RESEARCH ARTICLE

BORNEO SCIENCE
THE JOURNAL OF SCIENCE & TECHNOLOGY

Journal homepage: https://jurcon.ums.edu.my/ojums/index.php/borneo-science

BEYOND ANTIBIOTICS: PROBIOTICS, PREBIOTICS, AND SYNBIOTICS IN CATFISH (*Clarias gariepinus*) AQUACULTURE FOR THE CONTROL OF *Aeromonas hydrophila* IN MALAYSIA– A REVIEW

Arlene Debbie Lingoh[1], Sui Sien Leong[*1,2], Kamil Latif[1], Yih Nin Lee[3] and Shahrul Razid Sarbini[4]

[1] Department of Animal Sciences and Fishery, Faculty of Agricultural and Forestry Sciences, Universiti Putra Malaysia Sarawak, 97008 Bintulu, Sarawak, Malaysia.
[2] Research Laboratory of Probiotics and Cancer Therapeutics (CANRES 2), UPM-MAKNA Cancer Research Laboratory (CANRES), Institute of Bioscience, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[3] Faculty of Engineering and Sciences, Curtin University, CDT 250, 98009 Miri, Sarawak, Malaysia
[4] Department of Crop Sciences, Faculty of Agricultural and Forestry Sciences, Universiti Putra Malaysia Sarawak, 97008 Bintulu, Sarawak, Malaysia.

[*]Correspondence:
leongsuisien@upm.edu.my

Received: 23 February 2025
Revised: 1 March 2025
Accepted: 29 December 2025
Published online:
31 December 2025

Doi :
10.51200/bsj.v46i2.6783

Keywords:
Antibiotics alternative; Aquaculture; Probiotics; Prebiotics; Synbiotics.

ABSTRACT. *Aquaculture remains the fastest-growing sector in global food production, providing a vital source of protein and supporting economic development. In Malaysia, freshwater aquaculture, particularly the farming of Clarias gariepinus, is central to food security, yet the intensification of production has heightened disease risks, feed inefficiencies, and vulnerability to bacterial pathogens such as Aeromonas hydrophila. Conventional use of antibiotics has proven unsustainable due to antimicrobial resistance and environmental concerns, driving the need for alternative management strategies. Functional feed additives, including probiotics, prebiotics, and synbiotics, have emerged as eco-friendly approaches to enhance growth performance, feed utilization, immune competence, and pathogen resistance. This review aims to critically evaluate recent progress (2015–2025) in the use of probiotics, prebiotics, and synbiotics in freshwater aquaculture, with a particular focus on catfish farming in Malaysia. It highlights their types, mechanisms of action, comparative effects on fish growth and immune modulation, and their role in disease resistance against A. hydrophila. By synthesizing current evidence, the review identifies both the opportunities and research gaps associated with these functional feed additives. The findings underscore their potential as sustainable alternatives to antibiotics, supporting healthier and more resilient aquaculture systems.*

INTRODUCTION

Aquaculture continues to be one of the most rapidly expanding sectors within global food production, driven by the increasing demand for sustainable and affordable sources of high-quality animal protein (Food and Agriculture Organization, 2022). Worldwide, aquaculture has surpassed capture fisheries in providing fish for human consumption, and its role in supporting food and nutritional security is expected to grow further in the coming decades (Naylor *et al*., 2021). In Malaysia, freshwater aquaculture is a vital component of the national food system, contributing to both economic development and rural livelihoods, with total harvests exceeding 40,000 tons annually in recent years (Department of Fisheries Malaysia, 2021). Catfish aquaculture constitutes a significant segment of Malaysia's freshwater aquaculture sector and plays an important role in supporting domestic fish supply. In Malaysia, catfish production represents an important segment of the freshwater aquaculture sector, with annual outputs reaching tens of thousands of tonnes in recent years. Commercial farming is largely dominated by African catfish (*Clarias gariepinus*) and its hybrids with local species, reflecting their rapid growth, tolerance to intensive culture conditions, and strong market demand (Department of Fisheries Malaysia, 2021). In addition to these farmed species, several other catfish taxa are present in Malaysia, including Asian walking catfish (*Clarias batrachus*), striped catfish (*Pangasianodon hypophthalmus*), river catfish (*Mystus* spp.), bagrid catfish (*Hemibagrus* spp.), silurid catfish (*Ompok* spp.), and the giant sheatfish (*Wallago leerii*), which are primarily associated with capture fisheries or produced at smaller aquaculture scales.

Despite this progress, the intensification of aquaculture in Malaysia has also given rise to several constraints, including inconsistent growth performance, inefficient feed utilization, and recurrent disease outbreaks. Among the pathogens of concern, *Aeromonas hydrophila* has been identified as a major cause of high mortality and economic losses in catfish culture (Ridzuan *et al*., 2022). Episodes of motile *Aeromonas septicaemia* have affected cultured species such as tilapia (*Oreochromis* spp.) and African catfish (*Clarias gariepinus*), leading to acute mortality, haemorrhagic lesions, fin erosion, and septicaemia, especially under intensive farming conditions (Omeje & Kolndadacha, 2024). Several outbreaks documented in ponds and cage culture systems have been linked to environmental stressors, including elevated water temperature, poor water quality, and high stocking density, which facilitate opportunistic *Aeromonas* infections. These disease events have resulted in substantial stock losses and increased reliance on antimicrobial treatments, underscoring the continuing challenge posed by *Aeromonas* infections to freshwater fish health management in Malaysia. Basri *et al*. (2020) stated that cultured tilapia have been affected by co-infections involving Tilapia Lake Virus (TiLV) together with *Aeromonas hydrophila* and *Streptococcus agalactiae*, resulting in mortality rates of up to around 70 % on affected farms in Selangor in early 2020, highlighting the threat of viral and bacterial synergy in intensive systems. The reliance on antibiotics for disease control has further triggered concerns regarding antimicrobial resistance and environmental risks, highlighting the need for safer and more sustainable solutions (Leong *et al*., 2013; Lingoh *et al*., 2020). To address these challenges, hybridization strategies have been applied to enhance growth, feed efficiency, and resilience of aquaculture species. Hybrid catfish, for example, exhibit heterosis effects that improve survival and adaptability (Wang *et al*., 2022). However, hybridization alone may not be sufficient to overcome disease-related and nutritional limitations, which has prompted increasing attention toward the use of functional feed additives.

In this context, probiotics, prebiotics, and their combination as synbiotics have been extensively studied as alternatives to antibiotics and chemotherapeutics in aquaculture nutrition and health management (Leong *et al*., 2023). Probiotics, defined as live beneficial microorganisms, support gut microbiota balance, enhance digestion, and modulate immune responses (Lingoh *et al*., 2025). Prebiotics, commonly non-digestible oligosaccharides, selectively promote the proliferation of beneficial microbes, contributing to intestinal health and nutrient absorption (Rawi *et al*., 2020). Synbiotics integrate both components, providing synergistic effects that translate into improved growth, feed utilization, immune stimulation, and resistance to infectious diseases (Khanjani *et al*., 2024).

Recent studies from 2015 to 2025 consistently report positive effects of these additives on fish or shrimp growth performance, feed conversion efficiency, and health status (Hosseini *et al*., 2024). Importantly, they have also demonstrated protective roles against opportunistic pathogens such as *A. hydrophila*, one of the most problematic bacteria in Malaysian freshwater aquaculture. By stimulating mucosal barriers, enhancing immune responses, and reducing pathogen colonization, these additives offer a promising approach to improve the sustainability and productivity of aquaculture systems (Leong *et al*., 2023).

Therefore, the present review aims to consolidate current knowledge on the use of probiotics, prebiotics, and synbiotics in aquaculture, with a special focus on Malaysian freshwater catfish production. Specifically, it discusses global aquaculture trends, the development and challenges of Malaysian aquaculture, and the roles of probiotics, prebiotics, and synbiotics in improving growth performance, feed utilization, immune system function, and resistance against *A. hydrophila*. By integrating recent evidence, this review provides insights into the potential of these functional supplements as sustainable alternatives to antibiotics in Malaysian aquaculture.

MATERIALS AND METHODS

Literature Search

A structured literature search was carried out to identify studies and reviews addressing the use of probiotics, prebiotics, and synbiotics as alternative supplements in aquaculture. Relevant publications were retrieved from major scientific databases, including PubMed, Web of Science, Scopus, and Google Scholar. The initial screening yielded approximately 100 articles. Search terms applied included "probiotics," "prebiotics," "aquaculture," "fish immune system," "pathogen," and "lactic acid bacteria." To ensure the review reflected current knowledge, only studies published in the past ten years were considered. Furthermore, the selection was limited to English-language articles to maintain uniformity in analysis.

Inclusion and Exclusion

During the initial screening, 40 articles were excluded due to a lack of relevance. A further 60 publications were later removed after applying the selection criteria, which excluded studies limited to feed formulation supplements or those without empirical evidence and mechanistic insights. This stringent screening approach ensured that only the most relevant and informative studies were included, allowing for a focused synthesis of current trends and recent advances in the field.

Analysis of the Database

The gathered literature was carefully reviewed to capture emerging patterns and developments in aquaculture research. This process included analysing recent progress, such as the identification of novel probiotic and prebiotic strains as well as advances in their application strategies. A comparative evaluation was undertaken to examine the effectiveness of probiotics, prebiotics, and symbiotics on fish growth performance, drawing on reported outcomes across various species and culture environments. Differences in efficacy under distinct conditions were considered to provide a broader perspective. In addition, the methodological quality of the studies was assessed to gauge the reliability and validity of the evidence presented.

RESULTS AND DISCUSSIONS

Global Trends in Malaysian Aquaculture

Global aquaculture has experienced remarkable growth over the past decade, underlining its importance in meeting the increasing global demand for animal protein. Farmed finfish production alone reached approximately 57.5 million tonnes in 2020, generating an estimated USD 146.1 billion in value (Food and Agriculture Organization, 2022). Despite the challenges posed by the COVID-19 pandemic, including disruptions to supply chains and market access, the aquaculture sector continued to expand, demonstrating resilience and its integral role in sustainable food systems. This steady trajectory highlights aquaculture's capacity not only to supplement declining capture fisheries but also to contribute to global food and nutritional security. However, the intensification of aquaculture practices has been accompanied by significant challenges. Antibiotic resistance is the most alarming scenario in aquaculture because it not only reduces treatment efficacy against common pathogens such as *Aeromonas hydrophila* but also leads to recurrent outbreaks, economic losses, and the potential transfer of resistant genes from aquatic environments to human and animal health systems. High stocking densities and rapid system expansion have resulted in greater susceptibility to infectious diseases, particularly bacterial pathogens, which continue to cause heavy production losses (Walker & Winton, 2010). In addition, feed remains the highest operational cost, with rising prices of fishmeal and soybean meal exerting pressure on production sustainability (Naylor *et al*., 2021). Environmental concerns, such as nutrient loading and effluent discharge, further exacerbate the ecological footprint of the industry (Li *et al*., 2023). These issues underscore the urgent need for alternative, environmentally sound approaches that balance productivity with sustainability.

One promising avenue is the application of functional feed additives, including probiotics, prebiotics, and synbiotics. These biotic supplements have been widely studied for their potential to enhance growth performance, feed efficiency, gut health, and immune responses in aquaculture species while reducing dependence on antibiotics (Khairul *et al*., 2024). In Malaysia, aquaculture forms a cornerstone of the agri-food sector, supporting both economic development and national food security. The industry is broadly divided into three production categories: brackish-water aquaculture (dominated by shrimp and marine finfish), freshwater aquaculture (notably catfish and tilapia), and seaweed farming. Among these, freshwater aquaculture has shown consistent growth, reflecting strong domestic demand for affordable protein sources and continued government support through policies, subsidies, and research initiatives (Garlock *et al*., 2024). According to the Department of Fisheries Malaysia (2021), aquaculture production increased by 4.3% in volume and 10.1% in value between 2020 and 2021, even as inland capture fisheries experienced a 4% decline. This trend emphasizes the growing reliance on aquaculture to meet Malaysia's protein requirements and reduce pressure on natural fish stocks. Within freshwater aquaculture, catfish (*Clarias* spp.) occupy a dominant position. Production of catfish exceeded 417,000 metric tonnes in 2021, making it one of the most widely cultured freshwater species in the country (Department of Fisheries Malaysia, 2021).

Freshwater Aquaculture: Catfish

The African catfish (*Clarias gariepinus*) (Figure 1), first introduced to Malaysia in the late 1980s, has become a cornerstone species in the country's aquaculture sector. Its popularity stems from its rapid growth, tolerance to low water quality, adaptability to high-density culture systems, and strong consumer demand (Manyise *et al*., 2024). These traits make it particularly attractive for small- and medium-scale farmers, who rely on catfish farming as a cost-effective source of livelihood and a steady supplier of affordable animal protein. Production levels of *C. gariepinus* have consistently ranked among the highest in Malaysia's freshwater aquaculture. According to the Department of Fisheries Malaysia (2021), catfish production exceeded 417,000 metric tonnes in 2021, representing a significant proportion of total freshwater fish output. The species has also been prioritized under national food security initiatives due to its high market acceptance and relatively low production costs (Manyise *et al*., 2024).

Figure 1. African catfish (*Clarias gariepinus*).

Despite these advantages, the intensification of catfish farming presents notable challenges. Disease outbreaks, particularly motile *Aeromonas septicaemia* caused by *Aeromonas hydrophila*, remain a persistent constraint, often leading to high mortality rates and economic losses (Semwal *et al*., 2023). In addition, escalating feed costs, which account for up to 60–70% of production expenses, pose a threat to farm profitability (Pawlak & Kołodziejczak, 2020). Environmental concerns, such as effluent discharge and water quality deterioration in densely farmed areas, further complicate sustainable production. Addressing these challenges will require integrated management approaches, including functional feed additives, improved biosecurity, and selective breeding programs tailored to Malaysian aquaculture conditions.

Probiotics

Probiotics, derived from the Greek words' pro ("for") and bios ("life"), are defined as live microorganisms that confer health benefits to the host when administered in adequate amounts (Khairul *et al*., 2024). They have gained increasing recognition in aquaculture as sustainable alternatives to antibiotics and chemotherapeutics, largely driven by growing concerns over antimicrobial resistance, treatment costs, and the ecological impacts of conventional disease management (Lingoh *et al*., 2025). Probiotics in aquaculture are not only regarded as microbial feed additives that modulate the gut microbiota but also as functional components capable of improving host physiology and environmental quality (Hoseinifar *et al*., 2018; El-Saadony *et al*., 2021).

The beneficial effects of probiotics arise from multiple mechanisms of action. First, they competitively exclude pathogens by occupying adhesion sites on the intestinal epithelium and competing for available nutrients, thereby reducing pathogen colonization (Hoseinifar *et al*., 2018). Second, many probiotic strains secrete antimicrobial metabolites such as organic acids, hydrogen peroxide, and bacteriocins that directly inhibit pathogenic bacteria (El-Saadony *et al*., 2021). Third, probiotics promote gut microbiota balance, enhancing microbial diversity and resilience, which in turn reduces dysbiosis and improves digestive efficiency (Leong *et al*., 2023). Probiotic-derived enzymes, including amylases, proteases, and lipases, further facilitate nutrient assimilation and feed utilization, supporting growth performance (Tabassum *et al*., 2021). At the immunological level, probiotics enhance host defense by stimulating lysozyme activity, phagocytosis, cytokine production, and antimicrobial peptide expression, thus improving resistance against pathogens and environmental stressors (Wang *et al*., 2024). Collectively, these mechanisms explain why probiotics are increasingly viewed as critical tools in sustainable aquaculture.

Among the diverse microbial candidates, lactic acid bacteria (LAB) are the most widely studied due to their proven safety and effectiveness in terrestrial and aquatic systems. Enterococcus spp. has emerged as a promising probiotic group in freshwater aquaculture. These bacteria colonize the gastrointestinal tract, produce bacteriocins, and stimulate immune responses (Lingoh *et al*., 2020).

Prebiotics

Prebiotics are generally defined as indigestible compounds that withstand gastric acidity, undergo fermentation by intestinal microbiota, and selectively stimulate the growth and activity of beneficial microorganisms, thereby enhancing host health (Davani-Davari *et al*., 2019; Rawi *et al*., 2020). They are typically composed of long-chain complex carbohydrates that provide energy for probiotics or resident gut microbes, ultimately supporting host well-being. Most prebiotics are derived from plant-based sources (Mohammadi *et al*., 2020), with additional contributions from edible mushrooms (Balakrishnan *et al*., 2021), to a lesser extent, animal-derived dairy products, and fruit waste (Abdul Rahim *et al*., 2022). Natural sources of prebiotics include vegetables, fruits, legumes, seaweeds, microalgae, and animal milk (Ahmadifar *et al*., 2019; Van Doan *et al*., 2020). Beyond serving as a nutrient supply, prebiotics exert multiple biological functions: they prevent pathogen adhesion to intestinal epithelial cells, act as decoy receptors to block pathogen colonization, modulate immune system activity, and regulate inflammatory responses (Mohammadi *et al*., 2021).

Unlike probiotics, which introduce live microorganisms, prebiotics act as fermentable substrates that enhance the activity of resident or co-administered microbiota, contributing to gut stability and resilience in intensively farmed fish. Prebiotics are employed in aquaculture to stimulate the growth and metabolic activity of beneficial gut microbes, thereby supporting overall host health (Sanders *et al*., 2019; Rohani *et al*., 2021). Commonly applied prebiotics include β-glucans, inulin, arabinoxylan oligosaccharides (AXOS), mannan oligosaccharides (MOS), galactooligosaccharides (GOS), fructooligosaccharides (FOS), and other related oligosaccharides. Fermentation of prebiotics generates short-chain fatty acids (SCFAs), including acetate, propionate, and butyrate, which lower gut pH to suppress pathogens, provide energy for intestinal cells, and regulate immune functions (Wang *et al*., 2021). Prebiotics have been shown to improve growth performance (Li *et al*., 2019), enhance feed utilization (Shoaei *et al*., 2015), stimulate immune responses (Li *et al*., 2020), and strengthen disease resistance in aquaculture species (Abdel-Latif *et al*., 2022). Their use is therefore considered a valuable strategy to boost aquaculture productivity. Nevertheless, the effectiveness of prebiotics is highly dependent on host-specific gut microbiota interactions (Gibson *et al*., 2017), as not all prebiotics are universally effective in promoting beneficial microbial growth.

Synbiotic

Symbiotic, the combined use of probiotics and prebiotics, is increasingly applied in aquaculture to enhance growth, immunity, and disease resistance. The updated definition by Swanson *et al*. (2020) emphasizes symbiotic as "a mixture comprising live microorganisms and substrate(s) selectively utilized by host microorganisms that confers a health benefit on the host." Synbiotics are generally classified into two categories: complementary and synergistic. Complementary synbiotics combine probiotics and prebiotics that act independently but together contribute to host health, while synergistic synbiotics are specifically formulated so that the prebiotic selectively enhances the growth and activity of the co-administered probiotic, thereby amplifying their combined benefits. The majority of synbiotics available commercially, as well as those tested in clinical applications, fall under the complementary type. These typically combine probiotics such as *Lactobacillus* spp. and *Bifidobacterium* spp. with prebiotics like fructooligosaccharides (FOS), galactooligosaccharides (GOS), and inulin-type fructans (ITFs) (Smolinska *et al*., 2025). In recent years, complementary synbiotics have been widely investigated for managing metabolic and health-related conditions, including obesity, hypertension, gastrointestinal dysfunction, and immune disorders (Lee *et al*., 2024). However, because complementary synbiotics act independently, their effectiveness often depends on the host's existing gut microbiota composition. This variability highlights the need for more personalized approaches when applying such products. By contrast, synergistic synbiotics are designed to overcome these limitations by pairing probiotics with specific prebiotics that selectively enhance their activity. This targeted interaction may yield consistent benefits even in individuals who do not respond well to complementary formulations.

Application in *Clarias gariepinus*

Experimental studies have demonstrated the efficacy of probiotic supplementation across different catfish species. Dietary inclusion of *Enterococcus faecalis* has been shown to enhance growth performance, feed conversion efficiency, and innate immune indicators such as lysozyme activity in African catfish (*Clarias gariepinus*) (Allameh *et al*., 2017; Lingoh *et al*., 2025). Similarly, *Enterococcus hirae* supplementation improved immune-related gene expression and increased disease resistance in hybrid catfish (*C. gariepinus* × *C. macrocephalus*) (Hamid *et al*., 2021). Collectively, these findings indicate that species-specific and ecologically compatible probiotics—particularly *Enterococcus* strains can contribute meaningfully to addressing key constraints in Malaysian catfish farming, including suboptimal feed utilization and recurrent *Aeromonas hydrophila* infections.

Prebiotics further support intestinal health by reinforcing gut barrier integrity through enhanced mucin secretion, upregulation of tight junction proteins, and preservation of villus architecture, thereby limiting pathogen translocation and intestinal inflammation (Smolinska *et al*., 2025). These structural improvements are often accompanied by increased digestive enzyme activity and more efficient nutrient absorption, ultimately translating into improved growth performance and feed efficiency (Lingoh *et al*., 2025). In catfish aquaculture, several studies have demonstrated the functional benefits of prebiotic supplementation. For instance, dietary inulin has been reported to enhance growth performance, haematological parameters, and lysozyme activity in *C. gariepinus* (Kattakdad *et al*., 2025). Likewise, mannan-oligosaccharide (MOS) supplementation has been shown to improve gut histomorphology, digestive enzyme activity, and nutrient utilization in hybrid *Clarias* species, thereby supporting both health status and productivity under intensive culture conditions. Together, these findings highlight the potential of prebiotics as effective functional feed additives for improving growth, immunity, and disease resistance in freshwater catfish.

Synbiotics, which combine probiotics and prebiotics, are increasingly valued in catfish aquaculture because of their synergistic effects on gut function and host physiology, often exceeding the benefits observed when either component is applied alone. Their primary mode of action involves modulation of the intestinal microbiota, whereby prebiotics serve as selective substrates that enhance probiotic survival, colonization, and metabolic activity. This interaction promotes the production of beneficial metabolites, including bacteriocins, organic acids, and short-chain fatty acids (SCFAs), which suppress pathogenic bacteria and contribute to intestinal homeostasis (Khanjani *et al*., 2024). In addition to microbial regulation, synbiotics improve intestinal morphology by increasing villus height, goblet cell density, and mucosal thickness, thereby strengthening epithelial barrier function and facilitating more efficient nutrient absorption (Mohammed *et al*., 2022). A comparative overview of probiotics, prebiotics, and synbiotics in aquaculture nutrition, including their mechanisms of action, is summarized in Figure 2.

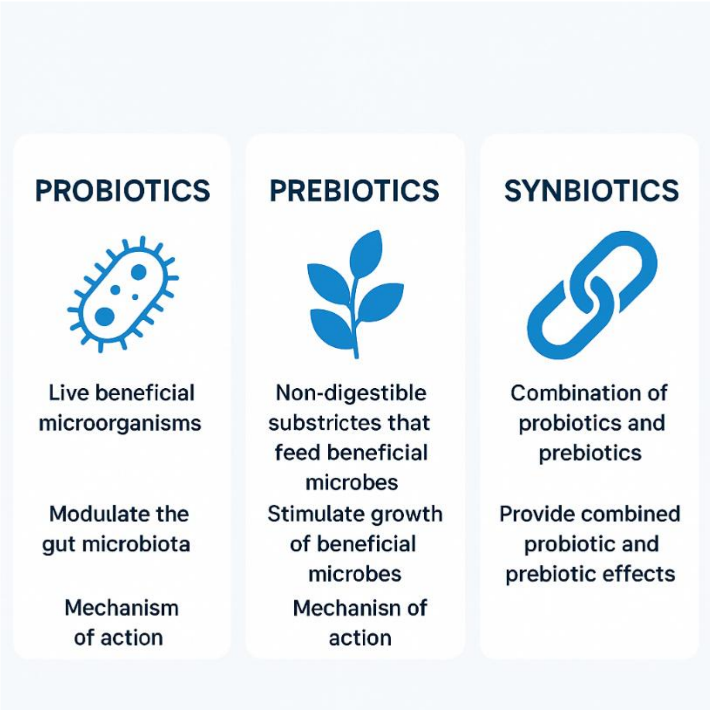

Figure 2. Comparison of probiotics, prebiotics, and synbiotics in aquaculture nutrition. The infographic illustrates their definitions, primary roles, and mechanisms of action.

At the immunological level, synbiotics stimulate key components of non-specific defense, including lysozyme activity, phagocytic capacity, complement activation, and respiratory burst responses. SCFAs generated during prebiotic fermentation further modulate cytokine expression and promote anti-inflammatory pathways, reinforcing mucosal and systemic immunity (Ghosh, 2025). In freshwater catfish, particularly *Clarias gariepinus* and hybrid *Clarias* species, synbiotic supplementation has consistently been associated with improved growth performance, enhanced feed efficiency, elevated innate immune parameters, and reduced mortality following bacterial challenge with *Aeromonas hydrophila* (Mohammed *et al*., 2022). Collectively, these findings underscore the strong potential of synbiotics as a sustainable nutritional strategy to enhance health, disease resistance, and productivity in intensive catfish aquaculture systems.

Which Is Better: Probiotics, Prebiotics, or Synbiotics?

The choice between probiotics, prebiotics, and synbiotics in catfish aquaculture depends largely on production objectives, health challenges, and economic considerations. Probiotics have been widely adopted due to their direct effects on pathogen inhibition, gut microbiota modulation, and immune stimulation. Their ability to produce antimicrobial compounds such as bacteriocins and organic acids makes them highly effective for disease control in systems prone to bacterial outbreaks (El-Saadony *et al*., 2021; Leong *et al*., 2025). However, their success depends on strain selection and the ability of the bacteria to colonize the gut under variable farming conditions.

Prebiotics, on the other hand, are cost-effective and stable feed additives that selectively stimulate beneficial microbial populations. They improve gut fermentation processes, SCFA production, and nutrient assimilation, indirectly enhancing host immunity and growth (Wang *et al*., 2021). Yet, their effectiveness can be host-specific, as not all prebiotics universally support the same gut microbiota composition across species or environments (Gibson *et al*., 2017). Synbiotics represent a combined approach, integrating the direct antimicrobial and immunomodulatory functions of probiotics with the selective stimulatory effects of prebiotics. This synergy enhances probiotic colonization, boosts immune responses, and strengthens gut barrier integrity. Evidence from catfish trials consistently shows that synbiotics deliver superior outcomes in terms of growth performance, feed efficiency, and resistance to pathogens such as *Aeromonas hydrophila* compared to probiotics or prebiotics alone (Khanjani *et al*., 2024). Thus, probiotics and prebiotics individually provide clear benefits to gut health and immunity; their effectiveness may be limited by strain survival, colonization efficiency, or substrate availability when applied alone. Synbiotics overcome these constraints by combining complementary microorganisms and fermentable substrates, thereby enhancing probiotic persistence, metabolic activity, and functional efficacy within the host intestine (Khanjani *et al*., 2024). Experimental evidence in aquaculture demonstrates that synbiotic formulations more consistently improve growth performance, feed efficiency, immune responses, and disease resistance than single-component supplements (Mohammed *et al*., 2022; Ghosh, 2025). This synergistic interaction supports the view that synbiotics represent a more robust and reliable nutritional strategy for sustainable fish health management compared with probiotics or prebiotics used independently. Overall, synbiotics are often considered the most effective strategy for intensive catfish farming, particularly in regions like Malaysia, where disease outbreaks and antibiotic resistance remain major challenges.

CONCLUSION

Probiotics, prebiotics, and synbiotics each contribute meaningfully to the advancement of sustainable freshwater aquaculture, particularly in catfish production, through complementary mechanisms that support gut health and host immunity. While probiotics exert direct antimicrobial and immunomodulatory benefits and prebiotics act as stable, cost-effective substrates that shape beneficial microbial communities, their individual efficacy can be constrained when applied in isolation. In contrast, synbiotics integrate both components to achieve synergistic effects, consistently resulting in superior growth performance, improved nutrient utilization, enhanced immune competence, and greater resistance to pathogens such as *Aeromonas hydrophila*. In the context of increasing antimicrobial resistance and mounting pressure to reduce antibiotic dependence, synbiotics emerge as a strategically superior and environmentally responsible feed-based intervention for intensive catfish aquaculture. Future research should prioritize the rational design of strain–substrate combinations tailored to host species, culture systems, and regional conditions, alongside mechanistic and field-scale validation to support their wider adoption in sustainable aquaculture practices.

ACKNOWLEDGEMENT

The cooperation of the supporting laboratory staff is appreciated. The first author appreciated the financial support from the Grant IPS, Universiti Putra Malaysia (GP-IPS/2024/9789900).

REFERENCES

Abdel-Latif, H.M.R., Yilmaz, E., Dawood, M.A.O., Ringø, E., Ahmadifar, E. & Yilmaz, S. 2022. Shrimp vibriosis and possible control measures using probiotics, postbiotics, prebiotics, and synbiotics: A review. *Aquaculture*, 551: 737951. https://doi.org/10.1016/j.aquaculture.2022.737951.

Abdul Rahim, E.F., Leong, S.S., Sarbini, S.R., Latif, K. & Malahubban, M. 2022. Banana (*Musa acuminata*), Orange (*Citrus reticulata*), and Watermelon (*Citrullus lanatus*) peels as prebiotic. *Borneo Journal of Resource Science and Technology*, 12(1): 81-94. https:doi.org/10.33736/bjrst.4528.2022.

Allameh, S.K., Noaman, V. & Nahavandi, R. 2017. Effects of probiotic bacteria on fish performance. *Advanced Techniques in Clinical Microbiology*, 1: 11.

Ahmadifar, E., Sheikhzadeh, N., Roshanaei, K., Dargahi, N. & Faggio, C. 2019. Can dietary ginger (*Zingiber officinale*) alter biochemical and immunological parameters and gene expression related to growth, immunity and antioxidant system in zebrafish (*Danio rerio*)? *Aquaculture*, 507: 341-348. https://doi.org/10.1016/j.aquaculture.2019.04.049.

Balakrishnan, K., Dhanasekaran, D., Krishnaraj, V., Anbukumaran, A., Ramasamy, T. & Manickam, M. 2021. Edible mushrooms: A promising bioresource for prebiotics. *Advances in Probiotics*, 81-97. https://doi.org/10.1016/b978-0-12-822909-5.00005-8.

Basri, L., Nor, R.M., Salleh, A., Md Yasin, I.S., Saad, M.Z., Abd Rahaman, N.Y., Barkham, T. & Amal, M.N.A. 2020. Co-infections of Tilapia lake virus, *Aeromonas hydrophila* and *Streptococcus agalactiae* in farmed red hybrid Tilapia. *Animals (Basel)*, 10(11): 2141. https://doi.org/10.3390/ani10112141

Davani-Davari, D., Negahdaripour, M., Karimzadeh, I., Seifan, M., Mohkam, M., Masoumi, S.J., Berenjian, A. & Ghasemi, Y. 2019. Prebiotics: definition, types, sources, mechanisms, and clinical applications. *Foods*, 8(3): 92. https://doi.org/10.3390/foods8030092.

Department of Fisheries Malaysia. 2021. *Annual Fisheries Statistics 2021*. Malaysia: Department of Fisheries Malaysia.

El-Saadony, M.T., Alagawany, M., Patra, A.K., Kar, I., Tiwari, R., Dawood, M.A.O., Dhama, K. & Abdel-Latif, H.M.R. 2021. The functionality of probiotics in aquaculture: An overview. *Fish and Shellfish Immunology*, 117: 36-52. https:doi.org/10.1016/j.fsi.2021.07.007.

Food and Agriculture Organization of the United Nations. 2022. *The state of world fisheries and aquaculture-Towards blue transformation*. Rome, Italy: Food and Agriculture Organization of the United Nations: 32.

Garlock, T.M., Asche, F., Anderson, J.L., Eggert, H., Anderson, T.M., Che, B., Chávez, C.A., Chu, J., Chukwuone, N., Dey, M.M., Fitzsimmons, K., Flores, J., Guillen, J., Kumar, G., Liu, L., Llorente, I., Nguyen, L., Nielsen, R., Pincinato, R.B.M., Sudhakaran, P.O., Tibesigwa, B. & Tveteras, R. 2024. Environmental, economic, and social sustainability in aquaculture: the aquaculture performance indicators. *Nature Communication*, 15: 5274. https://doi.org/10.1038/s41467-024-49556-8.

Gibson, G.R., Hutkins, R., Sanders, M.E., Prescott, S.L., Reimer, R.A., Salminen, S.J., Scott, K., Stanton, C., Swanson, K.S., Cani, P.D., Verbeke, K. & Reid, G. 2017. Expert consensus document: The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. *Nature Reviews Gastroenterology and Hepatology*, 14(8): 491-502. https://doi.org/10.1038/nrgastro.2017.75.

Ghosh, T. 2025. Recent advances in the potential and multifaceted role of probiotics in the development of sustainable aquaculture: Its current form and future perspectives. *The Microbe*, 7: 100317. https://doi.org/10.1016/j.microb.2025.100317.

Hamid, N.H., Daud, H.M., Kayansamruaj, P., Hassim, H.A., Mohd Yusoff, M.S., Abu Bakar, S.N. & Srisapoome, P. 2021. Short- and long-term probiotic effects of *Enterococcus hirae* isolated from fermented vegetable wastes on the growth, immune responses, and disease resistance of hybrid catfish (*Clarias gariepinus* × *Clarias macrocephalus*). *Fish and Shellfish Immunology*, 114: 1-19. https://doi.org/10.1016/j.fsi.2021.04.012.

Hoseinifar, S.H., Sun, Y.Z., Wang, A. & Zhou, Z. 2018. Probiotics as means of diseases control in aquaculture, a review of current knowledge and future perspectives. *Frontiers in Microbiology*, 9: 2429. https://doi.org/10.3389/fmicb.2018.02429.

Hosseini, S.S., Sudaagar, M., Zakariaee, H., Paknejad, H., Baruah, K. & Norouzitalab, P. 2024. Evaluation of the synbiotic effects of *Saccharomyces cerevisiae* and mushroom extract on the growth performance, digestive enzyme activity, and immune status of zebrafish *Danio rerio*. *BMC Microbiology*, 24(1): 331. https:doi.org/10.1186/s12866-024-03459-2.

Kattakdad, S., Phungam, N., Pongket, U., Muangmala, W., Udduang, S., Aripin, S.A. & Yuangsoi, B. 2025. Microencapsulated inulin as a prebiotic: Enhancing growth, digestive enzyme activity, and immune response in striped catfish (*Pangasianodon hypophthalmus*). *Aquaculture Reports*, 43: 102986. https://doi.org/10.1016/j.aqrep.2025.102986.

Khairul, S.R., Leong, S.S., Korel, F., Lingoh, A.D. & Toh, S.C. 2024. Systematic review of emerging trends in soil-based probiotics. *Malaysian Journal of Soil Science*, 28: 401-413.

Khanjani, M.H., Mozanzadeh, M.T., Gisbert, E. & Hoseinifar, S.H. 2024. Probiotics, prebiotics, and synbiotics in shrimp aquaculture: Their effects on growth performance, immune responses, and gut microbiome. *Aquaculture Reports*, 38: 102362. https://doi.org/10.1016/j.aqrep.2024.102362.

Lee, S., Choi, S.-P., Choi, H.-J., Jeong, H. & Park, Y.-S. 2024. A comprehensive review of synbiotics: an emerging paradigm in health promotion and disease management. *World Journal of Microbiology and Biotechnology*, 40(9). https://doi.org/10.1007/s11274-024-04085-w.

Leong S.S., Korel, F., Lingoh, A.D., Sarbini, S.R., Toh, S.C., Abit, L.Y. & Wong, S.C. 2023. Current probiotics application for aquaculture feed: A review. *Borneo Science Journal*, 44(2). https://doi.org/10.51200/bsj.v44i2.

Leong, S.S., Samuel, L., Ling, T.Y., Chia, H.C. & Lim, C.K. 2013. Isolation and characterization of antibiotic-resistant bacteria from swiftlet feces in swiftlet farmhouses in Sarawak, Malaysia. *Microbiology Indonesia Journal*, 7(4): 137-143.

Li, J., Li, X., Liu, H., Gao, L., Wang, W., Wang, Z., Zhou, T. & Wang, Q. 2023. Climate change impacts on wastewater infrastructure: A systematic review and typological adaptation strategy. *Water Research*, 242: 120282. https://doi.org/10.1016/j.watres.2023.120282.

Li, Y., Yuan, W., Zhang, Y., Liu, H. & Dai, X. 2020. Single or combined effects of dietary arabinoxylan-oligosaccharide and inulin on growth performance, gut microbiota, and immune response in Pacific white shrimp *Litopenaeus vannamei*. *Journal of Oceanology and Limnology*, 39(2): 741-754. https://doi.org/10.1007/s00343-020-9083-z.

Li, Z., Tran, N. T., Ji, P., Sun, Z., Wen, X. & Li, S. 2019. Effects of prebiotic mixtures on growth performance, intestinal microbiota and immune response in juvenile chu's croaker, *Nibea coibor*. *Fish and Shellfish Immunology*, 89: 564-573. https://doi.org/10.1016/j.fsi.2019.04.025.

Lingoh, A.D., Latif, K., Lee, Y.N., Abit, L.Y., Sarbini, S.R., Vincent Mojilis, M.I., Shamsul Azhar, F. M., Khairul, S.R. & Leong, S.S. 2025. Enrichment of artemia with synbiotic and its effects on growth nutrient utilization survival and gut microbial communities of larval hybrid catfish (*Clarias microstomus* × *Clarias gariepinus*). *Aquaculture Nutrition*, 2025: 6616288. https://doi.org/10.1155/anu/6616288

Lingoh, A.D., Leong, S.S. & Sarbini, S.R. 2020. Detection of lactic acid bacteria (LAB) from local chicken breed gut as probiotic agent in livestock. *Pakistan Journal of Nutrition*, 19: 197-203.

Manyise, T., Basiita, R.K., Mwema, C.M., Oyesola, O., Siriwardena, S., Fregene, B., Cole, S.M., Dompreh, E.B., Lam, R.D., Lozano, D.L., Rossignoli, C.M. & Benzie, J.A.H. 2024. Farmer perspectives on desired catfish attributes in aquaculture systems in Nigeria. An exploratory focus group study. *Aquaculture*, 588: 740911. https://doi.org/10.1016/j.aquaculture.2024.740911.

Mohammadi, G., Rafiee, G., El Basuini, M.F., Abdel-Latif, H.M.R. & Dawood, M.A. O. 2020. The growth performance, antioxidant capacity, immunological responses, and the resistance against *Aeromonas hydrophila* in Nile tilapia (*Oreochromis niloticus*) fed Pistacia vera hulls derived polysaccharide. *Fish and Shellfish Immunology*, 106: 36-43. https://doi.org/10.1016/j.fsi.2020.07.064.

Mohammed, A., Hu, J., Murugesan, R. & Cheng, H.-W. 2022. Effects of a synbiotic as an antibiotic alternative on behavior, production performance, cecal microbial ecology, and jejunal histomorphology of broiler chickens under heat stress. *PLOS ONE*, 17(9): e0274179. https://doi.org/10.1371/journal.pone.0274179.

Naylor, R.L., Kishore, A., Sumaila, U.R., Issifu, I., Hunter, B.P., Belton, B., Bush, S.R., Cao, L., Gelcich, S., Gephart, J.A., Golden, C.D., Jonell, M., Koehn, J.Z., Little, D.C., Thilsted, S.H., Troell, M. & Zhang, W. 2021. Blue food demand across geographic and temporal scales. *Nature Communications,* 12: 5413. https://doi.org/10.1038/s41467-021-25516-4.

Omeje, V.O. & Kolndadacha, O.D. 2024. *Motile aeromonas septicaemia infection in African catfish (Clarias gariepinus, Burchell, 1822): A review*. United Kingdom: CABI Reviews. https://doi.org/10.1079/cabireviews.2024.0010

Pawlak, K. & Kołodziejczak, M. 2020. The role of agriculture in ensuring food security in developing countries: considerations in the context of the problem of sustainable food production. *Sustainability*, 12(13): 5488. https://doi.org/10.3390/su12135488.

Rawi, M.H., Zaman, S.A., Pa'ee, K.F., Leong, S.S. & Sarbini, S.R. 2020. Prebiotics metabolism by gut-isolated probiotics. *Food Science and Technology*, 57: 2786-2799. https://doi.org/10.1007/s13197-020-04244-5

Ridzuan, M.S.M., Abdullah, A., Ramly, R., Mansor, N.N., Ramli, N. & Firdaus-Nawi, M. 2022. Current status and advances of fish vaccines in Malaysia. *Veterinary World*, 15(2): 465-482. https://doi.org/10.14202/vetworld.2022.465-482.

Rohani, M.F., Islam, S.M., Hossain, M.K., Ferdous, Z., Siddik, M. AB., Nuruzzaman, M., Padeniya, U., Brown, C. & Shahjahan, M. 2022. Probiotics, prebiotics and synbiotics improved the functionality of aquafeed: Upgrading growth, reproduction, immunity and disease resistance in fish. *Fish and Shellfish Immunology*, 120: 569-589. https://doi.org/10.1016/j.fsi.2021.12.037.

Sanders, M.E., Merenstein, D.J., Reid, G., Gibson, G.R. & Rastall, R.A. 2019. Probiotics and prebiotics in intestinal health and disease: from biology to the clinic. *Nature Reviews Gastroenterology and Hepatology*, 16(10): 605-616. https://doi.org/10.1038/s41575-019-0173-3.

Semwal, A., Kumar, A. & Kumar, N. 2023. A review on pathogenicity of *Aeromonas hydrophila* and their mitigation through medicinal herbs in aquaculture. *Heliyon*, 9(3): e14088. https://doi.org/10.1016/j.heliyon.2023.e14088.

Shoaei, R., Akrami, R., Ghobadi, S. & Razeghi Mansour, M. 2015. Effect of dietary of prebiotic mannan oligosaccharide and β-1, 3 glucan on growth performance, survival, body composition and serum lysozyme activity in Rainbow trout (*Oncorhynchus mykiss*) fingerling. *Journal of Marine Biology*, 7 (2): 45-56.

Smolinska, S., Popescu, F.-D. & Zemelka-Wiacek, M. 2025. A Review of the influence of prebiotics, probiotics, synbiotics, and postbiotics on the human gut microbiome and intestinal integrity. *Journal of Clinical Medicine*, 14(11): 3673. https://doi.org/10.3390/jcm14113673.

Swanson, K.S., Gibson, G.R., Hutkins, R., Reimer, R.A., Reid, G., Verbeke, K., Scott, K.P., Holscher, H.D., Azad, M.B., Delzenne, N.M. & Sanders, M.E. 2020. The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of synbiotics. *Nature Reviews Gastroenterology & Hepatology*, 17(11): 687-701. https://doi.org/10.1038/s41575-020-0344-2.

Tabassum, T., Sofi Uddin Mahamud, A.G.M., Acharjee, T.K., Hassan, R., Akter Snigdha, T., Islam, T., Alam, R., Khoiam, Md. U., Akter, F., Azad, Md. R., Al Mahamud, Md. A., Ahmed, G.U. & Rahman, T. 2021. Probiotic supplementations improve growth, water quality, hematology, gut microbiota and intestinal morphology of Nile tilapia. *Aquaculture Reports*, 21: 100972. https://doi.org/10.1016/j.aqrep.2021.100972.

Van Doan, H., Hoseinifar, S.H., Ringø, E., Ángeles Esteban, M., Dadar, M., Dawood, M.A.O. & Faggio, C. 2019. Host-associated probiotics: A key factor in sustainable aquaculture. *Reviews in Fisheries Science and Aquaculture*, 28(1): 16-42. https://doi.org/10.1080/23308249.2019.1643288.

Wang, H., Bruce, T.J., Su, B., Li, S., Dunham, R.A. & Wang, X. 2022. Environment-dependent heterosis and transgressive gene expression in reciprocal hybrids between the Channel Catfish *Ictalurus punctatus* and the Blue Catfish *Ictalurus furcatus*. *Biology (Basel)*, 11(1): 117. https://doi.org/10.3390/biology11010117.

Walker, P.J. & Winton, J.R. 2010. Emerging viral diseases of fish and shrimp. *Veterinary Research*, 41(6): 51. https://doi.org/10.1051/vetres/2010022.

.