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Gut Microbiota Modulation by Phytobiotics in Pacific White Shrimp (*Litopenaeus Vannamei*): A Literature Review

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ABSTRACT

Background: The Pacific white shrimp (*Litopenaeus vannamei*) is one of the most economically important aquaculture species worldwide. However, intensive farming practices have increased the incidence of disease outbreaks, environmental stress, and gut microbiota dysbiosis, resulting in reduced productivity and sustainability. Phytobiotics have emerged as promising natural feed additives due to their antimicrobial, antioxidant, and immunostimulatory properties, with increasing evidence suggesting their role in modulating gut microbial communities. Nevertheless, current findings remain fragmented across different phytobiotic sources and experimental approaches.

Aims: This systematic literature review aimed to synthesize current evidence regarding the effects of phytobiotics on gut microbiota composition, growth performance, immune responses, and disease resistance in *L. vannamei*.

Methods: Literature published between 2015 and 2025 was retrieved from Scopus, ScienceDirect, and Google Scholar following predefined inclusion criteria, and 20 eligible studies were included in the qualitative synthesis.

Results: The reviewed studies consistently demonstrated that phytobiotics promote beneficial gut bacteria while suppressing opportunistic pathogens, particularly *Vibrio* spp., thereby improving intestinal microbial balance and hepatopancreatic health. These microbial changes were associated with enhanced nutrient utilization, improved feed efficiency, stronger innate immune responses, increased antioxidant capacity, and greater resistance to bacterial infections, ultimately resulting in better growth performance. Although the available evidence supports the potential of phytobiotics as sustainable alternatives to antibiotics, microbiome-based studies remain limited.

Recommendation: Future research integrating high-throughput sequencing and multi-omics approaches is required to elucidate the mechanisms underlying phytobiotic–microbiota interactions and optimize their application in sustainable shrimp aquaculture.

1. Introduction

The Pacific white shrimp (*Litopenaeus vannamei*) is one of the most important aquaculture commodities, contributing substantially to global aquaculture production. Its rapid growth rate, high survival performance, adaptability to diverse environmental conditions, and continuously increasing market demand have made this species a dominant commodity in shrimp farming industries worldwide, including Indonesia. However, the intensification of shrimp culture practices aimed at meeting production demands is frequently accompanied by increased environmental stress, deterioration of water quality, disease outbreaks, and gastrointestinal health disorders, which ultimately reduce farming productivity (Ringø *et al.*, 2018; Piamsomboon & Han, 2022).

In recent years, intestinal health has become a major focus in modern shrimp aquaculture management. The gastrointestinal tract serves not only as a site for nutrient digestion and absorption but also as a habitat for diverse microbial communities collectively known as the gut microbiota. These microbial communities play crucial roles in nutrient metabolism, bioactive compound synthesis, immune regulation, protection against pathogen colonization, and maintenance of host physiological homeostasis. According to Bäckhed *et al.*, (2005), the gut microbiota can be considered a “second genome” because of its enormous genetic diversity and metabolic capacity that contribute significantly to host health and physiological functions.

The composition of the gut microbiota in shrimp is influenced by numerous factors, including diet composition, water quality, host age, stocking density, environmental conditions, and the presence of pathogenic microorganisms. Disruptions in microbial community structure, commonly referred to as dysbiosis, may impair digestive tract function, reduce nutrient utilization efficiency, and increase susceptibility to disease. Alterations in gut microbial communities have been closely associated with several major shrimp diseases, including Acute Hepatopancreatic Necrosis Disease (AHPND), White Feces Syndrome (WFS), and various infections caused by opportunistic bacteria belonging to the genus *Vibrio* (Piamsomboon & Han, 2022; Chang *et al.*, 2023; Priya *et al.*, 2024). Consequently, strategies aimed at maintaining or restoring gut microbial balance have emerged as important approaches for improving shrimp health and aquaculture productivity.

For several decades, antibiotics have been widely used as a primary strategy for disease control in shrimp farming. However, the continuous use of antibiotics has generated significant concerns, including the emergence of antimicrobial resistance, accumulation of antibiotic residues in aquaculture products, disruption of gut microbial balance, and environmental contamination of aquatic ecosystems (Cabello, 2006; Schar *et al.*, 2020). These concerns have stimulated the development of safer, environmentally friendly, and sustainable alternatives for maintaining the health of cultured aquatic organisms. Among these alternatives, phytobiotics have received increasing attention in recent years.

Phytobiotics are plant-derived feed additives containing a wide range of bioactive compounds, including flavonoids, alkaloids, saponins, tannins, polyphenols, terpenoids, and essential oils. These compounds exhibit antimicrobial, antioxidant, anti-inflammatory, and immunostimulatory properties that can enhance the health status of aquatic organisms. In shrimp aquaculture, phytobiotics have been reported not only to improve growth performance and feed utilization efficiency but also to strengthen immune responses and increase disease resistance (Reverter *et al.*, 2014; Hai, 2015). Furthermore, phytobiotics can influence the structure and composition of gut microbial communities by promoting beneficial bacteria while suppressing pathogenic microorganisms.

Over the past decade, numerous studies have demonstrated that dietary phytobiotics provide multiple benefits in Pacific white shrimp (*Litopenaeus vannamei*) culture. Beyond serving as natural alternatives

to antibiotics, phytobiotics have consistently been reported to improve growth performance, feed utilization efficiency, and survival through enhanced digestive enzyme activity and nutrient absorption. Several phytobiotic compounds, including cinnamaldehyde, citral, garlic extract, mangrove (*Rhizophora mucronata*) leaf extract, and phytogetic blends, have also been shown to stimulate innate immune responses by increasing total hemocyte count, phenoloxidase activity, antioxidant capacity, and resistance against bacterial pathogens, particularly *Vibrio* spp. Furthermore, recent advances in microbiome research suggest that many of these physiological improvements are closely associated with phytobiotic-induced modulation of the intestinal microbiota, indicating that gut microbial communities represent an important mediator linking dietary phytobiotics to host health and productivity.

In Indonesia, research on natural products as phytobiotic sources has expanded considerably in response to the increasing demand for sustainable aquaculture technologies. [Linayati et al., \(2023\)](#) reported that dietary supplementation with mangrove (*Rhizophora mucronata*) leaf extract improved the growth performance of Pacific white shrimp. Similarly, [Mardiana et al., \(2024\)](#) demonstrated that *R. mucronata* leaf-based feed additives enhanced growth and feed utilization efficiency in shrimp culture. Furthermore, [Hendriana et al., \(2024\)](#) reported that dietary supplementation with cinnamaldehyde, a well-known phytobiotic compound, improved nutrient utilization efficiency and growth performance in *L. vannamei*. These findings highlight the considerable potential of phytobiotics as sustainable tools for promoting healthier and more environmentally friendly shrimp production systems.

Interest in the role of gut microbiota in shrimp farming has also increased substantially in Indonesia. [Gustilatov et al., \(2024\)](#) reported that different culture systems significantly influenced intestinal bacterial composition, the abundance of *Vibrio* species, and the condition of intestinal microvilli in Pacific white shrimp. Meanwhile, [Wang et al., \(2007\)](#) demonstrated that manipulating intestinal microbial communities through supplementation with beneficial microorganisms improved both growth performance and survival rates of *L. vannamei*. These findings suggest that the management of gut microbial communities represents a critical factor for the success of modern shrimp aquaculture.

Recent studies have demonstrated that phytobiotics can modulate gut microbiota through several mechanisms, including the enhancement of beneficial microbial diversity, inhibition of pathogen colonization, improvement of intestinal epithelial integrity, and stimulation of host immune responses. Dietary supplementation with phytobiotic-based additives has been shown to improve gut microbial community structure, enhance hepatopancreatic health, and increase resistance against *Vibrio parahaemolyticus* infection in Pacific white shrimp ([Zokaeifar et al., 2012](#); [Li et al., 2018](#)). These findings indicate that the benefits of phytobiotics extend beyond their direct antimicrobial activity and are also associated with their capacity to maintain microbial ecosystem balance within the gastrointestinal tract, thereby supporting overall host health.

Although numerous studies investigating the application of phytobiotics in Pacific white shrimp culture have been published, information regarding their effects on gut microbiota modulation remains scattered across studies employing different phytobiotic sources, application methods, and evaluation parameters. To date, relatively few studies have systematically synthesized these findings to provide a comprehensive understanding of the mechanisms and effectiveness of phytobiotics in modulating gut microbiota in *L. vannamei*. Despite the growing body of literature on the application of phytobiotics in shrimp aquaculture, most previous studies have primarily focused on evaluating growth performance, feed utilization efficiency, antioxidant capacity, immune responses, and disease resistance. Comparatively fewer studies have comprehensively investigated the influence of phytobiotics on gut microbiota composition and function, particularly in *L. vannamei*. Moreover, existing findings remain fragmented due to the use of different phytobiotic sources, experimental designs, sequencing approaches, and microbiological assessment methods. As a result, a clear understanding of how phytobiotics modulate gut microbial communities and how these changes contribute to host health and productivity remains limited.

Furthermore, although several review articles have discussed the general benefits of phytobiotics in aquaculture, there is currently a lack of systematic reviews specifically synthesizing evidence on the interactions among phytobiotics, gut microbiota, immune responses, growth performance, and disease resistance in *L. vannamei*. Therefore, the novelty of the present review lies in its comprehensive synthesis of recent studies examining phytobiotic-induced modulation of shrimp gut microbiota and its implications for host physiology and health. By integrating findings from microbiological, nutritional, immunological, and disease-resistance perspectives, this review provides a more holistic understanding of the mechanisms through which phytobiotics contribute to sustainable shrimp aquaculture. Therefore, this systematic review aims to identify, evaluate, and synthesize available evidence regarding the effects of phytobiotics on gut microbiota composition, growth performance, immune responses, and disease resistance in Pacific white shrimp (*Litopenaeus vannamei*). The findings of this review are expected to provide a scientific basis for the development of more productive, healthy, and sustainable shrimp aquaculture strategies.

2. Methods

2.1 Study Design

This study was conducted using a systematic literature review approach to synthesize existing evidence regarding the effects of phytobiotics on gut microbiota, growth performance, immune responses, and disease resistance in Pacific white shrimp (*L. vannamei*). The review focused on studies published between 2015-2025, reflecting the increasing scientific interest in the application of plant-derived bioactive compounds as sustainable alternatives to antibiotics in modern aquaculture. Through a comprehensive evaluation of available literature, this review aims to provide both conceptual and practical insights into the role of phytobiotics in improving shrimp health and supporting sustainable aquaculture development.

2.2 Literature Selection Criteria

Articles were included in the review if they met the following criteria: (i) published between 2015-2025; (ii) focused on the effects of phytobiotics on gut microbiota, growth performance, immune responses, or disease resistance in *L. vannamei*; (iii) presented original research data or systematic review findings; and (iv) were published in peer-reviewed scientific journals indexed in national databases (e.g., SINTA) or international databases (e.g., Scopus and ScienceDirect).

Studies were excluded if they: (i) did not focus on shrimp species; (ii) were not related to phytobiotic applications; (iii) did not discuss gut microbiota or the utilization of phytobiotics; or (iv) lacked sufficient methodological or experimental information.

2.3 Search Strategy

Relevant literature was retrieved from Scopus, ScienceDirect, and Google Scholar using combinations of the following keywords: “phytobiotic”, “gut microbiota”, “intestinal microbiota”, “*Litopenaeus vannamei*”, “Pacific white shrimp”, “aquaculture”, “growth performance”, “immune response”, “disease resistance”, and “*Vibrio*”. Boolean operators (AND, OR) were applied to optimize the search process and improve the relevance of retrieved articles.

2.4 Study Selection Process

The literature selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A total of 50 records were initially identified through database searches, comprising 20 articles from Scopus, 15 from Science Direct, and 15 from Google Scholar. After duplicate removal, 35 records remained and were screened based on their titles and abstracts. During the screening stage, 10 articles were excluded because they were not focused on shrimp species

or were unrelated to phytobiotic applications. Subsequently, 25 full-text articles were assessed for eligibility. Five articles were excluded because they did not discuss gut microbiota or the utilization of phytobiotics. Ultimately, 20 studies met the inclusion criteria and were included in the final qualitative synthesis.

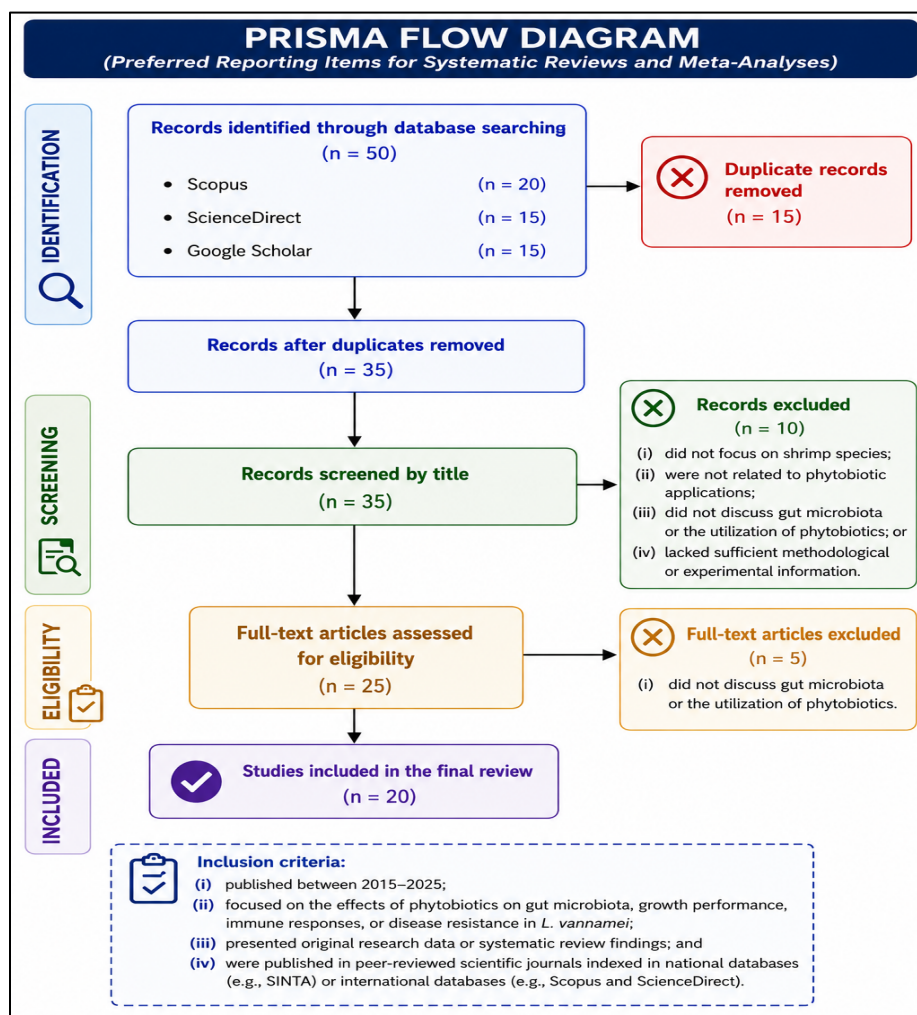


Figure 1. Prisma Flow Diagram

2.5 Data Extraction and Synthesis

Relevant information was extracted from each selected study, including phytobiotic source, experimental design, application method, duration of treatment, gut microbiota responses, growth performance indicators, immune parameters, disease resistance outcomes, and major findings. The collected information was subsequently synthesized descriptively to identify common trends, mechanisms of action, and potential benefits of phytobiotics in modulating gut microbiota and improving the health status of Pacific white shrimp.

2.6 Quality Assessment

The methodological quality of the selected studies was assessed based on study objectives, experimental design, sample size, phytobiotic characterization, microbiota assessment methods, and reporting completeness. Only studies providing sufficient methodological details and relevant outcome data were included in the final synthesis.

3. Results and Discussions

3.1 Phytobiotics in Pacific White Shrimp Culture

In Indonesia, research on the application of phytobiotics in Pacific white shrimp (*L. vannamei*) culture has developed rapidly in recent years. [Linayati et al., \(2023\)](#) reported that dietary supplementation with mangrove (*R. mucronata*) leaf extract significantly improved shrimp growth performance. Similar findings were reported by [Mardiana et al., \(2024\)](#), who demonstrated that the use of mangrove leaves as a feed additive enhanced feed efficiency and growth performance. Furthermore, [Hendriana et al., \(2024\)](#) found that dietary cinnamaldehyde supplementation positively affected nutrient utilization and growth performance in Pacific white shrimp. In addition, [Kurniawinata et al., \(2025\)](#) reported that extracts derived from garlic, *Eurycoma longifolia*, and white turmeric have the potential to enhance immune responses and increase resistance against pathogenic bacterial infections.

The phytobiotics investigated in the reviewed studies were highly diverse and included garlic (*Allium sativum*), turmeric (*Curcuma longa*), bitter herb (*Andrographis paniculata*), cinnamon (*Cinnamomum verum*), mangrove leaves (*Rhizophora mucronata*), *Eurycoma longifolia*, and various combinations of plant extracts and essential oils. These materials contain a wide range of bioactive compounds, including flavonoids, alkaloids, phenolic compounds, saponins, tannins, and terpenoids, which are known to possess antimicrobial, antioxidant, and immunostimulatory properties ([Firmino et al., 2021](#); [Ghosh et al., 2021](#); [Seong Wei et al., 2024](#)).

The parameters evaluated in the reviewed studies included weight gain, specific growth rate, feed conversion ratio, survival rate, digestive enzyme activity, antioxidant activity, hematological parameters, immune-related gene expression, gut microbiota composition, and resistance against bacterial and viral infections. According to [Ringø et al., \(2018\)](#), the evaluation of these parameters is essential for understanding the relationship between gut microbiota, intestinal health, and the production performance of aquatic organisms. Recent studies have increasingly employed 16S rRNA gene sequencing to evaluate phytobiotic-induced alterations in shrimp gut microbial communities ([Zeng et al., 2024](#); [Ma et al., 2024](#); [Lin et al., 2024](#)).

Most studies were conducted over culture periods ranging from 30 to 90 days, with phytobiotics primarily administered through dietary supplementation. The applied dosages varied depending on the phytobiotic source, active compounds, and research objectives. Despite differences in phytobiotic types, supplementation levels, and experimental conditions, most studies consistently reported improvements in gut health, growth performance, feed utilization efficiency, immune responses, and disease resistance following phytobiotic administration ([Ghosh et al., 2021](#); [Firmino et al., 2021](#); [Ma et al., 2024](#); [Seong Wei et al., 2024](#)). Collectively, these findings suggest that phytobiotics have considerable potential as sustainable and environmentally friendly tools for improving shrimp health and aquaculture productivity.

Table 1. Phytobiotics in Pacific White Shrimp Culture

No	Phytobiotic	Main Findings	References
1	Phytobiotic blend	Increased microbial diversity, improved hepatopancreas health, enhanced resistance against <i>Vibrio parahaemolyticus</i>	Ma et al., (2024)
2	<i>Allium sativum</i> , <i>Eurycoma longifolia</i> , <i>Curcuma zedoaria</i> extracts	Immune response and disease resistance	Kurniawinata et al., (2025)
3	Cinnamaldehyde	Growth performance, nutrient utilization, feed efficiency	Hendriana et al., (2024)

4	<i>Rhizophora mucronata</i> leaf extract	Growth performance	Linayati <i>et al.</i> , (2023)
5	<i>Rhizophora mucronata</i> leaf extract	Growth performance and feed conversion ratio (FCR)	Mardiana <i>et al.</i> , (2024)
6	Herbal phytobiotics	Gut microbiota composition, immune modulation	Lin <i>et al.</i> , (2024)
7	Plant-derived phytobiotics	Gut microbiota diversity, intestinal health, immune response	Zeng <i>et al.</i> , (2024)
8	Various phytobiotics used in marine shrimp aquaculture (review)	Growth performance, immune responses, antioxidant capacity, and gut microbiota modulation	Seong Wei <i>et al.</i> , 2024
9	Essential oils dan plant extracts	Growth performance, immune responses, and disease resistance	Firmino <i>et al.</i> , (2021)
10	Herbal phytobiotics	Growth performance, feed utilization efficiency, and immune responses	Ghosh <i>et al.</i> , (2021)
11	Phlorotannins (phenolic compounds derived from brown seaweeds)	Growth performance, immune responses, antioxidant activity, and gut microbiota composition	Wu <i>et al.</i> , (2024)
12	Phytogenic formulation	Growth performance, feed conversion ratio (FCR), gut microbiota composition, and resistance against vibriosis	Lee <i>et al.</i> , (2024)

3.2 Gut Microbiota in Pacific White Shrimp

The gut microbiota comprises diverse microbial communities that inhabit and dynamically interact within the gastrointestinal tract of aquatic organisms. In Pacific white shrimp (*L. vannamei*), the gut microbiota plays essential roles in nutrient digestion and absorption, digestive enzyme synthesis, bioactive metabolite production, immune regulation, and protection against pathogenic colonization (Ringø *et al.*, 2018; Lin *et al.*, 2024). These microbial communities establish mutualistic interactions with the host, thereby contributing to shrimp health maintenance and growth performance.

The gut microbiota of Pacific white shrimp is generally dominated by several major bacterial phyla, including Proteobacteria, Firmicutes, Bacteroidetes, and Actinobacteria. Proteobacteria is typically the most abundant phylum and plays a key role in nutrient metabolism and biogeochemical cycling within the digestive tract. Firmicutes contribute to carbohydrate fermentation and the production of short-chain fatty acids that support intestinal health. Bacteroidetes are recognized for their ability to degrade complex organic compounds through diverse carbohydrate-active enzymes, whereas Actinobacteria produce a wide range of bioactive metabolites that may contribute to host defense and intestinal homeostasis (Binda *et al.*, 2018; Zeng *et al.*, 2024).

The structure of the gut microbial community is influenced by numerous factors, including water quality, diet composition, host age, stocking density, culture system, and overall health status. Environmental disturbances can lead to dysbiosis, a condition characterized by a reduction in beneficial microbial populations and an increase in opportunistic microorganisms. Intestinal dysbiosis has been closely associated with the occurrence of major shrimp diseases, including Acute Hepatopancreatic Necrosis Disease (AHPND), White Feces Syndrome (WFS), and infections involving opportunistic *Vibrio* species (Xiong *et al.*, 2024; Piamsomboon & Han, 2022; Chang *et al.*, 2023).

Members of the genus *Vibrio* are among the most frequently detected microorganisms in diseased shrimp. Under normal conditions, certain *Vibrio* species may constitute part of the natural gut microbiota. However, disturbances in microbial balance can promote excessive proliferation of these bacteria, increasing the risk of disease outbreaks. In contrast, beneficial and commensal bacteria can inhibit pathogen colonization through niche competition, production of antimicrobial compounds, and stimulation of host immune responses (Ringø *et al.*, 2018).

Studies conducted in Indonesia have also highlighted the importance of gut microbial communities in shrimp culture. [Gustilatov et al., \(2024\)](#) reported that biofloc-based culture systems significantly influenced the abundance of *Vibrio* populations and the condition of intestinal microvilli in Pacific white shrimp. These findings indicate that microbial management within aquaculture systems can contribute substantially to intestinal health and growth performance.

Advances in molecular biology techniques, particularly 16S rRNA gene sequencing, have greatly enhanced our understanding of the relationship between gut microbiota and shrimp health. Numerous studies have demonstrated that the manipulation of gut microbial communities through probiotics, prebiotics, synbiotics, and phytobiotics can increase microbial diversity and suppress pathogenic bacteria ([Dawood et al., 2018](#); [Li et al., 2018](#); [Ma et al., 2024](#)). Therefore, gut microbiota modulation is increasingly recognized as a promising strategy for supporting productive, healthy, and sustainable shrimp aquaculture while reducing dependence on antibiotics.

Table 2. Gut Microbiota in Pacific White Shrimp

No	Dominant Phylum/Genus	Primary Role in the Shrimp Gut	References
1	Proteobacteria	Dominant bacterial phylum involved in nutrient metabolism, nitrogen cycling, and microbial community stability.	Lin et al., (2024) ; Zeng et al., (2024)
2	Firmicutes	Associated with carbohydrate fermentation, energy production, and maintenance of intestinal health.	Ringø et al., (2018) ; Lin et al., (2024)
3	Bacteroidetes	Specialized in the degradation of complex polysaccharides and organic substrates.	Zeng et al., (2024)
4	Actinobacteria	Known for producing bioactive metabolites that contribute to pathogen suppression and host defense.	Lin et al., (2024)
5	<i>Bacillus</i> spp.	Beneficial bacteria frequently associated with improved digestion, nutrient utilization, and immune stimulation.	Ringø et al., (2018)
6	<i>Lactobacillus</i> spp.	Contribute to microbial homeostasis through competitive exclusion of pathogens and production of antimicrobial compounds.	Ringø et al., (2018)
7	<i>Vibrio</i> spp.	Opportunistic bacteria that may proliferate during dysbiosis and are frequently associated with diseases such as AHPND and vibriosis.	Chang et al., (2023) ; Xiong et al., (2024) ; Ma et al., (2024) ; Gustilatov et al., (2024)

3.3 Effects of Phytobiotics on Gut Microbiota Composition

Phytobiotics are plant-derived bioactive compounds that have been widely investigated as alternatives to antibiotics in aquaculture. Numerous studies have demonstrated that phytobiotics function not only as natural antimicrobial agents and immunostimulants but also as modulators of gut microbial communities, thereby supporting intestinal health and shrimp performance. The modulation of gut microbiota by phytobiotics occurs through multiple mechanisms, including stimulation of beneficial bacterial growth, inhibition of pathogenic microorganisms, enhancement of intestinal epithelial integrity, and improvement of the intestinal microenvironment ([Dawood et al., 2018](#); [Seong Wei et al., 2024](#)).

Alterations in gut microbial composition following phytobiotic supplementation are generally characterized by increased abundance of beneficial bacteria involved in nutrient metabolism and intestinal health, accompanied by a reduction in opportunistic pathogens. [Ma et al., \(2024\)](#) reported that dietary supplementation with a phytobiotic-based additive increased gut microbial diversity, improved

hepatopancreatic health, and enhanced resistance against *Vibrio parahaemolyticus* infection in Pacific white shrimp. These findings indicate that phytobiotics contribute to maintaining microbial equilibrium and promoting the stability of the intestinal ecosystem.

Phytobiotic compounds such as cinnamaldehyde and citral have also been reported to exert positive effects on shrimp gastrointestinal health. [Hendriana et al., \(2024\)](#) demonstrated that dietary cinnamaldehyde supplementation improved nutrient utilization efficiency and growth performance in Pacific white shrimp. Similarly, [Pratama et al., \(2023\)](#) found that citral supplementation enhanced both shrimp health and growth performance. Although these studies did not directly assess gut microbiota composition using molecular techniques, the observed improvements in intestinal health suggest the presence of beneficial shifts in microbial community balance.

The utilization of Indonesian indigenous plants as phytobiotic sources has also yielded promising results. [Linayati et al., \(2023\)](#) reported that supplementation with *R. mucronata* leaf extract enhanced shrimp growth performance. Likewise, [Mardiana et al., \(2024\)](#) demonstrated that mangrove leaf-based feed additives improved feed efficiency and growth performance. These beneficial effects are likely associated with the presence of flavonoids, tannins, and phenolic compounds that suppress pathogenic bacteria while supporting the development of a more balanced gut microbial community.

In addition to promoting beneficial bacteria, phytobiotics play a significant role in suppressing opportunistic pathogens such as *Vibrio* spp. According to [Xiong et al., \(2024\)](#), the proliferation of *Vibrio* populations within the gastrointestinal tract is frequently associated with dysbiosis and disease outbreaks in shrimp. Consequently, the antimicrobial activity of phytobiotics represents an important mechanism for maintaining intestinal health. Essential oils, flavonoids, and terpenoids have been shown to disrupt bacterial cell membranes and inhibit pathogen proliferation without substantially affecting beneficial microbial populations ([Seong Wei et al., 2024](#)).

Overall, the reviewed studies consistently demonstrate that phytobiotic supplementation exerts beneficial effects on the gut microbial community structure of Pacific white shrimp. Commonly reported outcomes include increased microbial diversity, enhanced abundance of beneficial and commensal bacteria, reduced pathogen populations, and improved intestinal health. These changes contribute to improved growth performance, feed utilization efficiency, immune responses, and disease resistance. Therefore, phytobiotics represent a promising strategy for gut microbiota management in sustainable and environmentally friendly shrimp aquaculture.

Table 3. Effects of Phytobiotics on Gut Microbiota Composition

No	Phytobiotic	Source	Effects on Gut Microbiota	Biological Effects	References
1	Phytobiotic blend	Mixture of plant extracts and essential oils	Increased diversity of beneficial bacteria and reduced opportunistic bacterial populations	Improved hepatopancreatic health and disease resistance	Ma et al., (2024)
2	Herbal-based phytobiotics	Various plant extracts	Modulated gut microbiota composition and enhanced bacterial community stability	Improved immune responses and intestinal health	Lin et al., (2024); Zeng et al., (2024)
3	Phytogenic formulation	Commercial plant-based phytogenic blend	Increased the abundance of several probiotic genera and reduced pathogenic bacterial genera based on 16S rRNA analysis	Enhanced resistance to vibriosis	Lee et al., (2024)

4	Cinnamaldehyde	Cinnamon (<i>Cinnamomum</i> spp.)	Effects on gut microbiota have not been directly evaluated Potentially supports beneficial bacterial populations and promotes gut health	Improved growth performance and nutrient utilization	Hendriana et al., (2024)
5	Garlic extract	Garlic bulb (<i>Allium sativum</i>)	through antimicrobial and immunostimulatory activities	Enhanced immune responses, digestive enzyme activity, and disease resistance	Abdel-Razek et al., (2025) ; Phan et al., (2026)
6	Citral	Citrus essential oil	Effects on gut microbiota have not been directly evaluated	Improved carbohydrate metabolism and immune responses	Pratama et al., (2023)
7	<i>Rhizophora mucronata</i>	Mangrove leaves	Potentially contributes to maintaining gut microbial balance	Improved growth performance and feed efficiency	Linayati et al., (2023) ; Mardiana et al., (2024)
8	Various phytobiotics	Diverse medicinal plants and essential oils	Modulated gut microbiota composition and enhanced bacterial community balance	Improved antioxidant capacity and disease resistance	Seong Wei et al., (2024)

3.4 Effects of Phytobiotics on Growth Performance and Feed Utilization

Growth performance and feed utilization efficiency are among the primary indicators of successful Pacific white shrimp (*L. vannamei*) culture. In recent years, phytobiotics have been extensively investigated as natural feed additives capable of enhancing growth performance without causing adverse environmental impacts. Various bioactive compounds present in phytobiotics, including flavonoids, alkaloids, phenolic compounds, terpenoids, and essential oils, have been reported to improve gastrointestinal health, enhance nutrient utilization, and support gut microbial balance, which plays a crucial role in digestion and metabolism ([Firmino et al., 2021](#); [Seong Wei et al., 2024](#)).

One of the principal mechanisms underlying phytobiotic-induced growth enhancement is the improvement of digestive tract function. A more balanced gut microbiota promotes increased digestive enzyme activity and more efficient nutrient absorption. According to [Ringø et al., \(2020\)](#), a stable gut microbial community plays a critical role in feed degradation, the synthesis of beneficial metabolites, and the maintenance of intestinal epithelial integrity. Therefore, phytobiotic-mediated modulation of gut microbiota may indirectly contribute to improved growth rates and feed utilization efficiency.

Several studies have demonstrated that dietary phytobiotic supplementation can significantly enhance the growth performance of Pacific white shrimp. [Hendriana et al., \(2024\)](#) reported that the inclusion of cinnamaldehyde in shrimp diets positively affected growth performance and nutrient utilization. Cinnamaldehyde, the major bioactive compound found in cinnamon essential oil, possesses antimicrobial and antioxidant properties that support intestinal health. Improvements in physiological condition consequently contribute to enhanced feed efficiency and shrimp growth.

Similar findings were reported by [Pratama et al., \(2023\)](#), who found that dietary citral supplementation improved both growth performance and overall health status in Pacific white shrimp. Citral, a major component of citrus essential oils, is known for its antibacterial and antioxidant activities. The beneficial effects of citral are believed to be associated with improved gastrointestinal conditions,

leading to enhanced nutrient absorption and superior growth performance compared with untreated control groups.

The utilization of local plant resources as phytobiotic sources has also shown promising results. [Linayati et al., \(2023\)](#) reported that dietary supplementation with mangrove (*R. mucronata*) leaf extract significantly enhanced shrimp growth performance. These findings were further supported by [Mardiana et al., \(2024\)](#), who demonstrated that the use of *R. mucronata* leaves as a feed additive improved both growth efficiency and feed utilization. The beneficial effects of mangrove leaves are likely attributable to their flavonoid, tannin, and phenolic contents, which contribute to intestinal health and suppress the proliferation of pathogenic microorganisms that may interfere with digestive processes.

In addition to promoting growth, several studies have reported improvements in feed conversion ratio (FCR) following phytobiotic supplementation. Lower FCR values indicate more efficient feed utilization for biomass production. According to [Ma et al., \(2024\)](#), phytobiotic-based feed additives not only improved intestinal health and microbial diversity but also positively affected growth performance and feed utilization efficiency. These findings highlight the close relationship among gastrointestinal health, gut microbial balance, and the ability of shrimp to effectively utilize dietary nutrients.

Overall, the reviewed studies indicate that phytobiotics possess substantial potential for enhancing growth performance and feed utilization efficiency in Pacific white shrimp. These benefits are associated with the ability of phytobiotics to modulate gut microbiota, improve intestinal health, enhance nutrient absorption, and suppress pathogenic microorganisms. Therefore, phytobiotic supplementation represents a promising strategy for improving shrimp productivity while reducing reliance on antibiotics in sustainable aquaculture systems.

Table 4. Effects of Phytobiotics on Growth Performance and Feed Utilization

No	Phytobiotic	Source	Parameters Evaluated	Biological Effects	References
1	Cinnamaldehyd	Cinnamon (<i>Cinnamomum</i> spp.)	Growth performance, carbohydrate metabolism, protein retention, and protein efficiency	Improved protein and carbohydrate utilization while maintaining growth performance under reduced dietary protein levels	Hendriana et al., (2024)
2	Phytogenic formulation	Commercial plant-based phytogenic blend	Gut microbiota composition (16S rRNA analysis), growth performance, and feed conversion ratio (FCR)	Increased the abundance of beneficial bacterial genera and reduced potential pathogenic bacteria, resulting in improved growth performance and feed efficiency	Lee et al., (2024)
3	Citral	Major component of lemongrass (<i>Cymbopogon citratus</i>) and citrus essential oils	Growth performance and feed utilization efficiency	Enhanced growth performance and feed efficiency	Pratama et al., (2023)
4	<i>Rhizophora mucronata</i>	Mangrove leaves	Growth performance	Improved growth performance of Pacific white shrimp	Linayati et al., (2023)
5	<i>Rhizophora mucronata</i>	Mangrove leaves	Growth performance and feed utilization efficiency	Improved growth performance and feed utilization efficiency	Mardiana et al., (2024)

6	Phytobiotic blend	Commercial mixture of plant extracts and essential oils	Growth performance and feed conversion ratio (FCR)	Improved growth performance and feed utilization efficiency	Ma <i>et al.</i> , (2024)
7	Garlic extract	Garlic (<i>Allium sativum</i>)	Growth performance	Enhanced growth performance	Abdel-Razek <i>et al.</i> , (2025)
8	Various phytobiotics	Diverse medicinal plants and essential oils	Gut microbiota modulation, bacterial community structure, growth performance	Improved gut microbial balance and enhanced growth performance	Seong Wei <i>et al.</i> , (2024)

3.5 Effects of Phytobiotics on the Immune System

The immune system of Pacific white shrimp (*L. vannamei*) serves as the primary defense mechanism against pathogenic infections, particularly bacteria, viruses, and parasites commonly encountered in aquaculture environments. Unlike vertebrates, shrimp lack an adaptive immune system; therefore, their defense relies predominantly on innate immunity, including hemocyte activity, phagocytosis, the prophenoloxidase (proPO) system, lysozyme activity, respiratory burst responses, and the production of antimicrobial peptides (Ringø *et al.*, 2020; Xiong *et al.*, 2024). Consequently, enhancing immune competence has become a major objective in sustainable shrimp farming.

Phytobiotics have been widely reported to exhibit immunostimulatory properties due to their rich content of bioactive compounds, such as flavonoids, alkaloids, phenolics, saponins, tannins, and essential oils. These compounds can enhance immune cell activity, strengthen antioxidant defenses, and reduce oxidative stress commonly associated with intensive aquaculture practices (Reverter *et al.*, 2014; Seong Wei *et al.*, 2024). Furthermore, phytobiotics can modulate gut microbiota composition, thereby creating favorable conditions for the development of a more effective immune system.

Ma *et al.*, (2024) demonstrated that dietary supplementation with a phytobiotic-based additive improved hepatopancreatic health, enhanced gut microbial balance, and increased resistance against *Vibrio parahaemolyticus* infection in Pacific white shrimp. The improved disease resistance observed in this study suggests that phytobiotics function not only as natural antimicrobial agents but also as stimulators of the shrimp innate immune system.

Essential oil-based phytobiotics have also been shown to exert beneficial effects on shrimp immune responses. Rairat *et al.*, (2024) reported that a combination of short- and medium-chain fatty acid monoglycerides with cinnamaldehyde enhanced immune responses and improved tolerance to hypoxic conditions in Pacific white shrimp. These findings indicate that phytobiotics can help shrimp maintain physiological stability under environmental stress conditions frequently encountered in intensive culture systems.

In addition to directly enhancing immune responses, phytobiotics contribute to maintaining gut microbial balance, which is closely linked to host defense mechanisms. According to Lin *et al.*, (2024), a balanced gut microbiota acts as a biological barrier against pathogen colonization, promotes the production of beneficial metabolites, and facilitates communication between intestinal microorganisms and the host immune system. Consequently, phytobiotic-mediated modulation of gut microbiota provides dual benefits by improving both intestinal health and immune competence.

The use of herbal plants as phytobiotic sources has also demonstrated considerable potential for enhancing disease resistance. Several studies have reported that plant extracts rich in phenolic compounds and flavonoids can increase phagocytic activity, total hemocyte counts, and the activity of

defense-related enzymes involved in non-specific immune mechanisms in crustaceans (Seong Wei *et al.*, 2024). Additionally, the antioxidant properties of phytobiotic compounds help protect immune cells from oxidative damage, thereby enabling more effective immune responses.

Overall, the reviewed studies indicate that phytobiotics play an important role in enhancing the immune system of Pacific white shrimp through multiple mechanisms, including stimulation of innate immune responses, enhancement of antioxidant activity, suppression of pathogenic microorganisms, and modulation of gut microbiota. By improving immune competence, shrimp become more resilient to environmental stressors and disease outbreaks, which are among the primary causes of production losses in aquaculture.

Table 5. Effects of Phytobiotics on the Immune System

No	Phytobiotic	Source	Immune Parameters Evaluated	Biological Effects	References
1	Phytobiotic blend	Mixture of plant extracts and essential oils	Resistance against <i>Vibrio parahaemolyticus</i> , hepatopancreatic health	Improved hepatopancreatic health and enhanced resistance to <i>V. parahaemolyticus</i> infection	Ma <i>et al.</i> , (2024)
2	Cinnamaldehyde + fatty acid monoglycerides	Cinnamaldehyde-based phytogetic additive	Immune-related gene expression, hypoxia tolerance, antioxidant capacity	Improved hypoxia tolerance, enhanced antioxidant status, and stimulated innate immune responses	Rairat <i>et al.</i> , (2024)
3	Citral	Major component of lemongrass (<i>Cymbopogon citratus</i>) and citrus essential oils	Total hemocyte count (THC), phenoloxidase (PO) activity, respiratory burst activity, antioxidant status	Enhanced immune responses and antioxidant capacity	Pratama <i>et al.</i> , (2023)
4	Garlic extract	Garlic (<i>Allium sativum</i>)	Total hemocyte count (THC), lysozyme activity, disease resistance	Improved immune responses and resistance to bacterial infections	Abdel-Razek <i>et al.</i> , (2025)
5	Phytogetic formulation	Commercial plant-based phytogetic blend	Resistance to vibriosis, immune-related gene expression	Enhanced resistance against <i>Vibrio</i> infection and stimulated immune-related gene expression	Lee <i>et al.</i> , (2024)
6	Various phytobiotics	Various medicinal plants	THC, phagocytic activity, phenoloxidase activity, respiratory burst activity	Enhanced innate immune responses and disease resistance	Ghosh <i>et al.</i> , (2021)
7	Various phytobiotics	Diverse medicinal plants and essential oils	Immune responses and disease resistance	Improved immunity and strengthened defense mechanisms against pathogens	Seong Wei <i>et al.</i> , (2024)
8	<i>Excoecaria agallocha</i> extract	Mangrove plant extract	Innate immune responses, disease resistance	Increased immune responses and resistance against	Vo <i>et al.</i> , (2024)

9	<i>Morinda citrifolia</i> extract	Noni fruit extract	Disease resistance, immune status	<i>Vibrio parahaemolyticus</i> Improved resistance to <i>Vibrio parahaemolyticus</i> infection and enhanced immune protection	Moh et al., (2024)
10	Ginseng saponins	<i>Panax ginseng</i>	Antioxidant capacity, immune status, stress resistance	Improved antioxidant defense and health status under nutritional stress	Lin et al. (2024)

3.6 Mechanisms of Gut Microbiota Modulation by Phytobiotics

Phytobiotics modulate the intestinal microbiota through multiple interconnected mechanisms involving selective antimicrobial activity, stimulation of beneficial microorganisms, enhancement of intestinal barrier integrity, and regulation of host immune responses. Recent studies employing 16S rRNA gene sequencing have shown that phytobiotic supplementation alters both the diversity and relative abundance of specific bacterial taxa associated with shrimp health. Rather than broadly suppressing microbial populations, phytobiotics selectively inhibit opportunistic pathogens while promoting beneficial bacteria that contribute to nutrient metabolism, immune regulation, and intestinal homeostasis.

At the bacterial taxonomic level, phytobiotic supplementation has consistently been associated with increased abundances of beneficial genera such as *Bacillus*, *Lactobacillus*, *Pseudomonas*, and members of the family *Rhodobacteraceae*, which are known to enhance digestive enzyme production, nutrient utilization, and competitive exclusion of pathogens. Conversely, several studies reported reductions in opportunistic pathogenic bacteria, particularly *Vibrio parahaemolyticus*, *Vibrio harveyi*, and other potentially pathogenic *Vibrio* spp., which are closely associated with acute hepatopancreatic necrosis disease (AHPND) and vibriosis in shrimp. These microbial shifts contribute to a more stable intestinal ecosystem and lower disease susceptibility.

One of the primary mechanisms involves selective antimicrobial activity against pathogenic bacteria. Phenolic compounds and essential oils can disrupt bacterial cell membranes, alter membrane permeability, and interfere with microbial metabolic processes. These effects contribute to the suppression of opportunistic pathogens such as *Vibrio* spp., which are frequently associated with disease outbreaks in Pacific white shrimp ([Xiong et al., 2024](#)). Reduced pathogen pressure allows beneficial and commensal bacteria to proliferate, thereby maintaining microbial balance within the gastrointestinal tract.

In addition to suppressing pathogenic microorganisms, phytobiotics can promote the abundance of beneficial bacteria. Certain phytochemicals may serve as substrates that support the growth of bacterial groups involved in nutrient digestion and metabolism. Increased populations of beneficial microorganisms contribute to digestive enzyme production, bioactive metabolite synthesis, and maintenance of intestinal epithelial integrity, ultimately enhancing nutrient absorption efficiency ([Ringø et al., 2018](#); [Lin et al., 2024](#)).

Gut microbiota modulation by phytobiotics is also closely associated with improved immune function. A balanced microbial community can stimulate innate immune responses through interactions between intestinal microorganisms and epithelial tissues. [Ma et al., \(2024\)](#) reported that phytobiotic-induced alterations in gut microbiota composition were associated with enhanced resistance against *Vibrio parahaemolyticus* infection, highlighting the close relationship between intestinal health and immune competence.

Furthermore, the antioxidant activity of phytobiotics contributes to maintaining intestinal stability. Antioxidant compounds reduce oxidative stress that may otherwise damage epithelial tissues and disrupt microbial community balance. Under healthier intestinal conditions, gut microbiota can develop more stably and effectively support physiological processes essential for shrimp growth and health.

Overall, the modulation of gut microbiota by phytobiotics involves complex interactions among plant-derived bioactive compounds, intestinal microbial communities, and host physiological systems. These interactions ultimately lead to improved gut health, enhanced nutrient utilization, stronger immune responses, and increased disease resistance. Therefore, phytobiotics represent a promising strategy for sustainable gut health management in Pacific white shrimp aquaculture.

Table 6. Mechanisms of Gut Microbiota Modulation by Phytobiotics

No	Mechanism	Effects on Gut Microbiota	Effects on the Host	References
1	Antimicrobial activity	Suppresses opportunistic and pathogenic bacteria, particularly <i>Vibrio</i> spp.	Reduces infection risk and improves survival performance	Xiong <i>et al.</i> , (2024); Seong Wei <i>et al.</i> , (2024); Ma <i>et al.</i> , (2024)
2	Stimulation of beneficial bacteria	Enhances microbial diversity and promotes a more stable gut microbial community	Improves intestinal health and nutrient metabolism	Lin <i>et al.</i> , (2024); Ma <i>et al.</i> , (2024); Li <i>et al.</i> , (2018)
3	Improvement of intestinal integrity	Creates a more stable and balanced microbial environment	Enhances nutrient absorption and feed utilization efficiency	Firmino <i>et al.</i> , (2021); Ringø <i>et al.</i> , (2018); Seong Wei <i>et al.</i> , (2024)
4	Antioxidant activity	Mitigates oxidative stress affecting both gut microbiota and intestinal tissues	Improves hepatopancreatic and intestinal health	Firmino <i>et al.</i> , (2021); Seong Wei <i>et al.</i> , (2024)
5	Immune modulation	Strengthens microbiota-immune interactions and maintains intestinal homeostasis	Enhances disease resistance and immune competence	Ma <i>et al.</i> , (2024); Ghosh <i>et al.</i> , (2021); Li <i>et al.</i> , (2018)
6	Enhancement of digestive enzyme activity	Supports microbial populations involved in nutrient degradation and metabolism	Improves growth performance and feed efficiency	Pratama <i>et al.</i> , (2023); Seong Wei <i>et al.</i> , (2024)
7	Prevention of dysbiosis	Prevents the overgrowth of pathogenic bacteria and maintains microbial balance	Reduces the risk of AHPND, White Feces Syndrome (WFS), and vibriosis	Xiong (2018); Chang <i>et al.</i> , (2023); Piamsomboon & Han (2022)

3.7. Research Gaps and Future Perspectives

Although research on phytobiotic applications in Pacific white shrimp culture has increased substantially in recent years, several important knowledge gaps remain. Most available studies focus primarily on growth performance, survival, and immune responses, whereas investigations specifically evaluating changes in gut microbiota composition using molecular approaches remain relatively limited. Consequently, the causal relationships among phytobiotic supplementation, gut microbial community shifts, and improvements in shrimp performance are not yet fully understood (Lin *et al.*, 2024; Xiong *et al.*, 2024).

Another significant gap concerns the limited understanding of the specific mechanisms by which plant-derived bioactive compounds influence gut microbial communities. Many studies report physiological outcomes without identifying the microbial taxa involved or elucidating the underlying

microbial interactions. Furthermore, variations in phytobiotic types, dosages, extraction methods, treatment durations, and culture conditions often make direct comparisons among studies challenging (Seong Wei *et al.*, 2024).

In Indonesia, phytobiotic research remains largely focused on growth performance and feed efficiency, while microbiota-based studies employing advanced sequencing technologies are still scarce. Considering Indonesia’s rich biodiversity, there is considerable potential for the discovery of novel phytobiotic compounds suitable for shrimp aquaculture. Indigenous plants such as mangroves, *Andrographis paniculata*, *Phyllanthus niruri*, turmeric, Java turmeric (*Curcuma xanthorrhiza*), and garlic warrant further investigation regarding their effects on gut microbial communities.

Recent advances in microbiome research technologies, including 16S rRNA gene sequencing, metagenomics, metatranscriptomics, and metabolomics, offer new opportunities to better understand the interactions among phytobiotics, gut microbiota, and shrimp health. Multi-omics approaches may facilitate the identification of key microbial taxa, metabolic pathways, and biomarkers that can be used to evaluate phytobiotic efficacy in modern shrimp farming systems (Ma *et al.*, 2024; Lin *et al.*, 2024).

Future research should not only focus on individual phytobiotics but also explore combinations of phytobiotics with probiotics, prebiotics, and synbiotics. Such integrated approaches may generate synergistic effects that further enhance microbial balance, immune responses, and disease resistance. Moreover, standardized protocols regarding dosage, application methods, and long-term safety assessments are needed to support the commercial implementation of phytobiotics in the aquaculture industry.

Overall, phytobiotics represent a highly promising alternative to antibiotics in Pacific white shrimp culture. However, broader adoption will require further interdisciplinary research integrating microbiology, immunology, nutrition, and molecular biology to achieve a more comprehensive understanding of phytobiotic-mediated gut microbiota modulation and its implications for sustainable aquaculture.

Table 7. Research gaps and future perspectives on the use of phytobiotics for gut microbiota modulation, immune enhancement, and sustainable production of Pacific white shrimp (*L. vannamei*)

No	Research Gap	Current Situation	Future Perspective
1	Limited data on gut microbiota	Most studies primarily focus on growth performance, feed utilization, and immune responses, with relatively few investigations assessing gut microbial communities directly.	Wider application of 16S rRNA gene sequencing, metagenomics, and microbiome-based approaches to better understand phytobiotic-induced microbial modulation.
2	Unclear mechanisms of phytobiotic action	Many studies report physiological and production outcomes without elucidating the underlying microbial and molecular mechanisms.	Investigation of molecular pathways, host–microbiota interactions, and microbial metabolite production associated with phytobiotic supplementation.
3	Lack of dose standardization	Considerable variation exists in phytobiotic sources, extraction methods, inclusion levels, and application protocols among studies.	Establishment of optimal dosage recommendations and standardized application protocols for commercial shrimp farming.
4	Limited studies from Indonesia	Most Indonesian studies emphasize growth performance and feed efficiency, while investigations on gut microbiota remain scarce.	Exploration of indigenous medicinal plants and local phytobiotic resources for their effects on gut microbiota composition and shrimp health.

5	Limited evaluation of feed additive combinations	Phytobiotics are generally applied as single additives, with few studies assessing synergistic effects.	Development of synbiotic approaches and combined phytobiotic–probiotic formulations to enhance gut health, immunity, and disease resistance.
6	Insufficient long-term studies	Most experiments are conducted under short-term laboratory or controlled culture conditions.	Long-term field-scale evaluations under commercial farming conditions to assess efficacy, safety, and economic feasibility.
7	Limited use of multi-omics approaches	Current studies mainly rely on growth and immune indicators, with limited integration of advanced molecular analyses.	Application of metagenomics, metatranscriptomics, metabolomics, and proteomics to comprehensively understand phytobiotic–microbiota–host interactions.
8	Lack of functional microbiome characterization	Changes in microbial composition are often reported without determining microbial functions or metabolic pathways.	Identification of key microbial taxa, functional genes, and biomarkers associated with improved shrimp health and performance.

4. Conclusions

Phytobiotics represent a promising and sustainable dietary strategy for improving the health and productivity of Pacific white shrimp (*Litopenaeus vannamei*). The available evidence indicates that phytobiotic supplementation modulates gut microbiota by promoting beneficial bacterial taxa while suppressing opportunistic pathogens, particularly *Vibrio* spp. These microbial changes are closely associated with improved intestinal health, nutrient utilization, innate immune responses, and disease resistance, ultimately leading to enhanced growth performance. However, current knowledge regarding the underlying microbial and molecular mechanisms remains limited due to the relatively small number of microbiome-based studies. Future research integrating high-throughput microbiome sequencing and multi-omics approaches is needed to clarify host–microbiota interactions and optimize phytobiotic applications for sustainable shrimp aquaculture.

5. Authors Note

The authors declare that there is no conflict of interest regarding to the publication of this article. Authors confirmed that the paper was free of plagiarism.

6. References

- Abdel-Razek, N., Khalil, R.H., Afifi, A.A.M., Alkhuriji, A.F., & Metwally, D.M. (2024). Nutritional Innovation Using Green Seaweed (*Ulva* sp.) and Garlic Powder Extracts for White-Leg Shrimp (*Litopenaeus vannamei*) Challenged by *Vibrio harveyi*. *Vet Med Sci*, 10(6), e70052. doi: 10.1002/vms3.70052.
- Bäckhed, F., Ley, R.E., Sonnenburg, J.L., Peterson, D.A., & Gordon, J.I. (2005). Host-bacterial mutualism in the human intestine. *Science*, 307(5717), 1915-1920. doi: 10.1126/science.1104816. PMID: 15790844.
- Binda, C., Lopetuso, L.R., Rizzatti, G., Gibiino, G., Cennamo, V., & Gasbarrini, A. (2018). Actinobacteria: A relevant minority for the maintenance of gut homeostasis. *Dig Liver Dis*, 50(5), 421-428. doi: 10.1016/j.dld.2018.02.012.
- Cabello, F.C. (2006). Heavy use of prophylactic antibiotics in aquaculture: a growing problem for human and animal health and for the environment. *Environ Microbiol*, 8(7), 1137-44. doi: 10.1111/j.1462-2920.2006.01054.x

- Chang, Y., Ko, H., Wu, P., Kumar, R., Wang, H., & Lu, H. (2023). Gut microbiota of Pacific white shrimp (*Litopenaeus vannamei*) exhibits distinct responses to pathogenic and non-pathogenic *Vibrio parahaemolyticus*. *Microbiol Spectr*, *11*(5). <https://doi.org/10.1128/spectrum.01180-23>
- Dawood, M., Koshio, S., Abdel Daim, M., & Doan, H. (2018). Probiotic application for sustainable aquaculture. *Reviews in Aquaculture*, *11*(3). 10.1111/raq.12272.
- Firmino, J.P., Galindo-Villegas, J., Reyes-López, F.E., & Gisbert, E. (2021). Phytogetic Bioactive Compounds Shape Fish Mucosal Immunity. *Front. Immunol*, *12*, 695973. doi: 10.3389/fimmu.2021.695973
- Ghosh, A.K., Panda, S.K., & Luyten, W. (2021). Anti-vibrio and immune-enhancing activity of medicinal plants in shrimp: A comprehensive review. *Fish & Shellfish Immunology*, *117*, 192-210. <https://doi.org/10.1016/j.fsi.2021.08.006>.
- Gustilatov, M., Widanarni, W., Ekasari, J., Julyantoro, P.G.S., & Waturangi, D.E. (2024). The influence of biofloc system on *Vibrio* composition, the growth and the gut microvilli performance of the Pacific white shrimp (*Penaeus vannamei*). *Jurnal Akuakultur Indonesia*, *23*(1), 12–23.
- Hai, N.V. (2015). The use of probiotics in aquaculture. *J Appl Microbiol*, *119*(4), 917-935. doi: 10.1111/jam.12886
- Hendriana, A., Setiawati, M., Jusadi, D., Suprayudi, M.A., Ekasari, J., & Wahjuningrum, D. (2024). Dietary evaluation of cinnamaldehyde supplementation with different protein energy levels and ratios in Pacific whiteleg shrimp (*Litopenaeus vannamei*). *Jurnal Akuakultur Indonesia*, *23*(1), 79–91.
- Kurniawinata, M.I., Sukenda, S., Wahjuningrum, D., Widanarni, W., Ekasari, J. (2025). Potential of *Eurycoma longifolia*, *Curcuma zedoaria*, and *Allium sativum* extracts as phytobiotics for shrimp health. *Jurnal Akuakultur Indonesia*, *24*(1), 71. 10.19027/jai.24.1.71-81
- Lee, Y.S., Umam, K., Kuo, T.F., Yang, Y.L., Shan Feng, C., & Chin Yang, W. (2024). Functional and mechanistic studies of a phytogetic formulation, Shrimp Best, in growth performance and vibriosis in whiteleg shrimp. *Sci Rep*, *14*, 11584. <https://doi.org/10.1038/s41598-024-62436-x>
- Li, E., Xu, C., Wang, X., Wang, S., Zhao, Q., Zhang, M., Qin, J.G., & Chen, L. (2018). Gut Microbiota and its Modulation for Healthy Farming of Pacific White Shrimp *Litopenaeus vannamei*. *Reviews In Fisheries Science & Aquaculture*, *26*(3), 381-399. <https://doi.org/10.1080/23308249.2018.1440530>
- Lin, X.Y., Shih, Y.J., Zhang, X.J., Cai, Y.S., Zhou, X.W., & Chen, J.S. (2024). Perspective on intestinal microbiota temporal changes of herbal additives treated shrimp in a natural aquaculture setting. *Front. Mar. Sci*, *11*, 1332585. doi: 10.3389/fmars.2024.1332585
- Lin, S., Yao, R., Cui, X., Guo, Y., Hu, D., Zhou, B., Zhou, Z., He, X., Liao, Z., Tan, B., & Niu, J. (2024). Optimizing shrimp nutrition and health: ginseng saponins as functional additives in low-fishmeal diets on *Litopenaeus vannamei*. *Front. Mar. Sci*, *11*, 1479921. doi: 10.3389/fmars.2024.1479921
- Linayati, L., Mardiana, T. Y., Syakirin, M. B., Fachriansyah, R., & Yahya, M. Z. (2023). Penambahan ekstrak daun mangrove *Rhizophora mucronata* dengan dosis berbeda pada pakan buatan terhadap pertumbuhan udang vaname (*Litopenaeus vannamei*). *Sains Akuakultur Tropis*, *7*(2), 207–213.
- Ma, Q., Zhao, G., Liu, J., Chen, I.T., Wei, Y., Liang, M., Dai, P., Nuez-Ortin, W.G., & Xu, H. (2024). Effects of a phytobiotic-based additive on the growth, hepatopancreas health, intestinal microbiota, and *Vibrio parahaemolyticus* resistance of Pacific white shrimp, *Litopenaeus vannamei*. *Front Immunol*, *15*, 1368444. doi: 10.3389/fimmu.2024.1368444.
- Mardiana, T.Y., Yahya, M.Z., Linayati, L., Syakirin, M.B., Pratama, H., & Oktaviani, N. (2024). Pemanfaatan daun *Rhizophora mucronata* sebagai feed additive terhadap efektivitas pertumbuhan udang vaname. *Sains Akuakultur Tropis*, *8*(2), 177–184.

- Moh, J.H.Z., Okomoda, V.T., Mohamad, N. (2024). *Morinda citrifolia* fruit extract enhances the resistance of *Penaeus vannamei* to *Vibrio parahaemolyticus* infection. *Sci Rep*, 14, 5668. <https://doi.org/10.1038/s41598-024-56173-4>
- Phan, T.T.C., Truong, T.P.T., Nguyen, T.K.L., & Huynh, T.G. (2026). Dietary supplementation of *Lactobacillus* sp. and garlic extract on growth performance, digestive enzyme, and disease resistance of the whiteleg shrimp, *Litopenaeus vannamei*. *International Journal of Aquatic Biology*, 14(2), 1–11. <https://doi.org/10.22034/ijab.v14i2.2492>
- Piamsomboon, P., & Han, J.E. (2022). White Feces Syndrome, A Multifactorial Syndrome of Cultured Shrimp: A Mini Review. *Fishes*, 7(6), 339. <https://doi.org/10.3390/fishes7060339>
- Priya, P.S., Vaishnavi, S., Sreekutty, A.R., Sudhakaran, G., Arshad, A., & Arockiaraj, J. (2024). White feces syndrome in shrimp: Comprehensive understanding of immune system responses. *Fish & Shellfish Immunology*, 151, 109704, <https://doi.org/10.1016/j.fsi.2024.109704>.
- Pratama, R.H., Ekasari, J., Suprayudi, M.A., Fauzi, I.A., & Wiyoto. (2023). Dietary citral increase growth and health performance of shrimp *Penaeus vannamei*. *Jurnal Akuakultur Indonesia*, 22(2), 200–209.
- Rairat, T., Kitsanayanyong, L., Keetanon, A., Phansawat, P., Wimanhaemin, P., Chongprachavat, N., Suanploy, W., Chow, E. P. Y., & Chuchird, N. (2024). Effects of monoglycerides of short and medium chain fatty acids and cinnamaldehyde blend on the growth, survival, immune responses, and tolerance to hypoxic stress of Pacific white shrimp (*Litopenaeus vannamei*). *PLOS ONE*, 19(8). <https://doi.org/10.1371/journal.pone.0308559>
- Reverter, M., Bontemps, N., Lecchini, D., Banaigs, B., & Sasal, P. (2014). Use of plant extracts in fish aquaculture as an alternative to chemotherapy: Current status and future perspectives. *Aquaculture*, 433, 50-61. <https://doi.org/10.1016/j.aquaculture.2014.05.048>
- Ringø, E., Hoseinifar, S.H., Ghosh, K., Doan, H.V., Beck, B.R., & Song, S.K. (2018). Lactic Acid Bacteria in Finfish—An Update. *Front. Microbiol*, 9, 1818. doi: 10.3389/fmicb.2018.01818
- Schar, D., Klein, E.Y., Laxminarayan, R. Gilbert, M., & Van Boeckel, T.P. (2020). Global trends in antimicrobial use in aquaculture. *Sci Rep*, 10, 21878.
- Seong Wei, L., Mohamad Sukri, S.A., Tahiluddin, A.B., Abdul Kari, Z., Wee, W., & Kabir, M.A. (2024). Exploring beneficial effects of phytobiotics in marine shrimp farming: A review. *Heliyon*, 10(14), e31074. doi: 10.1016/j.heliyon.2024.e31074.
- Vo, T.T.M., Mai, V.H., & Nhi, N.T.H. (2024). The effects of *Excoecaria agallocha* extract on growth, innate immune responses, and resistance to *Vibrio parahaemolyticus* in white shrimp, *Litopenaeus vannamei*. *International Journal of Aquatic Biology*, 12(3), 240–249. <https://doi.org/10.22034/ijab.v12i3.2257>
- Wang, Y.B. (2007). Effect of probiotic on growth performance and digestive enzyme activity of shrimp *Penaeus vannamei*. *Aquaculture*, 269, 259-264. 10.1016/j.aquaculture.2007.05.035.
- Wu, Z., Wu, W., Yang, S., Cheng, F., Lv, J., Shao, Y., Tang, X., Li, E., & Zhao, Q. (2024). Safety evaluation and effects of dietary phlorotannins on the growth, health, and intestinal microbiota of *Litopenaeus vannamei*. *Fish & Shellfish Immunology*, 150, 109569.
- Xiong, J.B., Sha, H.N., & Chen, J. (2024). Updated roles of the gut microbiota in exploring shrimp etiology, polymicrobial pathogens, and disease incidence. *Zool Res*, 45(4), 910-923. doi: 10.24272/j.issn.2095-8137.2024.158.
- Zeng, S., He, J. & Huang, Z. (2024). The intestine microbiota of shrimp and its impact on cultivation. *Appl Microbiol Biotechnol*, 108, 362. <https://doi.org/10.1007/s00253-024-13213-3>
- Zokaeifar, H., Balcázar, J.L., Saad, C.R., Kamarudin, M.S., Sijam, K., Arshad, A., & Nejat, N. (2012). Effects of *Bacillus subtilis* on the growth performance, digestive enzymes, immune gene expression and disease resistance of white shrimp, *Litopenaeus vannamei*. *Fish Shellfish Immunol*, 33(4), 683-689. doi: 10.1016/j.fsi.2012.05.027