interpretable method, and non-English papers lacking an accessible English translation were excluded.

Data extraction and synthesis

Thematic areas were identified and relevant information of the chosen studies was extracted and categorized such as (i) Sources and types of probiotics (e.g., *Bacillus, Lactobacillus*, yeasts) and (ii) Methods of probiotic application, (iii) Effects on fish health, growth performance and immunity, (iv) Effects on the water quality and pond life, and (v) Comparison with the use of antibiotics. Qualitative synthesis of data was made to determine patterns, trends and gaps in research. Probiotic and antibiotic applications in aquaculture systems were compared in terms of their application in aquaculture systems mainly in Asian countries, including Bangladesh, China, India, Vietnam, and Thailand (Rico et al. 2013; Liu et al. 2017; Chowdhury et al. 2022).

Descriptive and comparative synthesis

For the detailed quantitative synthesis, primary studies were coded according to publication year, country, cultured species, probiotic genus and strain, dosage, administration route, experimental duration, study setting, measured outcomes and proposed mechanisms. Review articles, marine-only studies and papers without sufficient study-level information were not included in the numerical analysis. Frequencies and percentages were calculated to describe publication trends, geographical distribution, cultured species, probiotic groups, administration routes and outcome categories. Because an individual study could investigate more than one probiotic group or outcome, percentages for these categories were not required to total 100%. A structured comparative synthesis was also conducted to examine differences between *Bacillus* and lactic acid bacteria, host-derived and commercial probiotics, single-strain and multistrain formulations, feed-based and water-based administration, and controlled and field-based studies.

Classification of probiotic application

Applications of probiotics were divided into groups according to their route of administration including (i) Feed supplementation- probiotics added to fish food to improve gut microbiota, digestion and immunity (Balcázar et al. 2006; Nayak 2010), (ii) Application of water - probiotics are directly applied to culture water to enhance the quality of the water and decrease the number of pathogenic organisms (Hlordzi et al. 2020), and (iii) Immersion methods - probiotics used in early stages of life to enhance colonization and resistance to diseases (Hoseinifar et al. 2018).

Analytical framework

The literature gathered was reviewed in the following frameworks: such as (i) Health performance indices: growth rate, feed to weight ratio (FCR), survival rate, and immune response (Amenyogbe 2023; Mohamed et al. 2025), (ii) Microbial interactions: probiotic-pathogen, antimicrobial compounds, and gut colonization (Sahu et al. 2008; Zorriehzahra et al. 2016), (iii) Environmental effects: alteration of the ammonia, nitrite, and organic matter concentrations in the aquaculture systems (Kumar et al. 2016; Qiu et al. 2023), and (iv) Antibiotic comparison: prevalence, risks, and patterns of resistance related to the use of antibiotics in aquaculture (Lulijwa et al. 2020; Malik et al. 2023).

Results

The review indicates that probiotics are gaining popularity as an effective and sustainable alternative to antibiotics in Asian freshwater aquaculture, and it has several advantages in terms of fish health, production efficacy, and environmental control. The application of probiotics is aimed at improving host health by enhancing disease resistance, promoting growth and reproduction, and improving the microbial composition of the surrounding water (Fig. 2).

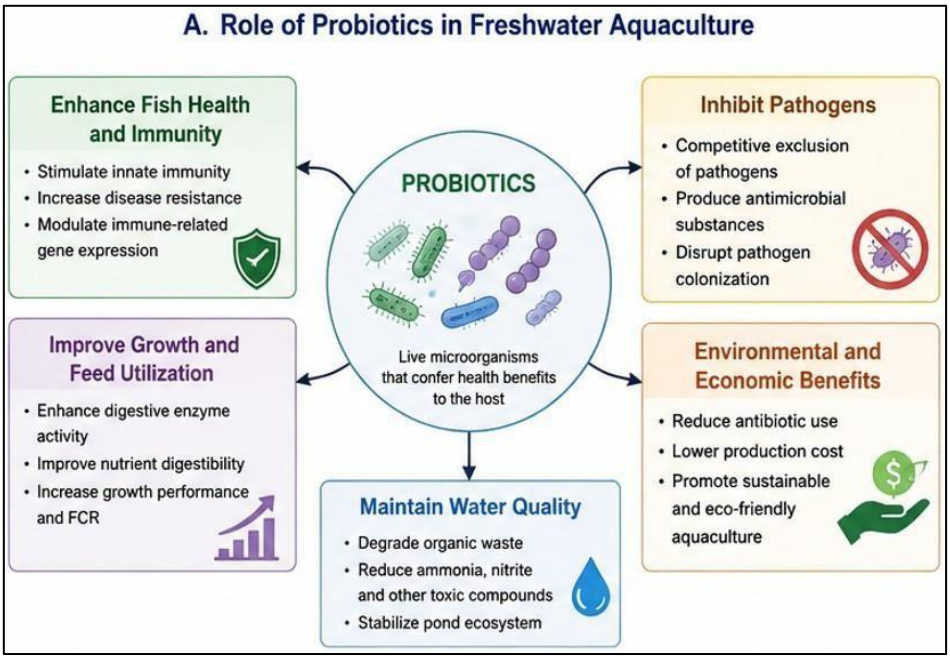


Fig. 2. Roles of probiotics in freshwater aquaculture (generated by AI).

Profile of the evidence base

A total of 12 primary studies published between 2014 and 2025 met the review criteria and provided sufficient study-level information for the detailed quantitative synthesis (Saini et al. 2014; Maji et al. 2016; Yi et al. 2018; Zhang et al. 2019; Chowdhury and Roy 2020; Govindaraj et al. 2021; Zhu et al. 2021; Gaffar et al. 2023; Qiu et al. 2023; Sam-on et al. 2023; Asha et al. 2024; Ferdous et al. 2025), as shown in Fig. 3.

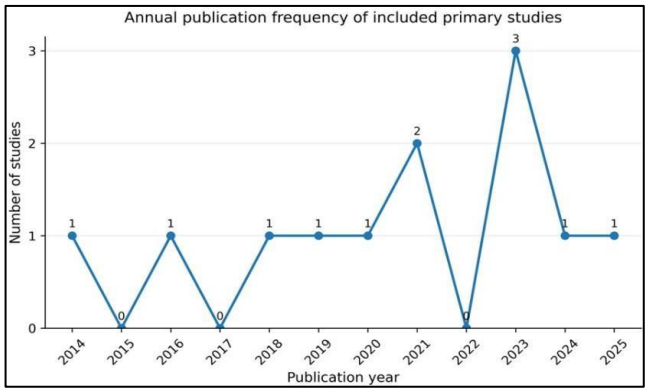


Fig. 3. Annual publication frequency of the primary studies included in the detailed quantitative synthesis (Saini et al. 2014; Maji et al. 2016; Yi et al. 2018; Zhang et al. 2019; Chowdhury and Roy 2020; Govindaraj et al. 2021; Zhu et al. 2021; Gaffar et al. 2023; Qiu et al. 2023; Sam-on et al. 2023; Asha et al. 2024; Ferdous et al. 2025).

Four studies, representing 33.3% of the evidence base, were published during 2014-2019, whereas eight studies, or 66.7%, were published during 2020-2025. This distribution indicates a substantial increase in research attention during the most recent six-year period.

Bangladesh and China each contributed four studies, accounting for 33.3% of the included evidence, while India contributed three studies, or 25.0%, and Malaysia contributed one study, or 8.3%. No eligible primary application study in the detailed evidence matrix was identified from Indonesia, Thailand, Vietnam, the Philippines, Pakistan, Nepal, Sri Lanka, Myanmar, Japan or Korea. Therefore, although the review addresses Asian freshwater aquaculture, its detailed experimental evidence is concentrated in four countries (Fig. 4).

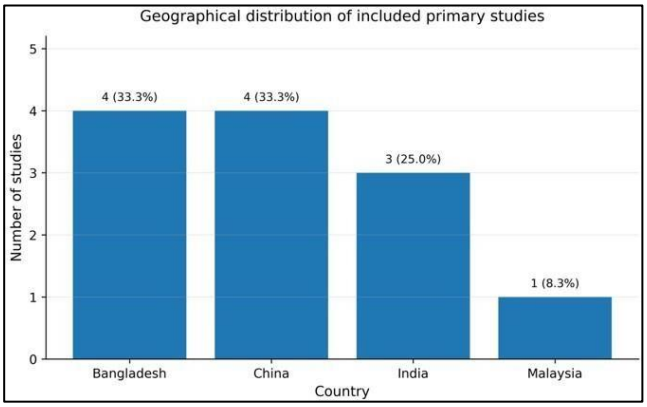


Fig. 4. Geographical distribution of the primary studies included in the detailed quantitative synthesis (Saini et al. 2014; Maji et al. 2016; Yi et al. 2018; Zhang et al. 2019; Chowdhury and Roy 2020; Govindaraj et al. 2021; Zhu et al. 2021; Gaffar et al. 2023; Qiu et al. 2023; Sam-on et al. 2023; Asha et al. 2024; Ferdous et al. 2025).

Nine of the 12 studies, or 75.0%, are involved in vivo probiotic administration, while three studies, or 25.0%, are involved in vitro screening or genomic characterization (Fig. 5).

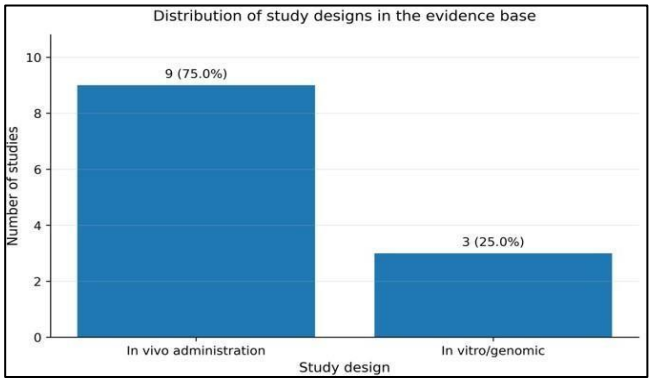


Fig. 5. Distribution of *in vivo* and *in vitro*/genomic study designs (Saini et al. 2014; Maji et al. 2016; Yi et al. 2018; Zhang et al. 2019; Chowdhury and Roy 2020; Govindaraj et al. 2021; Zhu et al. 2021; Gaffar et al. 2023; Qiu et al. 2023; Sam-on et al. 2023; Asha et al. 2024; Ferdous et al. 2025).

Among the nine in vivo studies, Rohu and Nile Tilapia were each investigated in two studies, representing 22.2% each. Freshwater prawns were also investigated in two studies, or 22.2%, while goldfish, striped catfish and Gangetic mystus were each examined in one study, representing 11.1% each. Thus, a limited number of commercially important species dominated the available experimental evidence.

Among the nine in vivo studies, feed supplementation was used in four studies, representing 44.4%, while direct water application was used in four studies, also representing 44.4%. One study, or 11.1%, used immersion administration (Fig. 6). Growth performance or feed-utilization outcomes were assessed in seven studies, representing 77.8% of the in vivo evidence. Immune responses were assessed in six studies, or 66.7%; disease resistance was tested in four studies, or 44.4%; gut microbiota or intestinal morphology was evaluated in five studies, or 55.6%; and water-quality outcomes were assessed in four studies, or 44.4%. Only one study, representing 11.1%, conducted a formal economic analysis (Fig. 7).

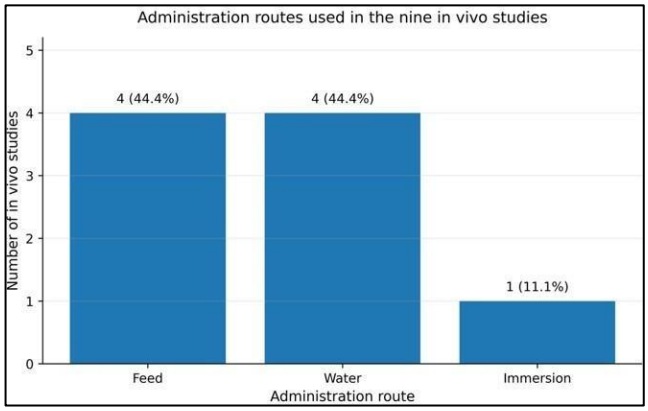


Fig. 6. Administration routes used in the nine *in vivo* studies (Saini et al. 2014; Maji et al. 2016; Yi et al. 2018; Zhang et al. 2019; Chowdhury and Roy 2020; Govindaraj et al. 2021; Zhu et al. 2021; Gaffar et al. 2023; Qiu et al. 2023; Sam-on et al. 2023; Asha et al. 2024; Ferdous et al. 2025).

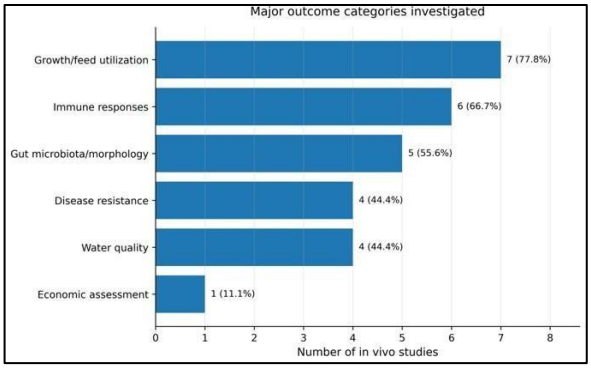


Fig. 7. Major outcome categories in the nine *in vivo* studies; categories overlap (Saini et al. 2014; Maji et al. 2016; Yi et al. 2018; Zhang et al. 2019; Chowdhury and Roy 2020; Govindaraj et al. 2021; Zhu et al. 2021; Gaffar et al. 2023; Qiu et al. 2023; Sam-on et al. 2023; Asha et al. 2024; Ferdous et al. 2025).

Among the studies that reported sufficient microbial-composition information, *Bacillus* occurred in eight studies and was the most frequently investigated probiotic genus. Lactic acid bacteria, including *Lactobacillus*, *Limosilactobacillus*, *Pediococcus*, *Weissella* and *Enterococcus*, occurred in five studies. These categories overlapped because several multistrain formulations contained both *Bacillus* and lactic acid bacteria (Fig. 8).

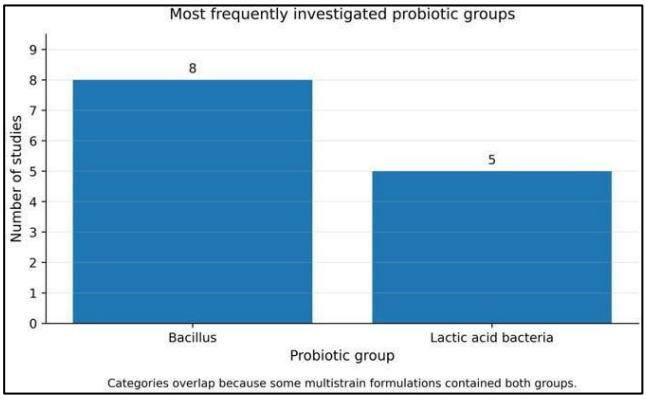


Fig. 8. Most frequently investigated probiotic groups; multistrain products create overlaps (Saini et al. 2014; Maji et al. 2016; Yi et al. 2018; Zhang et al. 2019; Chowdhury and Roy 2020; Govindaraj et al. 2021; Zhu et al. 2021; Gaffar et al. 2023; Qiu et al. 2023; Sam-on et al. 2023; Asha et al. 2024; Ferdous et al. 2025).

Four studies used a bacterial challenge model. *Aeromonas hydrophila* was used in two of these studies, representing 50.0% of the challenge evidence, while *Streptococcus agalactiae* and non-O1 *Vibrio cholerae* were each used in one study, representing 25.0% each. No eligible viral or parasitic challenge trial was represented in the detailed evidence matrix (Fig. 9).

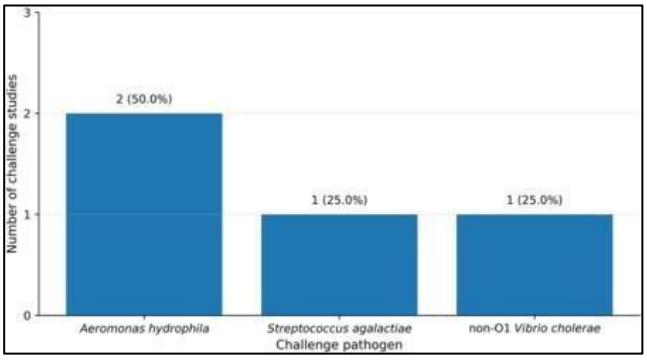


Fig. 9. Bacterial pathogens represented in challenge experiments (Saini et al. 2014; Maji et al. 2016; Yi et al. 2018; Zhang et al. 2019; Chowdhury and Roy 2020; Govindaraj et al. 2021; Zhu et al. 2021; Gaffar et al. 2023; Qiu et al. 2023; Sam-on et al. 2023; Asha et al. 2024; Ferdous et al. 2025).

Critical comparison of probiotic groups and applications

Bacillus-based probiotics showed the broadest range of reported functions across the reviewed studies. Dietary *Bacillus velezensis* enhanced immune-enzyme activities, immune-related gene expression and survival following bacterial challenge in goldfish and Nile tilapia (Yi et al. 2018; Zhang et al. 2019). Water or immersion application of *B. velezensis* and *B. subtilis* also improved selected immune, digestive and water-quality indicators in freshwater prawn systems (Zhu et al. 2021; Qiu et al. 2023). The ability of *Bacillus* species to form spores may improve their stability during feed processing, transportation and storage. However, these advantages should not be generalized to the entire genus because antimicrobial-metabolite production, host adhesion, environmental persistence and biosafety remain strain-specific.

Lactic acid bacteria were more frequently associated with intestinal adhesion, organic-acid production, bacteriocin production, digestive-enzyme activity and competitive exclusion of pathogens. Maji et al. (2016) identified *Lactobacillus*, *Pediococcus*, *Weissella* and *Enterococcus* isolates with acid and bile

tolerance and antagonistic activity against *A. hydrophila*. Similarly, Govindaraj et al. (2021) reported that *Limosilactobacillus fermentum* URLP18 tolerated highly acidic and bile-salt conditions, adhered to intestinal mucus and produced amylase, protease and lipase. Nevertheless, much of the evidence for lactic acid bacteria was obtained from in vitro screening rather than long-term farm trials. Moreover, probiotic status does not automatically establish safety because aquatic lactic acid bacteria, particularly some *Enterococcus* isolates, may carry antibiotic-resistance or virulence-associated determinants (Muñoz-Atienza et al. 2013). The findings also demonstrated that probiotic responses were dose-dependent rather than uniformly linear. In rohu, dietary supplementation with a commercial probiotic mixture at 4 g/kg produced the strongest growth and disease-resistance response, while increasing the dose to 5 g/kg did not produce an additional benefit (Saini et al. 2014). In striped catfish cage culture, supplementation at 0.20% produced the most favorable growth, feed-conversion and economic outcomes, while 0.25% did not significantly outperform the lower dose (Chowdhury and Roy 2020). These results indicate that increasing probiotic concentration beyond an optimal level may increase production costs without improving biological performance.

Formulation was another important source of variation. Gaffar et al. (2023) found that a laboratory-developed formulation containing *Bacillus subtilis*, *Lactobacillus buchneri* and *L. plantarum* produced stronger growth and intestinal responses than one of the commercial preparations tested in Gangetic mystus. In Nile tilapia biofloc culture, a formulation containing *Bacillus species* combined with digestive enzymes produced better weight gain, intestinal morphology and beneficial bacterial counts than the other commercial formulations (Asha et al. 2024). Multistrain formulations may therefore provide complementary functions, but a greater number of microorganisms do not automatically produce a better result. Strain incompatibility, unequal survival during storage, inaccurate viable cell counts and poor adaptation to the host or culture environment may reduce their performance.

Administration route influenced the location and type of benefit. Feed supplementation mainly targeted the gastrointestinal tract and was commonly associated with improved digestion, growth, intestinal condition and systemic immunity. Water and immersion applications affected both the animal and the culture environment and were more frequently associated with changes in ammonia, nitrite, biofloc microbial communities and environmental pathogen pressure (Zhu et al. 2021; Qiu et al. 2023; Asha et al. 2024). However, water-applied probiotics may be diluted, removed during water exchange or outcompeted by resident microorganisms. Their effectiveness may therefore be more sensitive to temperature, pH, oxygen, carbon availability and stocking density.

Finally, results obtained under controlled laboratory conditions cannot automatically be transferred to commercial farms. Laboratory trials control feed, temperature, stocking density, microbial exposure and water quality, whereas farm performance is affected by seasonal variation (Rahman et al. 2014; Siddik et al. 2014), pond microbiota, feed quality, rainfall, water exchange, disease history and farmer management practices. The successful field-cage trial reported by Chowdhury and Roy (2020) and the combined aquarium and pond experiments conducted by Gaffar et al. (2023) are therefore particularly valuable. Nevertheless, the small number of field studies remains insufficient to establish the long-term reliability of probiotic products across Asian freshwater farming systems.

Antibiotic-sparing potential and environmental risk

The results show that antibiotic resistance, environmental pollution, and food safety issues are the consequences of overuse of antibiotics in Asian aquaculture (Liu et al. 2017; Chowdhury et al. 2022). This reduction is important because resistant bacteria and resistance genes persist in aquaculture environments, creating long-term reservoirs of antimicrobial resistance (Mohammed et al. 2025). The antibiotics that are used in Asian aquaculture according to the reviewed papers are summarized in Table 2.

Table 2. Antibiotics reported in Asian aquaculture studies.

Country	Antibiotics reported	References
Bangladesh	Oxytetracycline, ciprofloxacin, amoxicillin, levofloxacin, erythromycin, sulfadiazine, trimethoprim, chlortetracycline, doxycycline, cotrimoxazole	Ali et al. (2016); Chowdhury et al. (2022); Hossain et al. (2022)
China	Enrofloxacin, norfloxacin, ciprofloxacin, oxytetracycline, tetracycline, florfenicol, sulfamethoxazole, sulfadiazine, amoxicillin, doxycycline, erythromycin	Rico et al. (2013); Liu et al. (2017)
India	Oxytetracycline, ciprofloxacin, chloramphenicol, ampicillin, gentamicin, cefuroxime, cotrimoxazole, nalidixic acid, tetracycline	Done et al. (2015); Hossain et al. (2022); Malik et al. (2023)
Vietnam	Enrofloxacin (69% farmers), florfenicol (63%), sulfamethoxazole+trimethoprim (44%), doxycycline (34%), amoxicillin, cephalexin, gentamycin, ciprofloxacin, oxytetracycline	Rico et al. (2013); Huong et al. (2021); Lulijwa et al. (2020)
Thailand	Oxytetracycline, norfloxacin, enrofloxacin, amoxicillin, sulfonamides, trimethoprim, florfenicol	Rico et al. (2013); Rico et al. (2014); Malik et al. (2023)
Malaysia	Oxytetracycline, tetracycline, doxycycline, enrofloxacin, ciprofloxacin, norfloxacin, sulfamerazine, sulfathiazole, nalidixic acid, ofloxacin, lincomycin	Thiang et al. (2021); Hossain et al. (2022)
Indonesia	Quinolones, penicillin, sulfonamides, tetracyclines, erythromycin, chloramphenicol	Done et al. (2015); Malik et al. (2023)
Sri Lanka	Oxytetracycline, tetracycline, amoxicillin, erythromycin, sulfamethoxazole, sulfadiazine	Manage (2018); Hossain et al. (2022)
Philippines	Oxytetracycline, chloramphenicol (banned), oxolinic acid, sulfadiazine, trimethoprim, erythromycin	Rico et al. (2012); Lulijwa et al. (2020)

Probiotics, on the contrary, are a non-antibiotic approach to disease management because they inhibit pathogens, without encouraging the development of resistance (Martinez Cruz et al. 2012). This change is especially significant since the prevalence of resistant genes (e.g., tet, sul) and antibiotic residues in aquaculture systems is common in Asia (Suzuki et al. 2019; Cheng et al. 2021).

Growth performance and feed utilization

Probiotic supplementation considerably enhances the growth parameters, feed conversion ratio (FCR), and nutrient utilization in cultured fish. Researchers have found that there are improvements in digestive enzyme activities (proteins: protease, amylase, lipase) and that it led to enhanced digestion and nutrient absorption (Elsabagh et al. 2018; Amenyogbe 2023). The improvements in growth are: (i) Higher specific growth rate (SGR), (ii) Greater weight gain and (iii) Better feed efficiency. These results affirm the role of probiotics as good growth promoters in various species including Nile tilapia and rohu (Saini et al. 2014; Elsabagh et al. 2018; Zibiene and Zibas 2019; Ferdous et al. 2025; Mohamed et al. 2025). Because dietary preference and food overlap change with fish size in carp polyculture, growth responses should be interpreted in relation to life stage and culture system (Rahman et al. 2009; Raina et al. 2026).

Feed Conversion Ratio (FCR) is defined as the amount of feed required to produce a unit gain in body weight of fish, and it is used as a key indicator of feed utilization efficiency (Elsabagh et al. 2018; Zibiene and Zibas 2019). It is calculated as:

$$\text{FCR} = \text{Total feed intake (g)} / \text{Weight gain (g)}$$

A lower FCR value indicates better feed efficiency and utilization, whereas a higher FCR reflects poor feed conversion. In probiotic-supplemented diets, FCR values for tilapia and rohu generally range between 1.2-2.0, compared to 2.0-3.0 in non-supplemented (control) groups (Saini et al. 2014; Ferdous et al. 2025; Mohamed et al. 2025).

Specific Growth Rate (SGR) is defined as the percentage increase in body weight per day over the culture/experimental period, reflecting the daily growth rate of fish (Zibiene and Zibas 2019; Amenyogbe 2023). It is calculated as:

$$\text{SGR (\%/day)} = [(\ln \text{Final weight} - \ln \text{Initial weight}) / \text{Culture period (days)}] \times 100$$

Higher SGR values indicate faster and more efficient growth. Probiotic-fed Nile tilapia and rohu typically show SGR values in the range of 2.5-4.5%/day, compared to 1.5-2.5%/day in control groups fed without probiotics (Saini et al. 2014; Elsabagh et al. 2018; Ferdous et al. 2025; Mohamed et al. 2025). Feeding regime itself strongly influences tilapia growth in pond culture and should therefore be standardized when probiotic effects are compared (Khan et al. 2026).

Immunity and disease resistance

Probiotics increase the innate and adaptive immune responses of fish as they activate immune parameters like the activity of lysozyme, phagocytosis, complement system, and cytokine expression (Zorriehzahra et al. 2016; Hasan and Banerjee 2020). For example, (i) Fish treated with probiotics have a reduced mortality rate when they are challenged with a pathogen, and (ii) *Aeromonas hydrophila* and *Streptococcus spp*. are the major pathogens that are observed to be very resistant (Saini et al. 2014; Zorriehzahra et al. 2016; Yi et al. 2018; Azad et al. 2021; Mohamed et al. 2025). Diseases of Asian freshwater aquaculture that are being reviewed in this article are summarized in Table 3. Therefore, probiotics are natural immunostimulants that enhance disease resistance (Fig. 10).

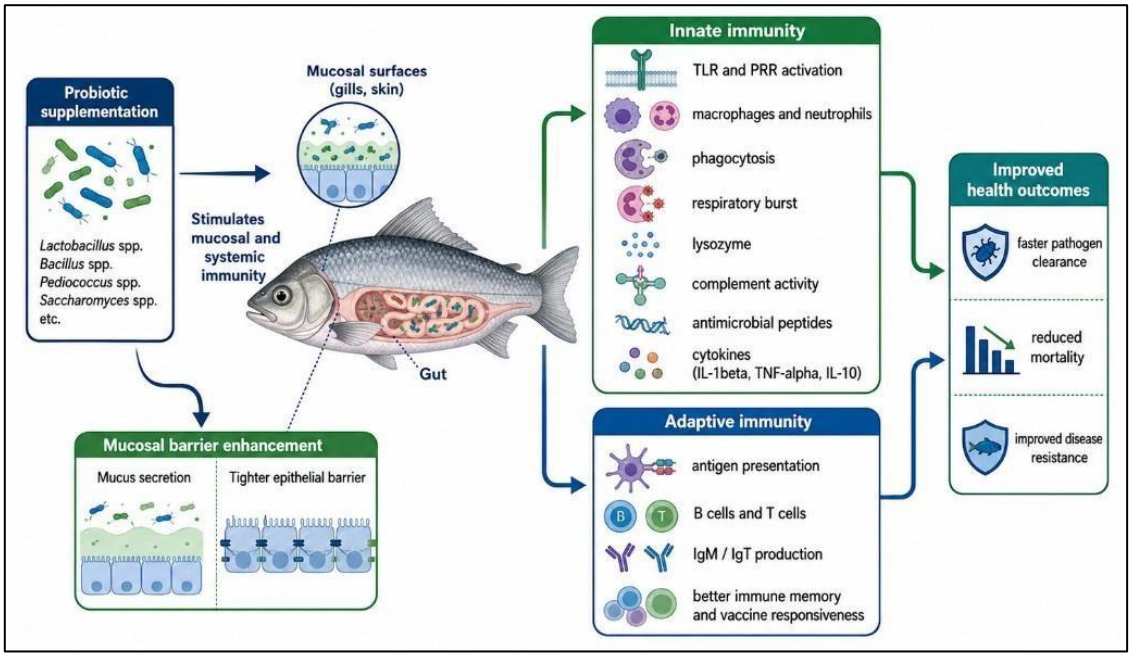


Fig. 10. Immunological pathway after applying probiotics (generated by AI).

Antimicrobial activity against pathogens

The research finds that probiotics have potent antimicrobial effects by: (i) Bacteriocin production, organic acid production, and H_2O_2 production, (ii) Pathogen competitive exclusion, and (iii) Interruption of pathogen quorum sensing systems. *Bacillus velezensis* and *Lactobacillus plantarum* strains exhibit broad-spectrum antagonistic properties against key aquaculture pathogens, minimizing disease occurrence without chemicals (Maji

et al. 2016; Zhang et al. 2019). The pathway through which probiotics reduce antimicrobial resistance (AMR) is illustrated in Fig. 11.

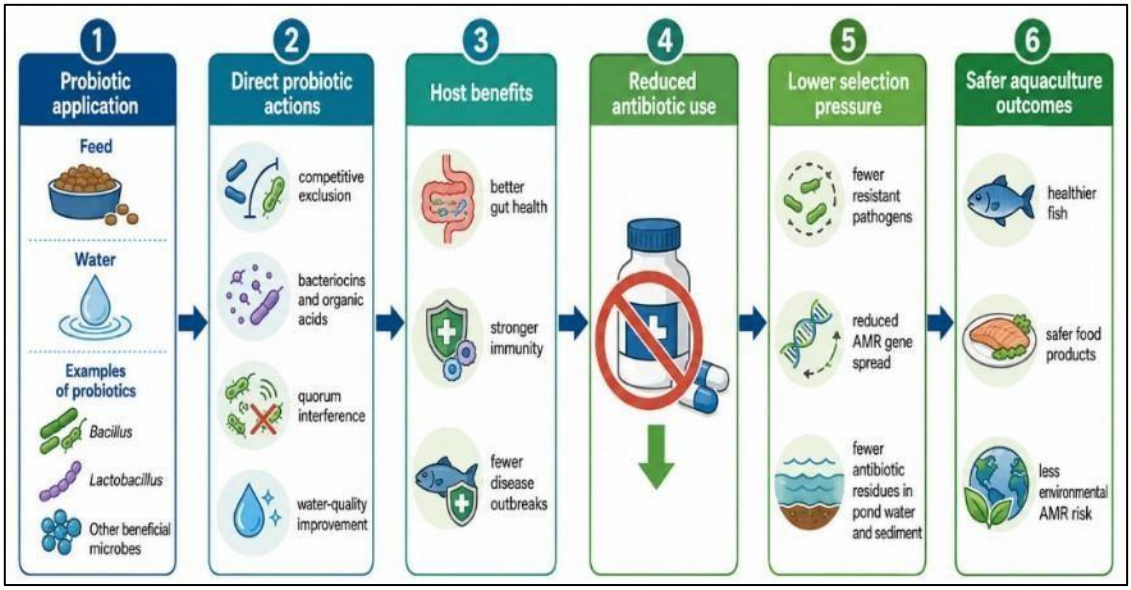


Fig. 11. Pathway of reducing antimicrobial resistance (AMR) via probiotics in aquaculture (generated by AI).

Water quality and pond ecology

One of the main discoveries is that probiotics have a dual function of bioremediators. They: (i) Lower ammonia, nitrite and organic waste, (ii) facilitate the nitrification processes through bacteria like *Nitrosomonas* and *Nitrobacter* and (iii) enhance dissolved oxygen and stabilization of pH. This results in healthier pond ecology, less environmental stress and healthier fish. Others found up to half the reduction of ammonia levels, which proved to be of great environmental value (Sahu et al. 2008; Zhou et al. 2009; Tuan et al. 2013; Kumar et al. 2016; Zorriehzahra et al. 2016; Qiu et al. 2023; Hlordzi et al. 2020; Mathew et al. 2025; Rudoy et al. 2025; Sharma et al. 2025). In earthen ponds, benthic feeding activity, nutrient resuspension and plankton dynamics also shape water quality, so probiotic effects should be interpreted alongside species composition and pond management (Rahman et al. 2008; Khan et al. 2024). The effects of probiotics on pond ecology are illustrated in Fig. 12.

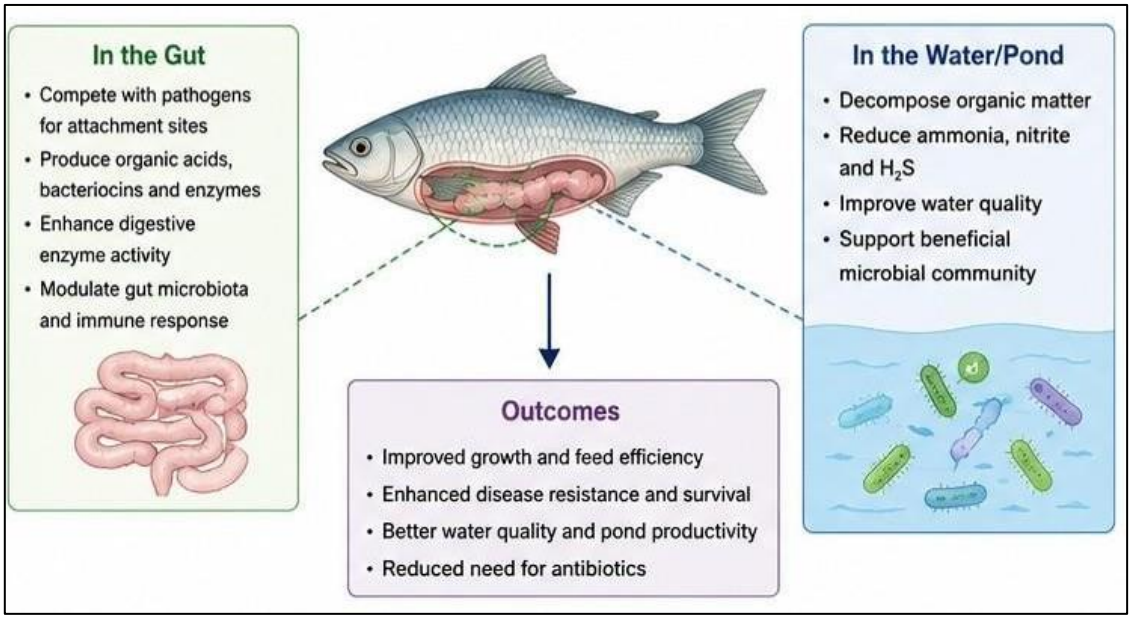


Fig. 12. Mechanisms of probiotic action in the host and environment (generated by AI).

Economic and production implications

The results show that probiotics can (i) raise survival and production rate, (ii) lower cost of treating disease and (iii) enhance farmers profitability. As an illustration, the use of probiotics in shrimp culture has been linked to the decrease in the amount of antibiotics used and increase in larval production (Vijayakumaran 2001). Reliable hatchery production is also important because indiscriminate exploitation of wild prawn postlarvae threatens fisheries resources, community livelihoods and biodiversity in Bangladesh (Ahamed et al. 2012).

Dominant probiotic groups

The review indicates that *Bacillus spp.* and lactic-acid bacteria are the most frequently represented probiotic groups in freshwater aquaculture because of their: (i) High environmental tolerance, (ii) Enzyme production ability and (iii) High antimicrobial activity (Fig. 13).

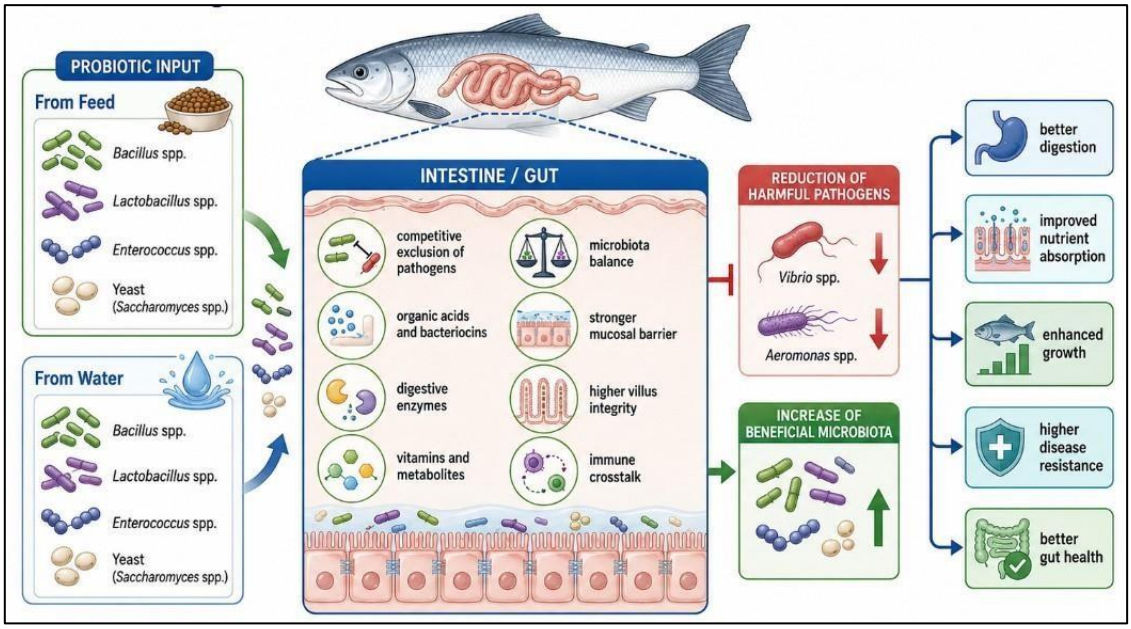


Fig. 13. Gut microbiome-probiotic interactions in aquaculture (generated by AI).

Most of the commercial probiotics formulations in use in Asia revolve around these groups (Irianto and Austin 2002; Sahu et al. 2008; Zorriehzahra et al. 2016; Das et al. 2017; Govindaraj et al. 2021; Mohamed et al. 2025). Table 4 summarizes the commercial probiotic strains and their trade names from the reviewed articles.

Genomics and probiotic selection

Recent discoveries have focused on the significance of genomic and molecular characterization of probiotic strains. Genomics assists: (i) To locate advantageous clusters of genes (e.g. antimicrobial peptides), (ii) To ascertain that there are no virulence or resistance genes and (iii) To create selective probiotics that are specific to host species. This is a change to next-generation, targeted probiotic uses in aquaculture (Ghosh et al. 2018; Kochetkov et al. 2024; Prazdnova et al. 2025; Rudoy et al. 2025)

Current limitations and research gaps

Although the results are promising, there are several limitations: (i) Absence of large-scale field validation, (ii) Inadequate knowledge about host-microbe-environment interactions, (iii) The need of region-specific and host-derived probiotics, and (iv) Under researched functions of fungi and viruses in probiotic systems. To maximize the utilization of probiotics in Asian aquaculture systems, it is necessary to address these gaps.

Discussion

This review emphasizes the increasing significance of probiotics as alternatives to antibiotics in the freshwater aquaculture of Asia. This shift has become even more pronounced in response to the rapid growth and intensification of aquaculture, which is currently mostly conducted in Asia where the majority of global aquaculture production takes place, including increased disease outbreaks, greater use of antibiotics, antimicrobial resistance (AMR), contamination of the environment and food safety concerns. Literature, however, varies in its elucidation of the primary reasons behind these issues. Rico et al. (2014) and Liu et al. (2017) mainly blame heavy antibiotic use on production intensification, which increases the stress and disease risk on fish, making them more susceptible to antibiotic use. Chowdhury et al. (2022) and Malik et al. (2023), on the contrary, focus more on weak veterinary services, inadequate monitoring and poor regulatory enforcement. As such, production intensity builds immediate disease pressure, whereas the adoption of inappropriate antibiotics is widespread primarily in the absence of good governance and professional oversight. Lulijwa et al. (2020) offer a more comprehensive view, stating that the pressure of production and weak regulations are not singular but intertwined. Overall, evidence points to an intensification that can create the need for a disease-control measure and a governance failure that will result in the responsible or indiscriminate use of antibiotics. This distinction is essential as it gives context to the synthesis of the major findings, evaluation of the existing evidence and the identification of the key research gaps in the use of probiotics in sustainable freshwater aquaculture (Rico et al. 2014; Liu et al. 2017; Lulijwa et al. 2020; Chowdhury et al. 2022; Malik et al. 2023).

The key lesson of this review is the explicit change in the approach to disease management towards the use of probiotics. Antibiotics have been successful at controlling bacterial infections over time but have resulted in the development of resistant pathogenic bacteria and the accumulation of harmful residues in the aquatic environment and food products (Chowdhury et al. 2022; Lulijwa et al. 2020). Resistance genes, such as tet(A), tet(M), sul1 and sul2, are common in aquaculture systems, emphasising the need for a shift towards alternative and safer feed products (Suzuki et al. 2019; Cheng et al. 2021). In this particular aspect, probiotics offer a multifaceted solution as they promote host immunity, growth rates, and keep the environment balanced without inducing resistance (Martinez Cruz et al.

2012; Mohamed et al. 2025). But this idea of probiotics being essentially nonresistant is not shared by everyone. Martinez Cruz et al. (2012) and Mohamed et al. (2025) argue that probiotics represent an alternative to the use of antibiotics; however, Muñoz-Atienza et al. (2013) directly challenges this assertion by screening aquatic lactic acid bacteria (LAB) and specifically *Enterococcus* isolates for antibiotic resistance or virulence in probiotics themselves. While Chowdhury et al. (2022) and Lulijwa et al. (2020) consider the problem of resistance to be the antibiotic residues and misuse, Muñoz-Atienza et al. (2013) demonstrates that the same risk can be transmitted through the organisms that are meant to provide the solution. The real issue here is not whether antibiotic resistance is a serious issue (all these authors agree), but whether it will not happen to probiotics at all or whether it will just happen to them somewhere else, in a less-examined area.

The mechanisms of beneficial effects of probiotics are diverse and well supported by literature. They are competitive exclusion of pathogens, the synthesis of antimicrobial compounds (e.g., bacteriocins, organic acids), host immune responses regulation, and enhancement of digestive enzyme functions (Balcázar et al. 2006; Hoseinifar et al. 2018). Interestingly, some species have exhibited high levels of antagonism against important fish pathogens like *Bacillus subtilis* and *Lactobacillus plantarum* against *Aeromonas hydrophila*, *Vibrio spp*. and *Streptococcus agalactiae*. These findings agree with the previous findings that fish population treated with probiotics showed significant reduction in the mortality rate and improved resistance to the diseases (Saini et al. 2014). This is a different way of describing the mechanisms than the way later synthesis work describes them, however, as a collection of discrete, additive processes. Competitive exclusion, antimicrobial synthesis, immune regulation and enzyme enhancement are largely regarded as distinct pathways, and in many cases can be investigated and validated individually, and Saini et al. (2014) agrees with this, claiming that probiotic intervention could reduce mortality measurably, without having to deconvolute the mechanism. However, Irianto and Austin (2002), Zorriehzahra et al. (2016), Zhu et al. (2021) and Qiu et al. (2023) disagree, stating that this is not really an isolated mechanism, but a result of one host-microbiome-environment system, where host immune stimulation, gut-level competitive exclusion and the environment all affect each other. The controversy is not whether these mechanisms exist (both groups of authors claim they do) but whether the assumption that they are distinct is a scientifically valid assumption or merely a convenient presentation of the evidence, which, in practice, was produced one mechanism at a time.

Production, in terms of growth performance and feed efficiency, has a significant effect of probiotics. The review reports the increase in certain growth rate (SGR), feed conversion ratio (FCR), and enzyme activities, which implies the improved use of nutrients (Elsabagh et al. 2018; Ferdous et al. 2025). These enhancements have got economic significance, especially to the small-scale farmers in Asia since they translate to high productivity and profitability. Furthermore, probiotics, which possess immunomodulatory properties such as increased lysozyme activity, phagocytic activity and cytokine expression are significant factors that promote improved survivability in intensive farming systems (Zorriehzahra et al. 2016; Hasan and Banerjee 2020). However, this trend of gradual improvement with higher doses of probiotics is not seen consistently in the dosage literature. The growth and feed-efficiency results of Elsabagh et al. (2018) and Ferdous et al. (2025) indicated that there was a linear relationship between the level of the probiotic and the growth and feed-efficiency. However, Saini et al. (2014) reported that the best response was obtained with a lower supplementation of 4 g/kg than a higher 5 g/kg supplementation, and Chowdhury and Roy (2020) also found that supplementation at 0.20% was more economically favorable than supplementation at 0.25%. The first results contradict the notion that "the more, the more" is a reliable strategy when it comes to the benefits of probiotics. The economic claims are similarly not well matched-Elsabagh et al. (2018) and Ferdous et al. (2025) refer to the increases in productivity, which translate into increased profitability for small-scale farmers, but Chowdhury and Roy (2020) is one of the only studies in the evidence base to formally test this hypothesis using a benefit-cost ratio, and thus the wider economic optimism in the literature is built on a narrower and more dose sensitive base than the production data alone would suggest.

Regulatory frameworks and farmer awareness are equally critical to probiotic adoption. Antibiotics remain widely used across Asia due to low cost and effectiveness, with weak governance and poor veterinary oversight enabling their misuse (Chowdhury et al. 2022). Probiotic adoption therefore requires not just scientific validation but supportive policy, training, and economic incentives. This institutional framing contrasts with the more technical focus elsewhere in the literature: Chowdhury et al. (2022) locates the barrier to probiotic uptake in governance failures rather than science, while Kochetkov et al. (2024) and Rudoy et al. (2025) focus almost entirely on genomic strain optimization, largely bypassing farmer willingness to adopt. Both sides agree probiotics should be used more widely but disagree on the binding constraint as Chowdhury et al. (2022) argues even an ideal strain will fail without policy support and training, whereas the genomics-focused view assumes strain quality alone drives adoption.

Based on the evidence presented in this study, probiotic benefits are related to a complex interplay between host, microbiome and environment, not to any single mechanism. Probiotics can be found in the gastrointestinal tract, where they act by competing with pathogens for nutrients and adhesion sites, by secreting bacteriocins, organic acids and other metabolites with inhibitory activity, as well as by providing digestive enzymes that help to increase the bioavailability of nutrients. These microbial effects may strengthen intestinal integrity, alter the composition and activity of the gut microbiota and improve the availability of nutrients to the host. Probiotic-associated molecular patterns and metabolites can activate lysozyme and complement, phagocytosis activity, antioxidant enzymes and cytokine related pathways at the host level. Under culture conditions, the selected strains could be responsible for the breakdown of organic matter, the transformation of ammonia and nitrite, and the suppression of opportunistic microorganisms (Irianto and Austin 2002; Balcázar et al. 2006; Zorriehzahra et al. 2016; Zhu et al. 2021; Qiu et al. 2023). This systems-level presentation is not, however, as it was presented in the earlier

literature. Balcázar et al. (2006) and Hoseinifar et al. (2018) had outlined competitive exclusion, antimicrobial synthesis and immune regulation and enzyme enhancement essentially as distinct pathways which could be tested separately, and Saini et al. (2014) operated within this framework: they stated that probiotics cause measurable mortality reduction but did not need to specify which individual pathway. New work by Irianto and Austin (2002), Zorriehzahra et al. (2016), Zhu et al. (2021), and Qiu et al. (2023) fundamentally changes this view, suggesting that gut-level, host-level and environmental effects are not distinct outputs but are interdependent parts of a single system, where alteration in one affect both the other and environmental outcomes as well. The dispute isn't about the existence of these effects, but both approaches describe the same underlying phenomena but whether they can be properly separated and attributed to a single mechanism or whether this separation is often somewhat contrived, as the more recent system approach suggests.

There are some drawbacks in the present synthesis. Primary evidence was detailed and mostly focused on Bangladesh, China, India and Malaysia meaning that generalization to Asia in general is limited. The interventions were mostly short-term and implemented in tanks, aquarium or controlled biofloc systems. A few field studies, pathogen challenge studies and economic evaluations were available. The detailed evidence matrix lacked models of viral and parasitic challenge. The methodological and geographical limitation makes the generalisation of some of the previous results found in the review difficult. These findings of antagonism against *Aeromonas hydrophila*, *Vibrio spp*. and *Streptococcus agalactiae* are not seen in other countries, in other settings with bioflocs or tanks, nor with other models of bacterial pathogens, all of which are mentioned in this passage as falling within the scope of the detailed evidence base, as far as I can tell. The absence of viral and parasitic challenge models is notable in the face of the confidence of the mechanistic literature: both Balcázar et al. (2006) and Hoseinifar et al. (2018) describe probiotic immunity stimulation in a way that could be broadly applied to include disease protection from viruses and parasites, but the authors' own accounts prove this to have been tested almost exclusively against bacterial pathogens. This is not an author versus author disagreement, but rather a general disagreement between the language used in the review to describe probiotic benefits and a much more restricted geographical, experimental and pathogen range that this closing assessment demonstrates that the actual evidence spans.

There was also a significant difference in study protocols with regards to probiotic strain, dose, route of administration, duration, host species, and reported outcomes. Some studies only evaluated general results (growth, survival) and not confirmed colonization, production of metabolites or changes in microbiomes. Negative and non-significant results may also be less likely to be published, leading to publication bias. The need for future research is to use standardized reporting, verified strain identification, viable counts and transparent reporting of both beneficial and non-significant results in longer farm trials. A few of the positive results explored above in the review take a retrospective backwash from this worry about protocol inconsistency and publication bias. In each of the above mentioned, different strains, doses, administration methods and host species have produced positive results, with none of these established as a common protocol to establish uniformity across the board, hence the optimistic result-specific conclusions made earlier are based on studies that were not directly comparable. The idea of broad outcome measurement is also contradictory to the mechanistic confidence of Balcázar et al. (2006) and Hoseinifar et al. (2018) who claimed that some studies examined only the growth or survival of the probiotics and did not test for colonisation, metabolite production or changes in the microbiome. In some cases, mechanisms such as competitive exclusion, bacteriocin production, immune regulation were therefore hypothesized rather than confirmed. Lastly, the consistency of the positive results from Saini et al. (2014) to Zorriehzahra et al. (2016) to Chowdhury and Roy (2020) is somewhat complicated by the possibility of publication bias (that is, negative or non-significant results are less likely to be published in the literature), which may only partially account for the apparent agreement among these studies.

Future perspectives

The development of future probiotics should shift from general commercial formulations to 'precision' probiotics specific to the product and/or the host. By using whole genome sequencing, genes involved in adhesion, stress resistance, production of enzymes, production of antimicrobial metabolites, and toxins, as well as transferable antibiotic-resistance genes, can be identified all in one. The probiotic markers and several clusters of secondary metabolites with antimicrobial potential were discovered in *B. velezensis FS26* through genome mining (Sam-on et al. 2023). But this approach to precision, genomically screened probiotics is not the same as most of the strain evaluations elsewhere in the review. However, none of these studies, except Sam-on et al. (2023) who used whole genome screening for toxins, virulence factors and transferable resistance genes to screen *B. velezensis FS26*, focused on the type of study to compare formulations, and neither Saini et al. (2014) nor Gaffar et al. (2023) and Asha et al. (2024) evaluated the formulations using this screening method. The difference here is methodological, not factual; Sam-on et al. (2023) show that the genomic markers and antimicrobial secondary-metabolite clusters can be identified before a strain is tested in vivo, while Saini et al. (2014), Gaffar et al. (2023) and Asha et al. (2024) all establish probiotic value after the fact, by observing antagonism or performance. The implication is that most of the strain selections reported as being favourably used previously in this review would not meet the safety and precision criterion that the genomic approach in Sam-on et al. (2023) is starting to make possible. A glimpse of future aquatic probiotics is illustrated in Fig. 14.

Conclusions

Taken as a whole, this review shows that probiotics are a scientifically credible and ecologically coherent alternative to routine antibiotic use in Asian freshwater aquaculture, but the strength of that case rests on a narrower and more uneven evidentiary base than the volume of positive reports suggests. The mechanisms invoked across the literature competitive exclusion, antimicrobial-metabolite synthesis, immune stimulation,

enzymatic support and nitrogenous-waste conversion are individually well supported, yet they have mostly been demonstrated as separate, laboratory-scale effects rather than as an integrated host-microbiome-environment system, and confirmed at the level of outcome (growth, survival, water chemistry) far more often than at the level of mechanism (colonisation, metabolite production, gene expression). The evidence is also geographically and taxonomically narrow: concentrated in Bangladesh, China, India and Malaysia; dominated by short-term tank, aquarium and biofloc trials against a handful of bacterial pathogens; and almost silent on viral and parasitic challenge, on fungal and viral components of the aquatic microbiome, and on how probiotic strains behave once heat stress, hypoxia or fluctuating water quality intrude on the stable conditions of a controlled trial.

These limitations converge on a single practical conclusion: efficacy and safety are not the same question, and the field has so far answered the first far more thoroughly than the second. A strain that suppresses a pathogen in vitro or improves feed conversion in a tank is not automatically a strain that will colonise reliably on a working farm, resist a novel dose-response relationship, or carry no transferable resistance or virulence genes of its own. Closing this gap calls for region- and host-specific strain selection grounded in whole-genome and functional screening rather than imported, one-size-fits-all commercial products; standardised protocols for strain identification, dosing, administration route and outcome reporting, so that studies can be compared rather than merely accumulated; and deliberate testing under the temperature, oxygen and salinity stress that Asian aquaculture will increasingly face under climate change (Mawa et al. 2022). Multi-omic tools - metagenomics, transcriptomics and metabolomics - offer a realistic route to verifying that a probiotic has actually colonised and altered host physiology rather than simply correlating with a favourable outcome, and postbiotic, paraprobiotic and synbiotic formulations merit the same rigour in dose, mechanism and economic evaluation that has so far been applied unevenly even to live strains.

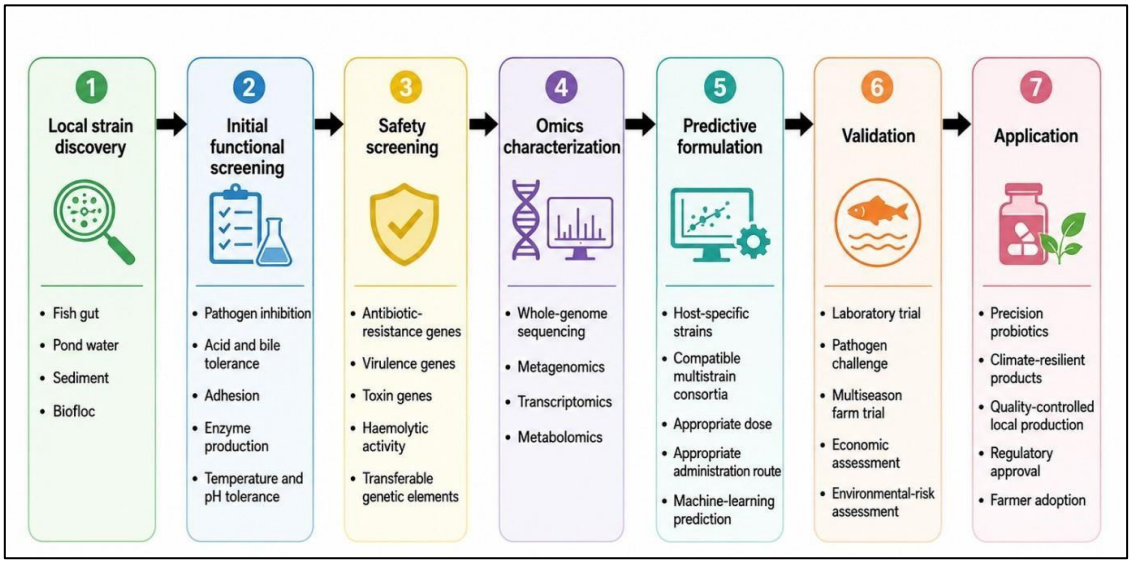


Fig. 14. Roadmap for safe, effective and climate-resilient precision probiotics for Asian freshwater aquaculture (generated by AI).

None of this diminishes the underlying case for probiotics. Even with its gaps, the evidence assembled here shows measurable, repeated benefits for growth performance, disease resistance, immune competence and water-quality management, delivered without the resistance-gene selection pressure and residue accumulation that routine antibiotic use carries. What the evidence does not yet support is treating probiotics as a proven, drop-in replacement for antibiotics across the full diversity of Asian freshwater systems. The more defensible position is that probiotics are a genuinely promising but still maturing technology, whose next phase of development depends less on demonstrating that they work in principle - that case is reasonably well made and more on the harder, less glamorous work of field validation, genomic safety screening, and standardization that would let farmers, regulators and researchers trust a given strain in a given pond rather than in the review that first described it.

For the smallholder-dominated aquaculture sector that predominates across Bangladesh, China, India and Malaysia, this is not merely an academic distinction. Antimicrobial stewardship, food safety and the long-term productivity of freshwater systems depend on probiotics being adopted for the right strains, at the right doses, under the right conditions - not simply because they are available. Achieving that will require sustained collaboration between microbiologists, aquaculturists, regulators and farmers, built on the region-specific, genomically characterised, climate-resilient precision probiotics that this review identifies as the necessary next step for sustainable Asian freshwater aquaculture.

Conflict of interest

There is no competing interest that might influence the research work.

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Supplements

Table 3. Common diseases reported in Asian aquaculture.

Disease	Pathogen name	Pathogen type	Affected fish species	Clinical signs	Reference
Bacterial diseases					
Motile Aeromonad Septicaemia (MAS)	*Aeromonas hydrophila, A. veronii, A. jandaei, A. caviae, A. sobria, A. dhakensis*	Bacteria	Indian major carps (*Catla catla, Labeo rohita, Cirrhinus mrigala*), tilapia, catfish, snakehead, grass carp, common carp, striped catfish, goldfish	Haemorrhagic and ulcerative lesions on skin/fins, exophthalmia, ascites, sudden death, high mortality	Vineetha & Abraham (2009); Mishra et al. (2017); Sahoo et al. (2020); Paul et al. (2022); Shinn et al. (2023)
Lactococcosis	*Lactococcus garvieae*	Bacteria	Nile tilapia (*Oreochromis niloticus*), red tilapia, rainbow trout, yellowtail	Ocular opacity, exophthalmia, haemorrhages, cataract, skin erosion, scale detachment; lamellar gill congestion, necrosis	Haenen et al. (2023)
Nocardiosis	*Nocardia seriolae*	Bacterium	Freshwater tilapia (*Oreochromis spp.*), marine fish	Multiple skin ulcers, red spots; greyish or haemorrhagic liver with white nodules; spleen necrosis, ascites; chronic infection up to 30% mortality	Haenen et al. (2023)
Aerococcosis	*Aerococcus viridans*	Bacterium	Nile tilapia (*O. niloticus*), other fish	Congested gills and abdomen; swollen gall bladder; severe liver diffusion; often in combination with other bacteria	Haenen et al. (2023)
Edwardsiellosis (eel type)	*Edwardsiella anguillarum*	Bacterium	Nile tilapia, eels	Similar to E. tarda; non-motile; virulence to tilapia in Costa Rica and Korea	Haenen et al. (2023)
Aeromoniasis	*Aeromonas schubertii*	Bacterium	Nile tilapia (*O. niloticus*), snakehead	Visceral white spots (liver, kidney) similar to francisellosis; multi-organ necrosis	Haenen et al. (2023)
Zoonotic bacterial diseases (contact/foodborne)					
Fish tank granuloma / Swimmer's granuloma	*Mycobacterium marinum*	Bacterium (acid-fast)	Warmwater fish including tilapia; zoonotic	In fish: chronic granulomatous disease ("fish tuberculosis"); in humans: skin nodules (fingers/hands) following injury; not a food zoonosis	Haenen et al. (2023)
Vibriosis (zoonotic)	*Vibrio vulnificus pathovar piscis* (serovars E and T)	Bacterium	Nile tilapia, eels; zoonotic	In fish: haemorrhagic septicaemia; in humans: necrotizing fasciitis, septicaemia from wound infection or ingestion of undercooked seafood	Haenen et al. (2023)
Edwardsiellosis	*Edwardsiella tarda*	Bacteria	Tilapia, catfish, eels, mullet, striped bass, olive flounder; zoonotic	Ulcerative abscesses in internal organs, haemorrhagic skin ulcers, rectal protrusion	Mishra et al. (2017); Shinn et al. (2023)

Disease	Pathogen name	Pathogen type	Affected fish species	Clinical signs	Reference
Columnaris disease	*Flavobacterium columnare*	Bacteria	Carp, tilapia, catfish, channel catfish, striped catfish, rainbow trout, walking catfish, snakehead	Haemorrhagic/ulcerative lesions on fins, head, back ("saddleback"); fin/tail rot; gill rot	Aftabuddin et al. (2016); Mishra et al. (2017); Shinn et al. (2023)
Pseudomoniasis	*Pseudomonas fluorescens*	Bacteria	Nile tilapia, grass carp, silver carp, bighead carp, walking catfish, Japanese and European eels	Haemorrhagic lesions on skin, fins and tail	Vineetha & Abraham (2009); Mishra et al. (2017); Shinn et al. (2023)
Streptococcosis	*Streptococcus agalactiae*	Bacteria	Tilapia (Nile and hybrid red tilapia), striped bass, channel catfish, rainbow trout, barramundi, snakeskin gourami; zoonotic (ST283)	Exophthalmia, corneal opacity, petechial haemorrhages, ascites, erratic swimming	Shinn et al. (2023)
Francisellosis	*Francisella orientalis*	Bacteria	Tilapia (*Oreochromis* spp.)	Whitish nodules (granulomas) on gills, spleen and kidney; anaemia, lethargy	Shinn et al. (2023)
Parasitic diseases					
Argulosis	*Argulus* spp. (carp lice)	Parasite (crustacean)	Indian major carps (especially *Labeo rohita*), common carp, tilapia, striped catfish, goldfish, *Lates calcarifer*	Skin lesions, haemorrhagic spots, ulcers, irritation, secondary infections, production loss	Vineetha & Abraham (2009); Mishra et al. (2017); Sahoo et al. (2020)
Dactylogyrosis	*Dactylogyrus* spp. (gill fluke)	Parasite (monogenean)	Cyprinids (common carp, grass carp, silver carp, bighead carp, Indian major carps), goldfish	Destruction of gill filaments, respiratory distress, white masses on gills, mortality in fry	Mishra et al. (2017); Sahoo et al. (2020); Paul et al. (2022); Shinn et al. (2023)
Gyrodactylosis	*Gyrodactylus* spp. (skin fluke)	Parasite (monogenean)	Tilapia, common carp, goldfish, catfish (*Clarias gariepinus*), Indian major carps	Skin and gill damage, excess mucus, frayed fins, entry points for bacteria	Mishra et al. (2017); Vineetha & Abraham (2009); Shinn et al. (2023)
Ich / White spot disease	*Ichthyophthirius multifiliis*	Parasite (ciliate)	Most freshwater fish species (cyprinids, cichlids, catfish, salmonids, etc.)	White cysts (~1 mm) on skin, fins and gills; respiratory distress, osmotic imbalance	Mishra et al. (2017); Shinn et al. (2023)
Trichodiniasis	*Trichodina* spp.	Parasite (ciliate)	Indian major carps, grass carp, silver carp, bighead carp, tilapia, catfish, *Pangasius* spp., *Clarias* hybrids	High mucus production, gill/skin abrasion, respiratory distress, especially in fry	Mishra et al. (2017); Paul et al. (2022); Shinn et al. (2023)
Myxosporidiasis	*Myxobolus* spp., *Myxosporidium* spp.	Parasite (myxozoan)	Indian major carps, grass carp, silver carp, bighead carp, common carp, tilapia, *Pangasius hypophthalmus*, *Colossoma macropomum*	Cysts on gills, skin and internal organs; weakness, scale loss, organ impairment	Mishra et al. (2017); Vineetha & Abraham (2009); Sahoo et al. (2020); Paul et al. (2022)
Lernaeasis	*Lernaea* spp. (anchor worm)	Parasite (crustacean)	Indian major carps, common carp, tilapia, goldfish, *Lates calcarifer*	Tissue damage at attachment sites, ulcers, secondary infections	Mishra et al. (2017); Shinn et al. (2023)
Fish-borne zoonotic trematode (FZT) infection	*Haplorchis pumilio*, *Centrocestus formosanus*, *Clonorchis sinensis*, *Procerovum varium*	Trematode metacercariae	Carps (grass carp, silver carp, rohu), tilapia, mullet, snakehead	No distinct clinical signs in fish; encyst in muscles, gills, fins; zoonotic - humans infected by eating raw/undercooked fish; high prevalence in nursery juveniles (48.6% after 4 weeks)	Phan et al. (2010); Naegel (1989)
Ichthyobodosis (Costiasis)	*Ichthyobodo necator* (formerly *Costia necatrix*)	Flagellated protozoan	Most freshwater fish, especially fry; salmonids, cyprinids, eels	Blue-grey or white film on skin (excess mucus); lethargy, anorexia, respiratory distress; severe gill damage	Buchmann (2022); Tonguthai (1997)
Ligulosis	*Ligula intestinalis* (plerocercoid)	Cestode	Cyprinids (bream, roach, minnows)	Large plerocercoid in peritoneal cavity (up to 1 m); cachexia, impaired reproduction, growth arrest, death	Piasecki et al. (2004)
Bothriocephalosis	*Bothriocephalus acheilognathi* (Asian tapeworm)	Cestode	Grass carp, common carp, cyprinids	Intestinal obstruction, mucosal damage; mortality after overwintering; introduced globally	Piasecki et al. (2004)
Anguillicolosis	*Anguillicola crassus*	Nematode	Eels (*Anguilla anguilla*, *A. japonica*)	Infection of swimbladder; inflammation, fibrosis, reduced swimbladder function; affects migration and marketability	Piasecki et al. (2004)
Diphyllobothriasis (zoonotic)	*Diphyllobothrium latum* (broad fish tapeworm)	Cestode	Piscivorous fish (pike, perch, salmonids); zoonotic	Plerocercoids in fish muscle; humans infected by raw/undercooked fish; adult tapeworm in human intestine	Piasecki et al. (2004)
Fungal / oomycete diseases					
Epizootic Ulcerative Syndrome (EUS)	*Aphanomyces invadans* (primary)	Oomycete	Snakehead (*Channa* spp.), catfish (*Clarias* spp.), climbing perch (*Anabas testudineus*), barbs (*Puntius* spp.), gourami (*Trichogaster* spp.), goby (*Oxyeleotris marmoratus*), eels, sand whiting (*Sillago ciliata*). Common carp resistant.	Deep ulcerative lesions penetrating muscle, high mortality	Aftabuddin et al. (2016); Shinn et al. (2023)
Saprolegniasis	*Saprolegnia parasitica*	Oomycete	Indian major carps, grass carp, common carp, tilapia, catfish, *Pangasianodon hypophthalmus*, *Channa punctata*	Cottonwool growth on skin/gills (secondary to injury or stress); osmoregulatory failure	Mishra et al. (2017); Shinn et al. (2023)
Branchiomycosis (gill rot)	*Branchiomyces* spp.	Oomycete	Cyprinids, tilapia, other freshwater fish	Gill necrosis, rotting of gill tissue, respiratory distress in poor water quality	Mishra et al. (2017); Shinn et al. (2023)

Disease	Pathogen name	Pathogen type	Affected fish species	Clinical signs	Reference
Viral diseases					
TiLV disease	Tilapia Lake Virus (TiLV)	Virus	Tilapia (*Oreochromis niloticus*, hybrid red tilapia), giant gourami, African cichlids	Lethargy, exophthalmia, skin erosion, scale protrusion, syncytial hepatitis; 20-90% mortality	Shinn et al. (2023)
Koi Herpesvirus disease (KHVD)	*Cyprinid Herpesvirus 3* (KHV)	Virus	Common carp, koi carp, ghost carp; tilapia (experimentally susceptible)	Gill necrosis, sunken eyes, excessive mucus, 80-90% mortality	Bondad-Reantaso et al. (2005); Shinn et al. (2023)
Koi Sleepy Disease (KSD)	Carp Edema Virus (CEV)	Virus	Common carp, koi carp	Gill necrosis, lethargy ("sleeping"), sunken eyes, mortality	Sahoo et al. (2020); Shinn et al. (2023)
Grass Carp Haemorrhagic Disease	Grass Carp Reovirus (GCRV)	Virus	Grass carp, black carp, *Pseudorasbora parva*, *Gobiocypris rarus*; asymptomatic in silver carp and bighead carp	Exophthalmia, dark coloration, severe internal/external haemorrhages, up to 80% mortality	Shinn et al. (2023)
White Spot Disease (WSD)	White Spot Syndrome Virus (WSSV)	Virus	*Penaeus monodon*, *P. vannamei*, *P. indicus*, many crustaceans	White spots (calcium deposits) on carapace and appendages; lethargy, reduced feeding, red discolouration; 100% mortality within 5-7 days	Mishra et al. (2017); Flegel & Alday-Sanz (1998)
Yellow Head Disease (YHD)	Yellow Head Virus (YHV)	Virus	*Penaeus monodon*, *P. vannamei*, *P. stylirostris*	Yellowish discolouration of cephalothorax (hepatopancreas); rapid spread, 100% mortality within 3-5 days	Mishra et al. (2017)
White Tail Disease (WTD)	*Macrobrachium rosenbergii* Nodavirus (MrNV) + Extra Small Virus (XSV)	Virus	Giant freshwater prawn (*Macrobrachium rosenbergii*)	Whitish to milky-white tail and abdominal muscle; high mortality in hatchery post-larvae and nursery juveniles	Mishra et al. (2017)
Monodon Baculovirus Disease	Monodon Baculovirus (MBV)	Virus	*Penaeus monodon*, *P. indicus*	Faecal-oral transmission; occlusion bodies in hepatopancreatic nuclei; reduced growth, mortality in larvae/post-larvae	Mishra et al. (2017)
Infectious Hypodermal & Haematopoietic Necrosis	IHHNV	Virus	*Penaeus stylirostris* (high mortality), *P. vannamei*, *P. monodon* (runt-deformity syndrome)	Runt-deformity syndrome (RDS): cuticular deformities of rostrum, antennae; reduced growth; no mass mortality in *P. monodon*	Mishra et al. (2017)
Acute Hepatopancreatic Necrosis Disease / Early Mortality Syndrome (AHPND/EMS)	*Vibrio parahaemolyticus* (specific strains)	Bacterium	*Penaeus vannamei, P. monodon*	Mass mortality within first 35 days; pale, shrunken, atrophied hepatopancreas; empty gastrointestinal tract	Mishra et al. (2017)
Hepatopancreatic Microsporidiosis (HPM)	*Enterocytozoon hepatopenaei* (EHP)	Microsporidian parasite	*Penaeus monodon, P. vannamei*	Slow growth syndrome; white or milky faecal strings; retarded growth; not directly fatal but increases susceptibility to bacterial infections	Mishra et al. (2017)
Mixed infections					
Mixed parasitic	*Dactylogyrus* + *Trichodina* + *myxosporideans*	Multiple parasites	Indian major carps (*Catla catla, Labeo rohita*), fry and fingerlings of carps, *Anabas testudineus*	Severe gill damage, high mucus, anorexia, mortality in fry and fingerlings	Paul et al. (2022); Sahoo et al. (2020)
Mixed bacterial + parasitic	*Argulus* + *Aeromonas hydrophila*; or *Dactylogyrus* + *Aeromonas*	Parasite + bacterium	Indian major carps (*Catla catla*, *Labeo rohita*), koi carp, African catfish (*Clarias gariepinus*), goldfish	Haemorrhagic ulcers, gill damage, sluggishness, mass mortality	Paul et al. (2022)

Table 4. Commercial probiotic products reported in Asian aquaculture, including declared composition, dosage, use, and proposed action.

Trade name	Microbial strain(s) reported	Reported dosage & application	Primary use	Reported / proposed action	Administration route	Region	Reference
Eco-Pro	Exact strain designations were not reported; composition requires verification due to conflicting reviews listing *Rhodopseudomonas palustris* instead of the three *Bacillus* species.	Not reported in the cited source	Pond bioremediation and productivity improvement	Photosynthetic bacteria may utilize organic metabolites, improve microbial balance, and contribute to pond-water remediation.	Not reported	India	Hasan and Banerjee (2020)
AQUALACT	Exact strain designations not reported. Reported species: *Lactobacillus acidophilus*, *L. plantarum*, and *Bacillus subtilis*.	5 g/kg feed every alternate day from day 15 until harvest in a shrimp-pond study	Gut conditioning and feed utilization	LAB may produce organic acids and inhibitory metabolites, while *Bacillus* may provide digestive enzymes and suppress opportunistic microorganisms.	Mixed with feed	India and Vietnam; use in Bangladesh requires confirmation	Hasan and Banerjee (2020)
PRO-W	Product identity requires verification: commercial "PRO-W" formulations vary (e.g., *B. pumilus, B. amyloliquefaciens*, and *B. subtilis* in a Bangladesh survey versus *B. subtilis* and *B. licheniformis* in Sanolife PRO-W), and strain codes were omitted.	Pro-W reported in Bangladesh: 7-10 g/kg feed. Sanolife PRO-W: 0.007 g/m³ every two weeks in one pond study.	Feed supplementation or water-quality management, depending on the product	Enzyme production, organic-matter degradation, suppression of undesirable bacteria, and possible improvement of nutrient utilization.	Mixed with feed or added directly to pond water, depending on the formulation	India, Bangladesh, Thailand, and Vietnam	Shefat (2018); Kumar et al. (2016); product identity must be specified

Trade name	Microbial strain(s) reported	Reported dosage & application	Primary use	Reported / proposed action	Administration route	Region	Reference
Pond Care 3S	Exact strain designations not reported. Declared species: *B. subtilis*, *B. licheniformis*, *B. polymyxa*, *B. pumilus*, *B. megaterium*, *Aspergillus niger*, and *A. oryzae*.	Not reported in the cited source	Organic-waste degradation and pond management	Microbial and fungal enzymes may break down organic residues, recycle nutrients, and reduce pond-bottom waste.	Added directly to pond water	India	Kamruzzaman et al. (2024)
Gut-Pro	Exact strain designations not reported. Declared microorganisms: unidentified *Lactobacillus spp., Enterococcus faecium* and an unidentified yeast.	Not reported in the cited source	Digestive and intestinal health	Proposed actions include competitive exclusion of pathogens, organic-acid production, microbiota stabilization, and digestive support.	Not reported	Bangladesh	Hossain et al. (2021)
Epicin	Exact strain designations not reported. Reviews generally describe the product as a consortium of unidentified *Bacillus, Pediococcus*, and *Enterococcus* strains.	Product-specific dosage was not reported by Rico et al. (2013). A separate field protocol reported approximately 70 g per 1,800 m² of pond every two days, but this should not be attributed to Rico et al. without verification.	Water-quality improvement, growth support, and disease management	Proposed to promote beneficial pond microbiota, degrade organic matter, compete with pathogens, and stabilize culture-water conditions.	Added directly to pond water	Vietnam and the Philippines	Rico et al. (2013); Balcázar et al. (2006)
Zymetin	Unreported strain designations; confirmed species (*Bacillus mesentericus*, *Clostridium butyricum*, *Enterococcus faecalis*) do not support the original listing of *B. subtilis* and *B. cereus*.	5 g/kg diet for 60 days in an experimental prawn study. A Bangladesh field survey separately reported a label dose of 25.5 g/kg feed.	Feed utilization, growth, immunity, and intestinal microbial management	Production of digestive metabolites, modulation of intestinal and water microbiota, pathogen suppression, and stimulation of cellular immune responses.	Mixed with feed	Bangladesh and Thailand	Azad et al. (2021); Ghosh et al. (2016)
Bio-Aqua	Exact strain designations not reported. Unidentified *Bacillus* spp. and *Saccharomyces cerevisiae* are reported, but strain-level composition was not provided.	Not reported	Pond ecology and water-quality management	Proposed actions include organic-matter degradation, microbial-community modification, digestive support, and reduction of toxic metabolites.	Added directly to pond water	Bangladesh and Southeast Asia	Hossain et al. (2021); source composition should be verified
Pond-care, SK+F	Unreported strain designations; declared species comprise *Bacillus subtilis*, *B. licheniformis*, *B. polymyxa*, *B. pumilus*, *B. megaterium*, *B. coagulans*, *B. amyloliquefaciens*, *Aspergillus niger*, and *A. oryzae*.	1-2 g/decimal of pond area	Water-quality and plankton management	Claimed to reduce hardness and turbidity, improve dissolved oxygen, regulate plankton, and provide microbial biomass for zooplankton and aquatic larvae.	Added directly to pond water	Bangladesh	Hossain et al. (2023)
Safegut	Individual microorganisms and exact strain designations not disclosed. Described as a non-antibiotic mixture of probiotics, vitamins, and enzymes.	2 g/decimal of pond area	Growth promotion	Intended to support digestion, nutrient use, intestinal microbial balance, and growth. The specific organisms responsible for these effects were not disclosed.	Added directly to pond water	Bangladesh	Hossain et al. (2023)
GPA	Exact strain designations not reported. Declared microorganisms: *B. subtilis*, unidentified *Lactobacillus* spp., and *Saccharomyces cerevisiae*. Also contains lipase, protease, and amylase.	0.5 g/decimal of pond area	Gut health, digestion, growth, and immunity	Digestive enzymes break down feed and organic substrates; declared microorganisms are claimed to inhibit harmful bacteria, improve survival, reduce FCR, and stimulate immunity.	Added directly to pond water	Bangladesh	Hossain et al. (2023)
PROFS	Exact strain designations not reported. Declared microorganisms: *B. subtilis* and unidentified *Pediococcus* spp. Also contains protease, lipase, amylase, β-galactosidase, and pectinases.	1.5 g/decimal of pond area	Water, soil, and organic-waste management	Claimed to increase beneficial microorganisms, inhibit harmful bacteria, decompose complex organic compounds, improve water and soil fertility, and reduce toxic gases and turbidity.	Added directly to pond water	Bangladesh	Hossain et al. (2023)
IKI-IKI	Exact strain designations not reported. Declared species: *B. subtilis*, *B. licheniformis*, and *B. amyloliquefaciens*.	1-2 g/decimal of pond area	Pathogen control and biological-waste degradation	Claimed to suppress detrimental microorganisms, enhance denitrification, and accelerate the decomposition of biological debris.	Added directly to pond water	Bangladesh	Hossain et al. (2023)
Gasonil	Exact strain designations not reported. Declared species: *B. subtilis*, *B. licheniformis*, *B. polymyxa*, *B.*	1.5-2 g/decimal of pond area	Ammonia reduction, stress control, growth,	*Bacillus* organisms are claimed to suppress undesirable microorganisms and decompose waste,	Added directly to pond water	Bangladesh	Hossain et al. (2023)

Trade name	Microbial strain(s) reported	Reported dosage & application	Primary use	Reported / proposed action	Administration route	Region	Reference
	megaterium, and *B. coagulans*. Also contains 30% yucca.		and disease resistance	while yucca may bind or reduce ammonia. The product is also claimed to buffer pH and support immunity.			
Gasonex Plus	Exact strain designations not reported. Declared microorganisms: *B. subtilis*, *B. megaterium*, *Pseudomonas sp.* reported on the label as "*P. florecium*," *Nitrococcus sp*., *Thiothrix sp.* and *Rhodospirillum sp*.	0.8-1.6 g/decimal with 4 g of Zeolite Gold	Toxic-gas removal and pond-water management	The microbial consortium and zeolite are claimed to reduce toxic gases, improve microbial transformation of wastes, prevent oxygen-related stress, and support growth.	Added to pond water, usually with zeolite	Bangladesh	Hossain et al. (2023)
Aqua-Star Pond	Exact strain designations not reported. Declared species: *B. subtilis*, *Enterococcus faecium*, *Thiobacillus denitrificans*, and *Paracoccus pantotrophus*.	2 g/decimal of pond area	Denitrification and organic-debris degradation	*T. denitrificans* and *P. pantotrophus* may participate in nitrogen transformation, while *Bacillus* and *Enterococcus* organisms may contribute to waste decomposition and microbial balance.	Added directly to pond water	Bangladesh	Hossain et al. (2023)
Biozyme Aqua	Exact strain designations not reported. Declared species: *B. polymyxa*, *B. pumilus*, and *B. megaterium*.	500 g/100 kg feed	Growth, survival, FCR, and disease management	Proposed to enhance digestion and nutrient utilization, suppress pathogenic microorganisms, and improve growth and survival.	Mixed with feed	Bangladesh	Hossain et al. (2023)
Eco Marine	Exact strain designations not reported. Declared microorganisms: *E. faecium*, *P. pantotrophus* and unidentified *Bacillus spp*.	2-3 tablets/acre	Pond-bottom and organic-waste management	Claimed to digest organic wastes, convert residues into micronutrients, and reduce ammonia, hydrogen sulphide, and other toxic gases.	Added directly to pond water	Bangladesh	Hossain et al. (2023)
Probio-Aqua LQ	Exact strain designation not reported. Declared species: *Rhodopseudomonas palustris*.	25 mL/decimal of pond area	Promotion of beneficial pond microorganisms	Photosynthetic bacteria are claimed to produce useful metabolites, suppress undesirable microorganisms, and remain functional in freshwater, marine, rainy, and cloudy conditions.	Added directly to pond water	Bangladesh	Hossain et al. (2023)
Product I	Exact strain designations not reported. Declared species: *B. subtilis*, *Pediococcus acidilactici*, *L. acidophilus* and *S. cerevisiae*. Also contains phytase and amylase.	Not reported in the reviewed source	Feed digestibility in shrimp	Microbial and supplemental enzymes are proposed to hydrolyse feed components, improve nutrient availability, and support intestinal microbial balance.	Mixed with feed	Vietnam	Rico et al. (2013)
LAC-Shield™	Heat-inactivated *Lacticaseibacillus paracasei MCC1849*.	Aquaculture-specific dosage not reported by Ordanel et al. (2025)	Immune modulation and resistance to bacterial infection	Heat-inactivated cells stimulate immunity and enhance resistance.	Aquaculture-specific administration route not reported	Japan	Ordanel et al. (2025)