Heliyon 10 (2024) e31074

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

Exploring beneficial effects of phytobiotics in marine shrimp farming: A review

Lee Seong Wei [a,b,*], Suniza Anis Mohamad Sukri [a], Albaris B. Tahiluddin [c,f], Zulhisyam Abdul Kari [a], Wendy Wee [d,**], Muhammad Anamul Kabir [e]

[a] Department of Agricultural Sciences, Faculty of Agro-Based Industry, Universiti Malaysia Kelantan, Jeli Campus, 17600, Jeli, Kelantan, Malaysia
[b] Tropical Rainforest Research Centre (TRaCe), Universiti Malaysia Kelantan, Pulau Banding, 33300, Gerik, Perak, Malaysia
[c] College of Fisheries, Mindanao State University-Tawi-Tawi College of Technology and Oceanography, Sanga-Sanga, Bongao, Tawi-Tawi, 7500, Philippines
[d] Center for Fundamental and Continuing Education, Universiti Malaysia Terengganu, 21030, Kuala Nerus, Terengganu, Malaysia
[e] Department of Aquaculture, Sylhet Agricultural University, Sylhet, 3100, Bangladesh
[f] Department of Aquaculture, Institute of Science, Kastamonu University, Kastamonu, 37200, Turkey

ARTICLE INFO

Keywords:
Antioxidant
Disease resistance
Immune system
Growth performance
Gut microbiota
Stress mitigation

ABSTRACT

Marine shrimp farming, mainly *Penaeus monodon* and *Litopenaeus vannamei*, is an important component of the aquaculture industry. Marine shrimp farming helps produce a protein source for humans, provides job opportunities, and generates lucrative profits for investors. Intensification farming practices can lead to poor water quality, stress, and malnutrition among the farmed marine shrimp, resulting in disease outbreaks and poor production, impeding the development of marine shrimp farming. Antibiotics are the common short-term solution to treat diseases in marine shrimp farming. Moreover, the negative impacts of using antibiotics on public health and the environment erode consumer confidence in aquaculture products. Recently, research on using phytobiotics as a prophylactic agent in aquaculture has become a hot topic. Various phytobiotics have been explored to reveal their beneficial effects on aquaculture species. In this review paper, the sources and modes of action of phytobiotics are presented. The roles of phytobiotics in improving growth performance, increasing antioxidant capacity, enhancing the immune system, stimulating disease resistance, and mitigating stress due to abiotic factors in marine shrimp culture are recapitulated and discussed.

1. Introduction

Aquaculture is the most rapidly-growing industry in food production and plays a crucial role in contributing to nearly half of total world fish production [1]. Crustaceans, such as whiteleg shrimp (*Litopenaeus vannamei*), black tiger shrimp (*Penaeus monodon*), mud crab (*Scylla* sp.), and mitten crab are popular seafood all around the world [2]. High growth rate, high nutritional profile, and high return on investment attract many investors to crustacean farming [3,4]. Shrimp farming is a major industry mainly carried out in tropical countries and generates hundreds of millions of USD per annum for most countries in Latin America and Asia [5,6]. Black tiger

* Corresponding author. Department of Agricultural Sciences, Faculty of Agro-Based Industry, Universiti Malaysia Kelantan, Jeli Campus, 17600, Jeli, Kelantan, Malaysia.
** Corresponding author.
E-mail addresses: leeseong@umk.edu.my (L. Seong Wei), wendy@umt.edu.my (W. Wee).

https://doi.org/10.1016/j.heliyon.2024.e31074
Received 19 November 2023; Received in revised form 8 May 2024; Accepted 9 May 2024
Available online 10 May 2024

Table 1
The beneficial effects of phytobiotics in marine shrimp.

Phytobiotics	Crustacean (life stage/weight)	Doses – Duration	Impacts	References
Garlic, *Allium sativum*, powder	*Litopenaeus vannamei*, (2.29 g)	2–6% of diet – 60 days	Enhance shrimp production	[65]
Garlic, *A. sativum*, extract	*L. vannamei*, (0.5 g)	0.5–1.5 % of diet – 56 days	Improve growth performance; Enhance shrimp production	[66]
Polygain™, polyphenol-rich sugarcane extract (PRSE)	*Penaeus monodon* (post-larval stage day 15)	2–6 g/kg of diet – 70 days	Improve growth performance; Stimulate disease resistance to HPV, GAV, IHHNV, YHV7, YHV1, WSSV, *Vibrio parahaemolyticus*	[9]
Boesenbergia paniculata and *Solanum ferox* extracts	*P. monodon* (2.26 g)	20 mL/kg of feed – 40 days	Improve growth performance; Enhance flesh quality	[67]
Mangrove leaf litter solution (*Avecennia officinalis*, *Heritiera fomes*, *Sonneratia apetala*, *S. caseolaris*)	*P. monodon* (post-larval stage 1)	1 g/L – 28 days	Enhance color; Improve growth performance	[68]
Microalgae, *Tetraselmis chuii* bead	*P. monodon* (post-larval stage 1)	2 beads/mL (10^3 cells/mL in a bead) – 14 days	Maintain water quality; Improve growth performance; Enhance nutrition profile of flesh quality	[69]
Microalgae, *Chaetoceros muelleri*, *Thalassiosira weissflogii* and *Spirulina*	*P. monodon* (larval stage)	Live *Chaetoceros muelleri* – 1×10^5 cells/ml *Thalassiosira weissflogii* – 1×10^4 cells/ml Powdered *Spirulina* – 0.2 mg/L	Maintain water quality; Promote larval metamorphosis; Enhance survival rate; Increase larval digestive system	[70]
Microalga, *Aurantiochytrium* sp. Supplemented with Artemia	*P. monodon* (post-larval stage)	10–20 g/kg of feed – 28 days	Improve growth performance; Enhance the nutrition profile of shrimp flesh; Supplemented with artemia can enhance growth performance	[2]
Silver nanoparticle (AgNPs) seagrass (*Cymodocea serrulata*) extract	*P. monodon* (post-larval stage, day 20)	1g/100 g of feed – 14 days	Stimulate disease resistance against *V. parahaemolyticus*	[71]
Wakame (*Undaria pinnatifida*)	*P. monodon* (Juvenile)	2.17–2.87 % of feed – 56 days	Improve growth performance; Increase feed utilization; Enhance immune system	[72]
AquaImmu – Polyherbal *Emblica officinalis*, *Tinospora cordifolia*, *Withania sominifera*, *Ocimum sanctum*	*P. monodon* (post-larval stage, day 15)	300 mg/kg of feed – 90 days	Improve growth performance; Enhance immune system	[73]
Forsythia suspensa extract	*P. monodon* (3.02 g)	0.01–0.06 % of diet – 60 days	Improve growth performance; Stimulate disease resistance to *V. parahaemolyticus*; Modulate transcription level of immune-related genes	[74]
Fermented cottonseed meal	*L. vannamei* (0.16 g)	10.5–42 % - 56 days	Enhance the nutrition profile of flesh quality; Promote the gut microbiota's growth	[75]
β-glucan	*L. vannamei* (0.26 g)	0.05–0.4 % of diet – 35 days	Enhance immune system; Increase antioxidant capacity; Mitigate stress due to low salinity	[76]
Ethanol extract of *Salvinia cucullata*	*L. vannamei* (4.89 g)	10 g/kg of feed – 56 days	Improve growth performance; Enhance immune system; Stimulate disease resistance to *V. parahaemolyticus*	[77]
Andrographis paniculata extract	*L. vannamei* (2.311 g)	0.25–0.5 % of diet – 28 days	Elevate growth performance; Stimulate disease resistance to *V. alginolyticus*; Enhance immune system	[78]
Poultry by-product meal Antarctic krill meal	*L. vannamei* (2.55 g)	50 % of fish meal replacement – 56 days	Enhance the quality and flavor of the flesh	[79]
Tannic acid	*L. vannamei* (0.3 g)	400–800 mg/kg of diet – 56 days	Improve growth performance; Enhance immune system; Increase antioxidant capacity; Mitigate stress due to ammonia	[12]
Sea grape, *Caulerpa lentillifera*	*L. vannamei* (0.46 g)	1kg/m^3- 56 days	Improve growth performance; Maintain water quality in the polyculture system	[80]
Fermented Siwu decoction	*L. vannamei* (1.62 g)	0.2–0.8 % - 42 days	Enhance immune system; Modulate gut microbiota; Stimulate disease resistance to *V. harveyi*	[81]
Sarcodia suae	*L. vannamei* (0.6 g)	2.5–7.5 % of diet – 20 days	Enhance immune system; Stimulate disease resistance to *V. alginolyticus*	[82]
Moringa oleifera leaves extract	*L. vannamei* (15 g)	2.5 g/kg of diet – 60 days	Elevate growth performance; Improve immune system; Stimulate disease resistance to *V. alginolyticus*	[83]
Polysaccharide derived from *Amphiroa fragilissima*	*L. vannamei* (1.62 g)	Bioencapsulation in Artemia at 0.1–0.2 g/L Given the Artemia to shrimp for 45 days	Increase growth performance; Elevate antioxidant activity	[53]

(*continued on next page*)

Table 1 (*continued*)

Phytobiotics	Crustacean (life stage/weight)	Doses – Duration	Impacts	References
Jania adharens extract	*L. vannamei* (1.24 g)	0.5–1.5 g/kg of feed – 56 days	Elevate growth performance; Increase antioxidant activity; Enhance immune system; Stimulate disease resistance to *Photobacterium damselae*	[54]
Powdered *Syzygium cumini* leaves	*L. vannamei* (5–6 g)	1 % of feed – 28 days	Increase antioxidant capacity; Enhance immune system; Stimulate disease resistance to *V. parahaemolyticus*	[84]

HPV – hepatopancreas parvovirus; GAV – gill-associated virus; IHHNV – infectious hypodermal and hematopoietic necrosis virus; YHV7 - yellow head virus genotype 7, YHV1 – yellow head virus genotype 1, WSSV – white spot syndrome virus.

shrimp is the second-most commercially available crustacean farmed worldwide, with production recorded at 4200 MT in 2019 and a market value of USD 4.8 billion [7]. It has been estimated that about 1.2 million people are involved in black tiger shrimp farming [8]. Furthermore, in 2016, the total world production of *P. monodon* and *L. vannamei* was recorded at nearly 5 million tons [9]. *L. vannamei* has become an important marine shrimp after the downfall of *P. monodon* and is farmed intensively worldwide due to the steadily increasing demand [10,11]. In 2020, *L. vannamei* accounted for more than half of the total world marine shrimp production (51.7 %), with a volume recorded at 5.81 million tons [12]. *L. vannamei* is a preferred choice for aquaculture due to its favorable attributes, such as high growth rate, low feed conversion rate, ability to survive at low salinity, and high market value [13]. Overall, marine shrimp farming is a promising investment opportunity, providing job opportunities and producing high-nutrition aquaculture products [14].

High density in crustacean farming leads to stress among aquaculture species and water quality deterioration. This results in mortality, disease outbreaks, and economic loss [15]. As crustacean farming is gearing toward intensification, disease outbreaks are identified as the main problem hindering the industry's expansion [16]. Various common diseases have been reported to infect farmed crustaceans, and some of them can devastate the whole farm operation [17]. These diseases include vibriosis, white spot syndrome virus (WSSV) disease, early mortality syndrome (EMS) or acute hepatopancreatic necrosis disease (AHPND), yellow head virus (YHV) disease, gill-associated virus (GAV) disease, infectious hypodermal and hematopoietic necrosis virus (IHHNV) disease, and microsporidiosis caused by *Enterocytozoon hepatopenaei* [18–23]. WSSV disease can infect any stage of life of crustaceans, especially *Penaeus* spp., whereas AHPND is reported to infect and cause high mortality in crustaceans at the growing stage [24]. Vibriosis due to *Vibrio parahaemolyticus* has been found to cause high mortality at an early stage of shrimp [25], leading to huge economic loss [26].

Traditionally, antibiotics and chemicals were used as prophylactic agents in marine shrimp farming to control disease problems. Intensified marine shrimp farming often uses antibiotics to boost production and manage the health of marine shrimp [27]. However, overuse of these traditional prophylactic agents has adverse effects on public health and the environment [28]. As a result, probiotics, prebiotics, symbiotics, vaccines, and phytobiotics have been explored as alternatives to antibiotics and chemicals in crustacean farming [29–32]. Phytobiotics offer several advantages: they are abundant, inexpensive, and easy to apply in large-scale marine shrimp farming. Moreover, some phytobiotics are commercially available, making them readily accessible to marine shrimp farmers. Many studies have revealed the potential of phytobiotics in marine shrimp farming. For example, chamomile oil, used as a feed additive in *P. indicus* farming, can elevate growth performance, increase antioxidant capacity, and stimulate disease resistance to *V. parahaemolyticus* [33]. In this review, the current trend of phytobiotic application in marine shrimp farming for immune system enhancement, growth performance improvement, antioxidant capacity increment, disease resistance stimulation, and stress mitigation are discussed and summarized.

2. Sources and modes of action of phytobiotics

Phytobiotics is a broad term encompassing plant materials, including vegetables, fruits, herbs, seaweeds, mushrooms, and even agricultural wastes like fruit wastes, rice bran, and palm kernel cake. This also includes plant bioactive compounds such as tannin, alkaloids, saponins, essential oil, phenolic acid, flavonoids, and polysaccharides [34–38]. The bioactive compounds are responsible for the medicinal values of phytobiotics and offer a range of benefits, including antimicrobial, antioxidant, anti-inflammatory, antidiabetic, immunostimulant, etc. [39]. Phytobiotics have been widely explored for their beneficial effects on various organisms, including humans, animals, and aquatic animals. Studies have shown that phytobiotics can elevate growth performance, improve the immune system, increase antioxidant capacity, modulate gut microbiota, stimulate disease resistance, and mitigate stress [39,40]. Notably, phytobiotics can enhance the growth of beneficial gut bacteria like *Lactobacilli* and *Bifidobacteria,* which play a crucial role in maintaining a balanced gut microbiome [41]. A balanced gut microbiome is essential for the immune system and increases the antioxidant capacity, ultimately protecting the host against harmful microorganisms [42].

3. The roles of phytobiotics in improving growth performance in marine shrimp farming

Microalgae are a vital component of live feeds in aquaculture, providing essential nutrients to aquaculture species [43,44]. The nutritional profile of microalgae has been well documented, with reports indicating a high content of protein, polyunsaturated fatty acids (PUFAs), vitamins, pigments, and sterols [45]. Their roles have been extensively explored in improving growth performance, relieving stress, stimulating disease resistance, and enhancing the flesh quality of aquaculture species [46,47] (Table 1). Macroalgae have been used as functional ingredients in animal feed, and their benefits have been widely recorded in the literature. Many species of seaweeds, such as *Carpoblepharis flaccida*, *Ecklonia maxima*, *Gracilaria gracilis*, *Laminaria japonica*, *Ulva rigida,* and *U. lactuca,* were explored as feed additives in aquafeed, revealing positive effects on various aquatic species [48–52]. Previous studies have also shown the potential of seaweeds as feed additives in crustacean farming (*P. monodon* and *L. vannamei*), with examples including *G. tenuitipitata*, *G. fisheri*, *Gelidium anansii*, *Jania adherens* and polysaccharide derived from *Amphiroa fragilissima* [53–57]. Seaweeds possess all the essential nutrients that aquatic animals need, such as fatty acids, essential amino acids, various minerals, vitamins, and bioactive compounds [58–60]. These compounds are believed to be responsible for positive impacts observed on growth performance, feed utilization, flesh quality, and immune system of aquatic animals [61–63]. Moreover, seaweeds are inexpensive and abundant, making them an attractive ingredient for fish farmers to utilize in aquafeed [64].

In addition, the polyculture of macroalgae and shrimp has been found to benefit both aquaculture species. For example, the polyculture of sea grapes (*Caulerpa lentillifera*) and *L. vannamei* can improve the growth of both organisms [80]. Sea grape can be found wild in the open seas of tropical countries [85]. This green seaweed, also known as green caviar due to its nutritional profile that can promote human health [86–89], is mainly farmed in China, Vietnam, Philippines, Taiwan, and Japan [89,90]. Sea grape has the ability to consume huge quantities of nutrients, making it favorable for use in wastewater treatment to enhance water quality. For instance, sea grape has been used to reduce nutrients from aquaculture wastewater, industrial wastewater containing toxic dyes and heavy metal-contaminated wastewater [89,91–93].

4. The roles of phytobiotics in modulating the immune system, enhancing antioxidant capacity, and stimulating disease resistance in marine shrimp farming

The potential of medicinal plants as immunostimulants in aquatic animals has been extensively studied, as shown in Table 1. These immunostimulants are used as feed additives to improve growth performance, strengthen the immune system, mitigate stress, and stimulate disease resistance in aquatic animal farming [84,74]. For example, *Andrographis paniculate,* a herb found wild in Southern Asia with reported medicinal properties like antimicrobial, antioxidant, and anti-inflammatory effects that can be utilized as a feed additive in Nile tilapia and *P. monodon* against pathogens *Streptococcus agalactiae* and *V. harveyi*, respectively [94,95]. Herbs have been widely studied and documented as feed additives in crustacean farming. Examples include *Allium sativum* and *Petalonia binghamiae* in *L. vannamei*, and *Eclipta erecta*, *Agati grandiflora*, *Justicia tranquebariensis*, *Cardiospermum halicacubum*, *Eclipta alba*, *Picrorhiza kurroa*, *Tinospora cordifolia*, *Aegle marmelos,* and *Cynodon dactylon* in *P. monodon* [65,66,96–99]. Furthermore, polyphenols, abundant compounds in a plant, typically have two hydroxyl groups attached to aromatic rings [100]. Polyphenols possess strong antimicrobial, antioxidant, and anti-inflammatory properties, which can improve the gut microbiota growth and enhance metabolism in the host body [101,102]. Studies have shown that these herbs can be utilized as immunostimulants and improve growth performance in crustacean farming, with minimal to no side effects on organisms [103,104].

Besides herbs, medicinal plants have also been reported to modulate the immune system of marine shrimp. For example, *Forsythia suspensa,* a plant commonly found in Korea, China, Japan, and some European countries, can be used as a feed additive in *P. monodon,* enhancing its immune system against disease. It has been used as traditional Chinese medicine for treating various ailments, such as pyrexia, ulcers, tonsillitis, pharyngitis, erysipelas, and nephritis [105]. The bioactive compounds in the plant, such as glycoside, lignin, triterpenoids, and essential oil, are responsible for its medicinal activities [106]. Another species of *Forsythia*, *F. fructus* has been reported to possess antioxidant activity, antimicrobial properties, and anti-inflammatory effects [106–108]. This plant, when used as a feed additive, has been found to have positive impacts on animals like rats and weaned pigs [106,109].

Syzygium cumini is a medicinal plant widely distributed in Southeast Asian countries, including Malaysia, Indonesia, Philippines, India, Bangladesh, and Sri Lanka. The leaves of this plant contain bioactive compounds like tannins, kaempferol, alkaloids, quercetin, triterpenoids, ellagic acid, gallic acid, etc. [110–112]. They are responsible for the medicinal activities of the plant leaf, such as antibacterial, anti-inflammatory, and antioxidant activities. *S. cumini* leaf has been used as an immunostimulant in marine shrimp farming (*P. monodon* and *L. vannamei*) against bacterial diseases, as summarized in Table 1. Moreover, the essential oil present in the plant leaf, namely sesquiterpenes, can act as a feed attractant, increasing the palatability for use in marine shrimp farming [113].

Moringa (*Moringa oleifera*) has been reported to contain high levels of nutrients and bioactive compounds, such as flavonoids and phenolic acid, which are responsible for its medicinal properties like anticancer, antimicrobial, antioxidant, anti-inflammatory, and antidiabetic [114–117]. The benefits of this plant on aquatic animals have been widely explored. Moringa has been utilized as a feed additive in various aquaculture species, including whiteleg shrimp (*L. vannamei*), giant freshwater prawn (*Macrobrachium rosenbergii*), Nile tilapia (*Oreochromis niloticus*), rainbow trout (*Oncorhynchus mykiss*), common carp (*Cyprinus carpio*), and grass carp (*Ctenopharyngodon idella*), to enhance growth performance, strengthen the immune system, increase antioxidant capacity, mitigate stress due to abiotic factors, and stimulate disease resistance [118–121]. *Salvinia cucullata*, a freshwater aquatic plant with a rapid growth rate on the water surface [122], possesses various bioactive compounds like tannins, phenols, quercetin, saponins, flavonoids, and alkaloids. These compounds are responsible for the plant's antimicrobial and antioxidant properties [123]. The ethanolic extract of this aquatic plant can improve the immune system of *L. vannamei* and stimulate disease resistance against *V. parahaemolyticus*.

Red seaweeds have been found to stimulate disease resistance in crustacean farming. For example, *Sarcodia suae* and *Jania adhaerens* can stimulate disease resistance to *V. alginolyticus* and *Photobacterium damselae* infections in *L. vannamei*, respectively [53,54]. Additionally, *S. suae* has also been shown to stimulate disease resistance in Nile tilapia (*O. niloticus*) against *S. agalactiae* [124]. Furthermore, *S. suae* possesses a bioactive compound called acetyl-xylogalactan, which can play a role in inducing macrophage activity in fish organs like the kidney and liver [125]. The benefits of this red seaweed have also been extensively studied in medicine, especially for its ability to bioaccumulate heavy metals [126–128]. *J. adhaerens* has been reported to contain bioactive compounds such as tannin, ketosteroids, and flavonoids, which are responsible for its antimicrobial properties [54,129]. Moreover, the ethanolic extract of *J. adhaerens* can suppress the growth of microorganisms like *Micrococcus* spp., *Klebsiella* spp., and *Pseudomonas* spp. [54].

The use of Chinese herbal medicine in aquaculture practice is a current trend gaining significant attention [81]. However, Chinese herbal medicines can have side effects due to the presence of toxic compounds [130]. Therefore, fermentation is applied as a method to reduce and minimize the toxic compounds in the herbs [131]. Fermentation has been shown to not only reduce antinutritional factors but also produce new bioactive compounds that may enhance the immune system in aquatic animals [132]. An example of such an herbal combination is Siwu decoction, which comprises a group of herbs, including *Paeonia lactiflora*, *Rehmannia glutinosa*, *Ligusticum chuanxiong,* and *Angelica sinensis* [81]. This herb combination possesses antioxidant and anti-inflammatory properties, offering potential benefits like promoting blood circulation, relieving pain, and improving anemia [133–135].

β-Glucan, a plant-derived polysaccharide, is widely reported to play a crucial role as an immunostimulant in aquatic animals. β-Glucan is commercially available in the market, making it easily accessible for fish farmers to incorporate into their aquaculture practices. Previous studies have shown that β-Glucan can improve growth performance by modulating the growth of gut microbiota in aquaculture species [136,137]. Additionally, it can enhance the immune system and stimulate disease resistance in crustacean farming, as reported in banana shrimp (*P. merguiensis*) and black tiger shrimp (*P. monodon*) [138,139]. Furthermore, β-Glucan derived from *Saccharomyces cerevisiae* has been found to stimulate disease resistance of black tiger shrimp (*P. monodon*) against WSSV [140].

5. The roles of phytobiotics in mitigating stress caused by abiotic factors in marine shrimp farming

Tannin acid, a plant-derived compound, offers several beneficial influences on numerous aquatic animals. For instance, tannic acid can help *L. vannamei* relieve stress caused by the presence of ammonia in an aquaculture system [12]. The mode of action of tannic acid is to enhance the immune system and increase the antioxidant capacity of the shrimp [12]. Tannin acid can also be used as a feed additive in mussels (*Unio tumidus*), grass carp (*C. idella*), zebrafish (*Lateolabrax japonicus*), and Nile tilapia (*O. niloticus*), exhibiting beneficial effects, such as improved growth performance, stimulated disease resistance, and enhanced the immune systems [141–145]. Tannin acid has also been reported to improve the health and growth performance of livestock, including chickens and weaned piglets [146,147]. Similarly, β-Glucan has been shown to improve the immune system and antioxidant capacity of whiteleg shrimp (*L. vannamei*), allowing the shrimp to relieve stress caused by a low salinity environment [76]. Commercial β-Glucan has been found to mitigate stress in Golden pompano (*Trachinotus ovatus*) exposed to low salinity [148]. Due to its affordability and abundance, β-Glucan is a practical choice for use in marine shrimp farming.

6. Conclusion

Marine shrimp farming represents a significant economic driver in numerous countries, particularly those located in tropical and subtropical countries. However, disease outbreaks pose a substantial impediment to the continued advancements of this industry. While antibiotics have demonstrably controlled these diseases, their use has become a contentious issue due to public health and environmental ramifications. Phytobiotics, with lower environmental impact, have emerged as a promising alternative for prophylactic measures in aquaculture practices. Their affordability and abundance make them readily accessible to marine shrimp farmers. Additionally, several commercially available phytobiotics exist, including tannic acid, Polygain™ (polyphenol-rich sugarcane extract, PRSE), Wakame (*Undaria pinnatifida*), AquaImmu – Polyherbal, β-Glucan, and Sea grape (*C. lentillifera*). These can readily incorporated into large-scale marine shrimp operations. Phytobiotic feed additives present the most practical approach due to their cost-effectiveness and scalability. However, improper dosing, whether excessive or insufficient, can have detrimental effects on the performance of marine shrimp. A thorough understanding of the molecular and cellular pathways involved in immune response regulation within marine shrimp farming, particularly in response to diverse pathogens and abiotic stressors, is crucial for fully elucidating the beneficial effects of phytobiotics in this context.

Funding

This research was funded by Universiti Malaysia Kelantan Matching Grant (R/MTCH/A0700/00387A/009/2023/01161) and the Ministry of Higher Education, Malaysia, under the Niche Research Grant Scheme (NRGS) (R/NRGS/A0.700/00387A/006/2014/00152).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors without undue reservation.

CRediT authorship contribution statement

Lee Seong Wei: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Suniza Anis Mohamad Sukri:** Writing – review & editing. **Albaris B. Tahiluddin:** Writing – review & editing. **Zulhisyam Abdul Kari:** Writing – review & editing. **Wendy Wee:** Writing – review & editing. **Muhammad Anamul Kabir:** Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Lee Seong Wei, Associate Editor, Heliyon If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research article is a collaboration between Universiti Malaysia Kelantan, Sylhet Agricultural University, Mindanao State University-Tawi-Tawi College of Technology and Oceanography, and Universiti Malaysia Terengganu. This collaboration is a part of the planning by the Advanced Livestock and Aquaculture Research Group – ALAReG under the Faculty of Agro-Based Industry, Universiti Malaysia Kelantan, Jeli Campus.

References

[1] M.K. Zakaria, Z.A. Kari, H. Van Doan, M.A. Kabir, H. Che Harun, S.A. Mohamad Sukri, K.W. Goh, W. Wee, M.I. Khoo, L.S. Wei, Fermented soybean meal (FSBM) in african catfish (Clarias gariepinus) diets: effects on growth performance, fish gut microbiota analysis, blood haematology, and liver morphology, Life (2022) 1851.

[2] J.K. V, S. Ebeneezar, S. P, A.V. Nair, K. P, Dietary supplementation of microalgae, Aurantiochytrium sp. and co-feeding with Artemia enhances the growth, stress tolerance and survival in Penaeus monodon (Fabricius, 1798) post larvae, Aquaculture (2021) 736176, https://doi.org/10.1016/j.aquaculture.2020.736176.

[3] Z.-B. Lu, Y.-D. Li, S.-G. Jiang, Q.-B. Yang, S. Jiang, J.-H. Huang, L.-s. Yang, X. Chen, F.-L. Zhou, Transcriptome analysis of hepatopancreas in penaeus monodon under acute low pH stress, Fish Shellfish Immunol. (2022) 1166–1172, https://doi.org/10.1016/j.fsi.2022.11.031.

[4] P.S. Shyne Anand, S. Kumar, M.P.S. Kohli, J.K. Sundaray, A. Sinha, G.H. Pailan, S. Dam Roy, Dietary biofloc supplementation in black tiger shrimp, Penaeus monodon: effects on immunity, antioxidant and metabolic enzyme activities, Aquacult. Res. (2017) 4512–4523, https://doi.org/10.1111/are.13276.

[5] T. Viet Nguyen, L.W. Ryan, J. Nocillado, M. Le Groumellec, A. Elizur, T. Ventura, Transcriptomic changes across vitellogenesis in the black tiger prawn (Penaeus monodon), neuropeptides and G protein-coupled receptors repertoire curation, Gen. Comp. Endocrinol. (2020) 113585, https://doi.org/10.1016/j.ygcen.2020.113585.

[6] Z. He, X. Chen, J. Zhao, D. Hou, Z. Fu, Y. Zhong, X. Hu, S. Zhang, C. Sun, Establishment of infection mode and Penaeus monodon hemocytes transcriptomics analysis under decapod iridescent virus 1 (DIV1) challenge, Aquaculture (2021) 736816, https://doi.org/10.1016/j.aquaculture.2021.736816.

[7] M.L. Rahi, W. Sabbir, K.R. Salin, D. Aziz, D.A. Hurwood, Physiological, biochemical and genetic responses of black tiger shrimp (Penaeus monodon) to differential exposure to white spot syndrome virus and Vibrio parahaemolyticus, Aquaculture (2022) 737337, https://doi.org/10.1016/j.aquaculture.2021.737337.

[8] M.L. Rahi, M.S. Shah, Triploidization in rohu × mrigal hybrid and comparison of growth performance of triploid hybrid, Aquacult. Res. (2012) 1867–1879, https://doi.org/10.1111/j.1365-2109.2011.02996.x.

[9] S. Penglase, T. Ackery, B. Kitchen, M. Flavel, K. Condon, The effects of a natural polyphenol extract from sugarcane (saccharum officinarum) on the growth, survival, and feed conversion efficiency of juvenile black tiger shrimp (Penaeus monodon), Appl. Sci. (2022) 8090.

[10] S. Kim, H. Jeon, S.C. Bai, K.-W. Kim, S. Lee, J.W. Hur, H.-S. Han, Effects of dietary supplementation with Arthrobacter bussei powder on growth performance, antioxidant capacity, and innate immunity of Pacific white shrimp (Litopenaeus vannamei), Aquacult Rep (2022) 101270, https://doi.org/10.1016/j.aqrep.2022.101270.

[11] F. Li, J. Xiang, Signaling pathways regulating innate immune responses in shrimp, Fish Shellfish Immunol. (2013) 973–980, https://doi.org/10.1016/j.fsi.2012.08.023.

[12] H. Gong, Z. Qin, Z. Chen, J. Li, Z. Chang, J. Li, P. Chen, Effects of dietary tannic acid on growth, digestion, immunity and resistance to ammonia stress, and intestinal microbial community in pacific white shrimp (Litopenaeus vannamei), Fishes-Basel (2022) 327.

[13] G. Bardera, N. Usman, M. Owen, D. Pountney, K.A. Sloman, M.E. Alexander, The importance of behaviour in improving the production of shrimp in aquaculture, Rev. Aquacult. (2019) 1104–1132, https://doi.org/10.1111/raq.12282.

[14] A.-A. Mamun, F.J. Murray, M. Sprague, B.J. McAdam, N. Roos, B. de Roos, A. Pounds, D.C. Little, Export-driven, extensive coastal aquaculture can benefit nutritionally vulnerable people, Front. Sustain. Food Syst. (2021), https://doi.org/10.3389/fsufs.2021.713140.

[15] P. Sanguanrut, N. Munkongwongsiri, J. Kongkumnerd, J. Thawonsuwan, S. Thitamadee, V. Boonyawiwat, V. Tanasomwang, T.W. Flegel, K. Sritunyalucksana, A cohort study of 196 Thai shrimp ponds reveals a complex etiology for early mortality syndrome (EMS), Aquaculture (2018) 26–36, https://doi.org/10.1016/j.aquaculture.2018.04.033.

[16] A.R. Ochoa-Meza, A.R. Álvarez-Sánchez, C.R. Romo-Quiñonez, A. Barraza, F.J. Magallón-Barajas, A. Chávez-Sánchez, J.C. García-Ramos, Y. Toledano-Magaña, N. Bogdanchikova, A. Pestryakov, C.H. Mejía-Ruiz, Silver nanoparticles enhance survival of white spot syndrome virus infected Penaeus vannamei shrimps by activation of its immunological system, Fish Shellfish Immunol. (2019) 1083–1089, https://doi.org/10.1016/j.fsi.2018.10.007.

[17] P.K. Patil, R. Geetha, T. Ravisankar, S. Avunje, H.G. Solanki, T.J. Abraham, S.P. Vinoth, K.P. Jithendran, S.V. Alavandi, K.K. Vijayan, Economic loss due to diseases in Indian shrimp farming with special reference to Enterocytozoon hepatopenaei (EHP) and white spot syndrome virus (WSSV), Aquaculture (2021), https://doi.org/10.1016/j.aquaculture.2020.736231.

[18] C. Domínguez-Borbor, I. Betancourt, F. Panchana, S. Sonnenholzner, B. Bayot, An effective white spot syndrome virus challenge test for cultured shrimp using different biomass of the infected papilla, MethodsX (2019) 1617–1626, https://doi.org/10.1016/j.mex.2019.07.007.

[19] Z.M. Deris, S. Iehata, M. Ikhwanuddin, M.B.M.K. Sahimi, T. Dinh Do, P. Sorgeloos, Y.Y. Sung, L.L. Wong, Immune and bacterial toxin genes expression in different giant tiger prawn, penaeus monodon post-larvae stages following AHPND-causing strain of vibrio parahaemolyticus challenge, Aquacult Rep (2020), https://doi.org/10.1016/j.aqrep.2019.100248.

[20] J.A. Cowley, C.M. Dimmock, K.M. Spann, P.J. Walker, Detection of Australian gill-associated virus (GAV) and lymphoid organ virus (LOV) of Penaeus monodon by RT-nested PCR, Dis. Aquat. Org. (2000) 159–167, https://doi.org/10.3354/dao039159.

[21] P.G. Mohr, N.J.G. Moody, J. Hoad, L.M. Williams, R.O. Bowater, D.M. Cummins, J.A. Cowley, M.S. Crane, New yellow head virus genotype (YHV7) in giant tiger shrimp Penaeus monodon indigenous to northern Australia, Dis. Aquat. Org. (2015) 263–268.

[22] M.J. Sellars, J.A. Cowley, D. Musson, M. Rao, M.L. Menzies, G.J. Coman, B.S. Murphy, Reduced growth performance of Black Tiger shrimp (Penaeus monodon) infected with infectious hypodermal and hematopoietic necrosis virus, Aquaculture (2019) 160–166, https://doi.org/10.1016/j.aquaculture.2018.09.032.

[23] R. Mithun, G. Sathiyaraj, N. Biju, B. Babu, M. Varkey, K. Karthickkannan, R. Ganeshamurthy, M. Anup, S. Kandan, Characterization of Enterocytozoon hepatopenaei causing hepatopancreatic microsporidiosis in L. vannamei and a new molecular method for its detection in shrimps, and other environmental samples, J. Invertebr. Pathol. (2023) 107951, https://doi.org/10.1016/j.jip.2023.107951.

[24] L.H. Phuoc, M. Corteel, N.C. Thanh, H. Nauwynck, M. Pensaert, V. Alday-Sanz, W.V. den Broeck, P. Sorgeloos, P. Bossier, Effect of dose and challenge routes of Vibrio spp. on co-infection with white spot syndrome virus in Penaeus vannamei, Aquaculture (2009) 61–68, https://doi.org/10.1016/j.aquaculture.2009.02.004.

[25] P. De Schryver, T. Defoirdt, P. Sorgeloos, Early mortality syndrome outbreaks: a microbial management issue in shrimp farming? PLoS Pathog. (2014) https://doi.org/10.1371/journal.ppat.1003919.
[26] M. Vaiyapuri, S. Pailla, M. Rao Badireddy, D. Pillai, R. Chandragiri Nagarajarao, M. Prasad Mothadaka, Antimicrobial resistance in Vibrios of shrimp aquaculture: incidence, identification schemes, drivers and mitigation measures, Aquacult. Res. (2021) 2923–2941, https://doi.org/10.1111/are.15142.
[27] H.Y. Done, A.K. Venkatesan, R.U. Halden, Does the recent growth of aquaculture create antibiotic resistance threats different from those associated with land animal production in agriculture? AAPS J. (2015) 513–524, https://doi.org/10.1208/s12248-015-9722-z.
[28] R.K. Nadella, S.K. Panda, B. Madhusudana Rao, K. Pani Prasad, R.P. Raman, M.P. Mothadaka, Antibiotic resistance of culturable heterotrophic bacteria isolated from shrimp (Penaeus vannamei) aquaculture ponds, Mar. Pollut. Bull. (2021) 112887, https://doi.org/10.1016/j.marpolbul.2021.112887.
[29] A. Omont, E. Quiroz-Guzman, D. Tovar-Ramirez, A. Peña-Rodríguez, Effect of diets supplemented with different seaweed extracts on growth performance and digestive enzyme activities of juvenile white shrimp Litopenaeus vannamei, J. Appl. Phycol. (2019) 1433–1442, https://doi.org/10.1007/s10811-018-1628-6.
[30] A. Alloul, M. Wille, P. Lucenti, P. Bossier, G. Van Stappen, S.E. Vlaeminck, Purple bacteria as added-value protein ingredient in shrimp feed: Penaeus vannamei growth performance, and tolerance against Vibrio and ammonia stress, Aquaculture (2021) 735788, https://doi.org/10.1016/j.aquaculture.2020.735788.
[31] E. Delgado, D.J. Valles-Rosales, N.C. Flores, D. Reyes-Jáquez, Evaluation of fish oil content and cottonseed meal with ultralow gossypol content on the functional properties of an extruded shrimp feed, Aquacult Rep (2021), https://doi.org/10.1016/j.aqrep.2021.100588.
[32] C. Saejung, A. Chaiyarat, L.O. Sanoamuang, Optimization of three anoxygenic photosynthetic bacteria as feed to enhance growth, survival, and water quality in fairy shrimp (Streptocephalus sirindhornae) cultivation, Aquaculture (2021), https://doi.org/10.1016/j.aquaculture.2020.736288.
[33] M. Abdel-Tawwab, N. Abdel-Razek, A.A. Tahoun, S.M.M. Awad, A.M. El-Ashram, Effects of dietary supplementation of chamomile oil on Indian shrimp (Penaeus indicus) performance, antioxidant, innate immunity, and resistance to Vibrio parahaemolyticus infection, Aquaculture (2022), https://doi.org/10.1016/j.aquaculture.2022.738045.
[34] S.H. Hoseinifar, Y.-Z. Sun, Z. Zhou, H. Van Doan, S.J. Davies, R. Harikrishnan, Boosting immune function and disease bio-control through environment-friendly and sustainable approaches in finfish aquaculture: herbal therapy scenarios, Rev Fish Sci Aquac (2020) 303–321, https://doi.org/10.1080/23308249.2020.1731420.
[35] K.W. Goh, Z. Abdul Kari, W. Wee, H. Van Doan, M.F.H. Reduan, M.A. Kabir, M.I. Khoo, S.M. Al-Amsyar, L. Seong Wei, The roles of polysaccharides in carp farming: a review, Animals (2023) 244.
[36] L.S. Wei, K.W. Goh, N.K. Abdul Hamid, Z. Abdul Kari, W. Wee, H. Van Doan, A mini-review on co-supplementation of probiotics and medicinal herbs: application in aquaculture, Front. Vet. Sci. (2022), https://doi.org/10.3389/fvets.2022.869564.
[37] Z.A. Kari, W. Wee, N.K. Abdul Hamid, M.A.O. Dawood, N.N. Azwanida Binti Zakaria, L.S. Wei, The roles of polysaccharides in tilapia farming: a review, Aquaculture and Fisheries (2022), https://doi.org/10.1016/j.aaf.2022.09.005.
[38] Z.A. Kari, S.A.M. Sukri, N.D. Rusli, K. Mat, M.B. Mahmud, N.N.A. Zakaria, W. Wee, N.K.A. Hamid, M.A. Kabir, N.S.N.A. Ariff, S.Z. Abidin, M.K. Zakaria, K. W. Goh, M.I. Khoo, H.V. Doan, A. Tahiluddin, L.S. Wei, Recent advances, challenges, opportunities, product development and sustainability of main agricultural wastes for the aquaculture feed industry – a review, Ann. Anim. Sci. (2023) 25–38, https://doi.org/10.2478/aoas-2022-0082.
[39] Z.A. Kari, W. Wee, N.K.A. Hamid, K. Mat, N.D. Rusli, H.N.M. Khalid, S.A.M. Sukri, H.C. Harun, M.A.O. Dawood, A.H. Hakim, M.I. Khoo, I.M. Abd El-Razek, K. W. Goh, L.S. Wei, Recent advances of phytobiotic utilization in carp farming: a review, Aquacult. Nutr. (2022) 7626675, https://doi.org/10.1155/2022/7626675.
[40] W. Wee, N.K. Abdul Hamid, K. Mat, R.I.A.R. Khalif, N.D. Rusli, M.M. Rahman, M.A. Kabir, L.S. Wei, The effects of mixed prebiotics in aquaculture: a review, Aquaculture and Fisheries (2022), https://doi.org/10.1016/j.aaf.2022.02.005.
[41] F.C. Guo, B.A. Williams, R.P. Kwakkel, H.S. Li, X.P. Li, J.Y. Luo, W.K. Li, M.W. Verstegen, Effects of mushroom and herb polysaccharides, as alternatives for an antibiotic, on the cecal microbial ecosystem in broiler chickens, Poultry Sci. (2004) 175–182, https://doi.org/10.1093/ps/83.2.175.
[42] J. Bengtsson-Palme, E. Kristiansson, D.G.J. Larsson, Environmental factors influencing the development and spread of antibiotic resistance, FEMS Microbiol. Rev. (2018), https://doi.org/10.1093/femsre/fux053.
[43] A. Muller-Feuga, The role of microalgae in aquaculture: situation and trends, J. Appl. Phycol. (2000) 527–534, https://doi.org/10.1023/A:1008106304417.
[44] A.C. Guedes, F.X. Malcata, Nutritional value and uses of microalgae in aquaculture, Aquaculture (2012) 59–78.
[45] G. Merchie, P. Lavens, P. Dhert, M. Dehasque, H. Nelis, A. De Leenheer, P. Sorgeloos, Variation of ascorbic acid content in different live food organisms, Aquaculture (1995) 325–337, https://doi.org/10.1016/0044-8486(95)00049-8.
[46] A.J. Vizcaíno, G. López, M.I. Sáez, J.A. Jiménez, A. Barros, L. Hidalgo, J. Camacho-Rodríguez, T.F. Martínez, M.C. Cerón-García, F.J. Alarcón, Effects of the microalga Scenedesmus almeriensis as fishmeal alternative in diets for gilthead sea bream, Sparus aurata, juveniles, Aquaculture (2014) 34–43, https://doi.org/10.1016/j.aquaculture.2014.05.010.
[47] S. Rehberg-Haas, S. Meyer, M. Tielmann, S. Lippemeier, O. Vadstein, I. Bakke, E. Kjørsvik, J.O. Evjemo, C. Schulz, Use of the microalga Pavlova viridis as enrichment product for the feeding of Atlantic cod larvae (Gadus morhua), Aquaculture (2015) 141–150, https://doi.org/10.1016/j.aquaculture.2015.01.011.
[48] L. Alcantara, T. Noro, Growth of the abalone Haliotis diversicolor (Reeve) fed with macroalgae in floating net cage and plastic tank, Aquacult. Res. (2006) 708–717, https://doi.org/10.1111/j.1365-2109.2006.01484.x.
[49] C.L. Demetropoulos, C.J. Langdon, Enhanced production of Pacific dulse (Palmaria mollis) for co-culture with abalone in a land-based system: nitrogen, phosphorus, and trace metal nutrition, Aquaculture (2004) 433–455, https://doi.org/10.1016/j.aquaculture.2003.09.010.
[50] K. Naidoo, G. Maneveldt, K. Ruck, J.J. Bolton, A comparison of various seaweed-based diets and formulated feed on growth rate of abalone in a land-based aquaculture system, J. Appl. Phycol. (2006) 437–443, https://doi.org/10.1007/s10811-006-9045-7.
[51] M. Troell, D. Robertson-Andersson, R.J. Anderson, J.J. Bolton, G. Maneveldt, C. Halling, T. Probyn, Abalone farming in South Africa: an overview with perspectives on kelp resources, abalone feed, potential for on-farm seaweed production and socio-economic importance, Aquaculture (2006) 266–281, https://doi.org/10.1016/j.aquaculture.2006.02.066.
[52] L.M.P. Valente, A. Gouveia, P. Rema, J. Matos, E.F. Gomes, I.S. Pinto, Evaluation of three seaweeds Gracilaria bursa-pastoris, Ulva rigida and Gracilaria cornea as dietary ingredients in European sea bass (Dicentrarchus labrax) juveniles, Aquaculture (2006) 85–91, https://doi.org/10.1016/j.aquaculture.2005.11.052.
[53] C. Muttharasi, V. Gayathri, T. Muralisankar, K. Mohan, V. Uthayakumar, S. Radhakrishnan, P. Kumar, M. Palanisamy, Growth performance, digestive enzymes and antioxidants activities in the shrimp Litopenaeus vannamei fed with Amphiroa fragilissima crude polysaccharides encapsulated Artemia nauplii, Aquaculture (2021) 737263, https://doi.org/10.1016/j.aquaculture.2021.737263.
[54] P. Akbary, I. Adeshina, A. Jahanbakhshi, Growth performance, digestive enzymes, antioxidant activity and immune responses of Litopenaeus vannamei fed with Jania adhaerens J.V. Supplemented diet against Photobacterium damselae infection, Anim. Feed Sci. Technol. (2020) 114696, https://doi.org/10.1016/j.anifeedsci.2020.114696.
[55] K. Kanjana, T. Radtanatip, S. Asuvapongpatana, B. Withyachumnarnkul, K. Wongprasert, Solvent extracts of the red seaweed Gracilaria fisheri prevent Vibrio harveyi infections in the black tiger shrimp Penaeus monodon, Fish Shellfish Immunol. (2011) 389–396, https://doi.org/10.1016/j.fsi.2010.11.016.
[56] Y.-W. Fu, W.-Y. Hou, S.-T. Yeh, C.-H. Li, J.-C. Chen, The immunostimulatory effects of hot-water extract of Gelidium amansii via immersion, injection and dietary administrations on white shrimp Litopenaeus vannamei and its resistance against Vibrio alginolyticus, Fish Shellfish Immunol. (2007) 673–685, https://doi.org/10.1016/j.fsi.2006.08.014.
[57] S.-T. Yeh, C.-C. Li, W.-C. Tsui, Y.-C. Lin, J.-C. Chen, The protective immunity of white shrimp Litopenaeus vannamei that had been immersed in the hot-water extract of Gracilaria tenuistipitata and subjected to combined stresses of Vibrio alginolyticus injection and temperature change, Fish Shellfish Immunol. (2010) 271–278, https://doi.org/10.1016/j.fsi.2010.04.014.
[58] A.V. Galland-Irmouli, J. Fleurence, R. Lamghari, M. Luçon, C. Rouxel, O. Barbaroux, J.P. Bronowicki, C. Villaume, J.L. Guéant, Nutritional value of proteins from edible seaweed Palmaria palmata (Dulse), JNB (J. Nutr. Biochem.) (1999) 353–359, https://doi.org/10.1016/S0955-2863(99)00014-5.
[59] P. MacArtain, C.I.R. Gill, M. Brooks, R. Campbell, I.R. Rowland, Nutritional value of edible seaweeds, Nutr. Rev. (2007) 535–543, https://doi.org/10.1111/j.1753-4887.2007.tb00278.x.
[60] P. Burtin, Nutritional value of seaweeds, Electron. J. Environ. Agric. Food Chem. (2003) 498–503.

[61] L.E. Cruz-SuÁrez, M. Tapia-Salazar, M.G. Nieto-López, C. Guajardo-Barbosa, D. Ricque-Marie, Comparison of Ulva clathrata and the kelps Macrocystis pyrifera and Ascophyllum nodosum as ingredients in shrimp feeds, Aquacult. Nutr. (2009) 421–430, https://doi.org/10.1111/j.1365-2095.2008.00607.x.
[62] K.-i. Satoh, H. Nakagawa, S. Kasahara, Effect of Ulva meal Supplementation on disease Resistance of red sea bream, Nippon Suisan Gakkaishi (1987) 1115–1120, https://doi.org/10.2331/suisan.53.1115.
[63] G. Mustafa, S. Wakamatsu, T.-a. Takeda, T. Umino, H. Nakagawa, Effects of algae meal as feed additive on growth, feed efficiency, and body composition in red sea bream, Fish. Sci. (1995) 25–28, https://doi.org/10.2331/fishsci.61.25.
[64] M.G. Mustafa, H. Nakagawa, A Review: Dietary Benefits of Algae as an Additive in Fish Feed, Israeli Journal of Aquaculture-Bamidgeh, 1995, pp. 155–162.
[65] J.R.P. Labrador, R.C. Guiñares, G.J.S. Hontiveros, Effect of garlic powder-supplemented diets on the growth and survival of Pacific white leg shrimp (Litopenaeus vannamei), Cogent Food Agric. (2016) 1210066, https://doi.org/10.1080/23311932.2016.1210066.
[66] P.T.C. Tu, N.T.K. Lien, P.T.T. Ngan, T.Q. Phu, H.T. Giang, Effects of Garlic-Supplemented Diet on the Growth and Survival of the Whiteleg Shrimp (Liptopenaeus Vannamei), Livestock Research for Rural Development, 2023, pp. 1–16.
[67] E.H. Hardi, R.A. Nugroho, M. Agriandini, M. Rizki, M.E.N. Falah, I.F. Almadi, H.R. Susmiyati, R. Diana, N.P. Palupi, G. Saptiani, A. Agustina, A.N. Asikin, K. Sukarti, Application of phyto-stimulants for growth, survival rate, and meat quality improvement of tiger shrimp (Penaeus monodon) maintained in a traditional pond, Pathogens (2022) 1243.
[68] M.I. Alam, S. Yeasmin, M.M. Khatun, M.M. Rahman, M.U. Ahmed, A.O. Debrot, M.N. Ahsan, M.C.J. Verdegem, Effect of mangrove leaf litter on shrimp (Penaeus monodon, Fabricius, 1798) growth and color, Aquacult Rep (2022) 101185, https://doi.org/10.1016/j.aqrep.2022.101185.
[69] H. Khatoon, K.P. Penz, S. Banerjee, A.I. Mahmud, M.R. Rahman, S. Mian, T.M. Minhaz, S. Hossain, Improvement of water quality, survivality, growth performance, and proximate composition of Penaeus monodon postlarvae through immobilizing Tetraselmis chuii, Bioresour. Technol. Rep. (2021) 100755, https://doi.org/10.1016/j.biteb.2021.100755.
[70] Y. Tang, R. Wang, L. Tan, L. Guo, Y. Duan, L. Yang, S. Jiang, F. Zhou, S. Jiang, J. Huang, Effects of live microalgae and algae powder on microbial community, survival, metamorphosis and digestive enzyme activity of Penaeus monodon larvae at different growth stages, Aquaculture (2020) 735344, https://doi.org/10.1016/j.aquaculture.2020.735344.
[71] P. RathnaKumari, P. Kolanchinathan, D. Siva, B. Abirami, V. Masilamani, G. John, S. Achiraman, A. Balasundaram, Antibacterial efficacy of seagrass Cymodocea serrulata-engineered silver nanoparticles against prawn pathogen Vibrio parahaemolyticus and its combative effect on the marine shrimp Penaeus monodon, Aquaculture (2018) 158–164, https://doi.org/10.1016/j.aquaculture.2018.04.061.
[72] J. Niu, X. Chen, X. Lu, S.-G. Jiang, H.-Z. Lin, Y.-J. Liu, Z. Huang, J. Wang, Y. Wang, L.-X. Tian, Effects of different levels of dietary wakame (Undaria pinnatifida) on growth, immunity and intestinal structure of juvenile Penaeus monodon, Aquaculture (2015) 78–85, https://doi.org/10.1016/j.aquaculture.2014.08.013.
[73] M.N. Chandran, S. Moovendhan, A.M. Suganya, A. Tamilselvi, Bebin, G. Immanuel, A. Palavesam, Influence of polyherbal formulation (AquaImmu) as a potential growth promotor and immunomodulator in shrimp Penaeus monodon, Aquacult Rep (2016) 143–149, https://doi.org/10.1016/j.aqrep.2016.10.002.
[74] J.-J. Xie, X. Chen, T.-Y. Guo, S.-W. Xie, H.-H. Fang, Z.-L. Liu, Y.-M. Zhang, L.-X. Tian, Y.-J. Liu, J. Niu, Dietary values of Forsythia suspensa extract in Penaeus monodon under normal rearing and Vibrio parahaemolyticus 3HP (VP3HP) challenge conditions: effect on growth, intestinal barrier function, immune response and immune related gene expression, Fish Shellfish Immunol. (2018) 316–326, https://doi.org/10.1016/j.fsi.2018.02.030.
[75] F. Han, J. Qian, Y. Qu, Z. Li, H. Chen, C. Xu, H. Zhang, J.G. Qin, L. Chen, E. Li, Partial replacement of soybean meal with fermented cottonseed meal in a low fishmeal diet improves the growth, digestion and intestinal microbiota of juvenile white shrimp Litopenaeus vannamei, Aquacult Rep (2022) 101339, https://doi.org/10.1016/j.aqrep.2022.101339.
[76] Y. Qiao, L. Zhou, Y. Qu, K. Lu, F. Han, E. Li, Effects of different dietary β-glucan Levels on antioxidant Capacity and immunity, gut Microbiota and transcriptome Responses of white shrimp (Litopenaeus vannamei) under low salinity, Antioxidants 2282 (2022).
[77] P. Santhosh, M. Kamaraj, M. Saravanan, T.G. Nithya, Dietary supplementation of Salvinia cucullata in white shrimp Litopenaeus vannamei to enhance the growth, nonspecific immune responses, and disease resistance to Vibrio parahaemolyticus, Fish Shellfish Immunol. (2023) 108465, https://doi.org/10.1016/j.fsi.2022.108465.
[78] X. Yin, X. Zhuang, M. Liao, Q. Cui, C. Yan, J. Huang, Z. Jiang, L. Huang, W. Luo, Y. Liu, W. Wang, Andrographis paniculata improves growth and non-specific immunity of shrimp Litopenaeus vannamei, and protects it from Vibrio alginolyticus by reducing oxidative stress and apoptosis, Dev. Comp. Immunol. (2023) 104542, https://doi.org/10.1016/j.dci.2022.104542.
[79] L. Cai, J. Bai, Y. Lan, F. Song, Z. Wei, Effects of composite mixture of protein sources in replacing fish meal on nutritional value and flavor quality of Pacific white shrimp (Litopenaeus vannamei), Aquacult Rep (2023) 101437, https://doi.org/10.1016/j.aqrep.2022.101437.
[80] N.T.N. Anh, D.K. Murungu, L. Van Khanh, T.N. Hai, Polyculture of sea grape (Caulerpa lentillifera) with different stocking densities of whiteleg shrimp (Litopenaeus vannamei): effects on water quality, shrimp performance and sea grape proximate composition, Algal Res. (2022) 102845, https://doi.org/10.1016/j.algal.2022.102845.
[81] Y. Wang, X. Liu, C. Su, Y. Ding, L. Pan, Process optimization for fermented siwu decoction by multi-index-response surface method and exploration of the effects of fermented siwu decoction on the growth, immune response and resistance to Vibrio harveyi of Pacific white shrimp (Litopenaeus vannamei), Fish Shellfish Immunol. (2022) 633–647, https://doi.org/10.1016/j.fsi.2021.11.029.
[82] C.-H. Kuo, R. Ballantyne, P.-L. Huang, S. Ding, M.-C. Hong, T.-Y. Lin, F.-C. Wu, Z.-Y. Xu, K. Chiu, B. Chen, C.-H. Liu, Sarcodia suae modulates the immunity and disease resistance of white shrimp Litopenaeus vannamei against Vibrio alginolyticus via the purine metabolism and phenylalanine metabolism, Fish Shellfish Immunol. (2022) 766–777, https://doi.org/10.1016/j.fsi.2022.07.011.
[83] Z. Abidin, H.-T. Huang, Z.-H. Liao, B.-Y. Chen, Y.-S. Wu, Y.-J. Lin, F.-H. Nan, Moringa oleifera leaves' extract enhances nonspecific immune responses, Resistance against Vibrio alginolyticus, and Growth in whiteleg shrimp (Penaeus vannamei), Animals-Basel 42 (2022).
[84] D.L. Prabu, S. Chandrasekar, K. Ambashankar, J.S. Dayal, S. Ebeneezar, K. Ramachandran, M. Kavitha, P. Vijayagopal, Effect of dietary Syzygium cumini leaf powder on growth and non-specific immunity of Litopenaeus vannamei (Boone 1931) and defense against virulent strain of Vibrio parahaemolyticus, Aquaculture (2018) 9–20, https://doi.org/10.1016/j.aquaculture.2018.01.041.
[85] P. Famà, B. Wysor, W.H.C.F. Kooistra, G.C. Zuccarello, Molecular phylogeny of the genus Caulerpa (Caulerpales, Chlorophyta) inferred from chloroplast tufA gene, J. Phycol. (2002) 1040–1050, https://doi.org/10.1046/j.1529-8817.2002.t01-1-01237.x.
[86] T. Nagappan, C.S. Vairappan, Nutritional and bioactive properties of three edible species of green algae, genus Caulerpa (Caulerpaceae), J. Appl. Phycol. (2014) 1019–1027, https://doi.org/10.1007/s10811-013-0147-8.
[87] N.A. Paul, N. Neveux, M. Magnusson, R. de Nys, Comparative production and nutritional value of "sea grapes" - the tropical green seaweeds Caulerpa lentillifera and C. racemosa, J. Appl. Phycol. (2014) 1833–1844, https://doi.org/10.1007/s10811-013-0227-9.
[88] C. de Gaillande, C. Payri, G. Remoissenet, M. Zubia, Caulerpa consumption, nutritional value and farming in the Indo-Pacific region, J. Appl. Phycol. (2017) 2249–2266, https://doi.org/10.1007/s10811-016-0912-6.
[89] X. Chen, Y. Sun, H. Liu, S. Liu, Y. Qin, P. Li, Advances in cultivation, wastewater treatment application, bioactive components of Caulerpa lentillifera and their biotechnological applications, PeerJ (2019), https://doi.org/10.7717/peerj.6118.
[90] I. Lapong, N. Paul, A. Reza, Characterization of sea grape (Caulerpa lentillifera) from Vietnamese company's products, Mar. Chim. Acta (2019) 51–57.
[91] K. Marungrueng, P. Pavasant, Removal of basic dye (Astrazon Blue FGRL) using macroalga Caulerpa lentillifera, J. Environ. Manag. (2006) 268–274, https://doi.org/10.1016/j.jenvman.2005.04.022.
[92] N.A. Paul, R. de Nys, Promise and pitfalls of locally abundant seaweeds as biofilters for integrated aquaculture, Aquaculture (2008) 49–55, https://doi.org/10.1016/j.aquaculture.2008.05.024.
[93] H. Liu, F. Wang, Q. Wang, S. Dong, X. Tian, A comparative study of the nutrient uptake and growth capacities of seaweeds Caulerpa lentillifera and Gracilaria lichenoides, J. Appl. Phycol. (2016) 3083–3089, https://doi.org/10.1007/s10811-016-0858-8.
[94] P. Rattanachaikunsopon, P. Phumkhachorn, Prophylactic effect of Andrographis paniculata extracts against Streptococcus agalactiae infection in Nile tilapia (Oreochromis niloticus), J. Biosci. Bioeng. (2009) 579–582, https://doi.org/10.1016/j.jbiosc.2009.01.024.

[95] S. AftabUddin, M.A.M. Siddique, S.S. Romkey, W.L. Shelton, Antibacterial function of herbal extracts on growth, survival and immunoprotection in the black tiger shrimp Penaeus monodon, Fish Shellfish Immunol. (2017) 52–58, https://doi.org/10.1016/j.fsi.2017.03.050.

[96] T. Citarasu, V. Sivaram, G. Immanuel, N. Rout, V. Murugan, Influence of selected Indian immunostimulant herbs against white spot syndrome virus (WSSV) infection in black tiger shrimp, Penaeus monodon with reference to haematological, biochemical and immunological changes, Fish Shellfish Immunol. (2006) 372–384, https://doi.org/10.1016/j.fsi.2006.01.002.

[97] T. Rajasekar, J. Usharani, M. Sakthivel, B. Deivasigamani, Immunostimulatory effects of cardiospermum halicacubum against vibrio parahaemolyticus on tiger shrimp penaeus monodon, J. Chem. Pharmaceut. Res. (2011) 501–513.

[98] T. Kumaran, V.T. Viji, S. Velmurugan, T. Citarasu, Influence of selected antiviral herbal active principles against shrimp white spot syndrome virus (WSSV), Int. J. Mol. Biol Biochem. (2014) 41–49.

[99] J.-C. Chen, White shrimp Litopenaeus vannamei that have received Petalonia binghamiae extract activate immunity, increase immune response and resistance against Vibrio alginolyticus, J. Aquacult. Res. Dev. (2014), https://doi.org/10.4172/2155-9546.1000268.

[100] H. Sies, Polyphenols and health: update and perspectives, Arch. Biochem. Biophys. (2010) 2–5, https://doi.org/10.1016/j.abb.2010.04.006.

[101] H. Cory, S. Passarelli, J. Szeto, M. Tamez, J. Mattei, The role of polyphenols in human health and food systems: a mini-review, Front. Nutr. (2018), https://doi.org/10.3389/fnut.2018.00087.

[102] R. Puupponen-Pimiä, L. Nohynek, C. Meier, M. Kähkönen, M. Heinonen, A. Hopia, K.-M. Oksman-Caldentey, Antimicrobial properties of phenolic compounds from berries, J. Appl. Microbiol. (2001) 494–507, https://doi.org/10.1046/j.1365-2672.2001.01271.x.

[103] R. Harikrishnan, C. Balasundaram, M.-S. Heo, Impact of plant products on innate and adaptive immune system of cultured finfish and shellfish, Aquaculture (2011) 1–15, https://doi.org/10.1016/j.aquaculture.2011.03.039.

[104] A.C. Abreu, A.J. McBain, M. Simões, Plants as sources of new antimicrobials and resistance-modifying agents, Nat. Prod. Rep. (2012) 1007–1021, https://doi.org/10.1039/c2np20035j.

[105] Pharmacopoeia of People's Republic of China, Herbal Medicine, 2010, pp. 330–331.

[106] T. Lu, X.L. Piao, Q. Zhang, D. Wang, X.S. Piao, S.W. Kim, Protective effects of Forsythia suspensa extract against oxidative stress induced by diquat in rats, Food Chem. Toxicol. (2010) 764–770, https://doi.org/10.1016/j.fct.2009.12.018.

[107] H. Lim, J.G. Lee, S.H. Lee, Y.S. Kim, H.P. Kim, Anti-inflammatory activity of phylligenin, a lignan from the fruits of Forsythia koreana, and its cellular mechanism of action, J. Ethnopharmacol. (2008) 113–117, https://doi.org/10.1016/j.jep.2008.03.016.

[108] H. Qu, Y. Zhang, X. Chai, W. Sun, Isoforsythiaside, an antioxidant and antibacterial phenylethanoid glycoside isolated from Forsythia suspensa, Bioorg. Chem. (2012) 87–91, https://doi.org/10.1016/j.bioorg.2011.09.005.

[109] Y. Hao, D. Li, X. Piao, X. Piao, Forsythia suspensa extract alleviates hypersensitivity induced by soybean β-conglycinin in weaned piglets, J. Ethnopharmacol. (2010) 412–418, https://doi.org/10.1016/j.jep.2010.01.035.

[110] A.K. Timbola, B. Szpoganicz, A. Branco, F.D. Monache, M.G. Pizzolatti, A new flavonol from leaves of Eugenia jambolana, Fitoterapia (2002) 174–176, https://doi.org/10.1016/S0367-326X(02)00009-6.

[111] M. Ayyanar, P. Subash-Babu, Syzygium cumini (L.) Skeels: a review of its phytochemical constituents and traditional uses, Asian Pac. J. Trop. Biomed. (2012) 240–246, https://doi.org/10.1016/S2221-1691(12)60050-1.

[112] A. Pandey, P. Singh, Antibacterial activity of Syzygium aromaticum (clove) with metal ion effect against food borne pathogens, Asian J. Plant Sci. (2011) 69–80.

[113] R.R.P. Machado, D.F. Jardim, A.R. Souza, E. Scio, R.L. Fabri, A.G. Carpanez, R.M. Grazul, J.P.R.F. de Mendonça, B. Lesche, F.M. Aarestrup, The effect of essential oil of Syzygium cumini on the development of granulomatous inflammation in mice, Revista Brasileira de Farmacognosia (2013) 488–496, https://doi.org/10.1590/S0102-695X2013005000030.

[114] S. Mahfuz, X.S. Piao, Application of moringa (Moringa oleifera) as natural feed supplement in poultry diets, Animals-Basel (2019) 431.

[115] X. Coz-Bolaños, R. Campos-Vega, R. Reynoso-Camacho, M. Ramos-Gómez, G.F. Loarca-Piña, S.H. Guzmán-Maldonado, Moringa infusion (Moringa oleifera) rich in phenolic compounds and high antioxidant capacity attenuate nitric oxide pro-inflammatory mediator in vitro, Ind. Crop. Prod. (2018) 95–101, https://doi.org/10.1016/j.indcrop.2018.03.028.

[116] Z.F. Ma, J. Ahmad, H. Zhang, I. Khan, S. Muhammad, Evaluation of phytochemical and medicinal properties of Moringa (Moringa oleifera) as a potential functional food, South Afr. J. Bot. (2020) 40–46, https://doi.org/10.1016/j.sajb.2018.12.002.

[117] B. Mwamatope, D. Tembo, I. Chikowe, E. Kampira, C. Nyirenda, Total phenolic contents and antioxidant activity of Senna singueana, Melia azedarach, Moringa oleifera and Lannea discolor herbal plants, Scientific African (2020) e00481, https://doi.org/10.1016/j.sciaf.2020.e00481.

[118] I.V. Kaleo, Q. Gao, B. Liu, C. Sun, Q. Zhou, H. Zhang, F. Shan, Z. Xiong, L. Bo, C. Song, Effects of Moringa oleifera leaf extract on growth performance, physiological and immune response, and related immune gene expression of Macrobrachium rosenbergii with Vibrio anguillarum and ammonia stress, Fish Shellfish Immunol. (2019) 603–613, https://doi.org/10.1016/j.fsi.2019.03.039.

[119] H.S. Hamed, Y.S. El-Sayed, Antioxidant activities of Moringa oleifera leaf extract against pendimethalin-induced oxidative stress and genotoxicity in Nile tilapia, Oreochromis niloticus (L.), Fish Physiol. Biochem. (2019) 71–82, https://doi.org/10.1007/s10695-018-0535-8.

[120] M. Faheem, S. Khaliq, N. Mustafa, S. Rani, K.P. Lone, Dietary Moringa oleferia leaf meal induce growth, innate immunity and cytokine expression in grass carp, Ctenopharyngodon idella, Aquacult. Nutr. (2020) 1164–1172, https://doi.org/10.1111/anu.13073.

[121] E.A. Abd El-Gawad, A.M. El Asely, E.I. Soror, A.A. Abbass, B. Austin, Effect of dietary Moringa oleifera leaf on the immune response and control of Aeromonas hydrophila infection in Nile tilapia (Oreochromis niloticus) fry, Aquacult. Int. (2020) 389–402, https://doi.org/10.1007/s10499-019-00469-0.

[122] S. Cai, G. Chen, Y. Wang, Y. Huang, D.B. Marchant, Y. Wang, Q. Yang, F. Dai, A. Hills, P.J. Franks, E. Nevo, D.E. Soltis, P.S. Soltis, E. Sessa, P.G. Wolf, D. Xue, G. Zhang, B.J. Pogson, M.R. Blatt, Z.H. Chen, Evolutionary conservation of ABA signaling for stomatal closure, Plant Physiol. (2017) 732–747, https://doi.org/10.1104/pp.16.01848.

[123] P. Santhosh, T.G. Nithya, S.G. Lakshmi, G.L.S. Marino, B. Balavaishnavi, M. Kamaraj, Assessment of phytochemicals, antioxidant, antibacterial activity, and profiling of functional molecules in a freshwater fern, Salvinia cucullata Roxb, South Afr. J. Bot. (2022) 275–283, https://doi.org/10.1016/j.sajb.2022.02.030.

[124] P.T. Lee, C.M. Wen, F.H. Nan, H.Y. Yeh, M.C. Lee, Immunostimulatory effects of Sarcodia suiae water extracts on Nile tilapia Oreochromis niloticus and its resistance against Streptococcus agalactiae, Fish Shellfish Immunol. (2020) 159–168, https://doi.org/10.1016/j.fsi.2020.05.017.

[125] P.K. Pan, T.M. Wu, C.M. Wen, Y.Y. Chen, Y.S. Wu, Sarcodia suieae acetyl-xylogalactan regulates nile tilapia (Oreochromis niloticus) tissue phagocytotic activity and serum indices, J. Mar. Sci. Eng. (2022), https://doi.org/10.3390/jmse10010018.

[126] M.J.H. Libatique, M.-C. Lee, H.-Y. Yeh, F.-J. Jhang, The response of sarcodia suiae to long-term exposure of arsenic (arsenate): growth, morphology, and arsenic alterations, Water, Air, Soil Pollut. (2020) 212, https://doi.org/10.1007/s11270-020-04603-0.

[127] C.C. Shih, H.R. Hwang, C.I. Chang, H.M. Su, P.C. Chen, H.M. Kuo, P.J. Li, H.M.D. Wang, K.H. Tsui, Y.C. Lin, S.Y. Huang, Z.H. Wen, Anti-inflammatory and antinociceptive effects of ethyl acetate fraction of an edible red macroalgae sarcodia ceylanica, Int. J. Mol. Sci. (2017), https://doi.org/10.3390/ijms18112437.

[128] T.M. Wu, F.H. Nan, K.C. Chen, Y.S. Wu, Sarcodia suieae acetyl-xylogalactan regulate RAW 264.7 macrophage NF-kappa B activation and IL-1 beta cytokine production in macrophage polarization, Sci Rep-Uk (2019), https://doi.org/10.1038/s41598-019-56246-9.

[129] W.M. Alarif, S.E.N. Ayyad, S.M. El-Assouli, S.S. Al-Lihaibi, Antigenotoxic ketosteroid from the red algae Jania adhaerens, Nat. Prod. Res. (2012) 785–791, https://doi.org/10.1080/14786419.2010.548336.

[130] R. Bauer, Chinese herbal medicine in Europe: regulatory situation, problems and perspectives, Planta Med. (2011), https://doi.org/10.1055/s-0031-1282111.

[131] J.-H. Lee, J.-H. Lee, J.-S. Jin, Fermentation of traditional medicine: present and future, Oriental Pharmacy and Exp. Med. (2012) 163–165, https://doi.org/10.1007/s13596-012-0080-4.

[132] A. Hussain, S. Bose, J.-H. Wang, M. Yadav, G. Mahajan, H. Kim, Fermentation, a feasible strategy for enhancing bioactivity of herbal medicines, Food Res. Int. (2015), https://doi.org/10.1016/j.foodres.2015.12.026.

[133] D. Lee, S.H. Lee, M. Lee, S.H. Lee, Y.J. Shin, J.Y. Lee, H. Kim, Y.S. Kim, J. Song, Effects of Siwu decoction on chondrocyte proliferation of growth plate in adolescent rats, J. Ethnopharmacol. (2019) 108–113, https://doi.org/10.1016/j.jep.2019.01.048.

[134] Y.L. Lin, T.H. Wang, M.H. Lee, N.W. Su, Biologically active components and nutraceuticals in the Monascus-fermented rice: a review, Appl. Microbiol. Biotechnol. (2008) 965–973, https://doi.org/10.1007/s00253-007-1256-6.

[135] C.H. Lin, Y.T. Wei, C.C. Chou, Enhanced antioxidative activity of soybean koji prepared with various filamentous fungi, Food Microbiol. (2006) 628–633, https://doi.org/10.1016/j.fm.2005.12.004.

[136] K. Mohan, S. Ravichandran, T. Muralisankar, V. Uthayakumar, R. Chandirasekar, P. Seedevi, D.K. Rajan, Potential uses of fungal polysaccharides as immunostimulants in fish and shrimp aquaculture: a review, Aquaculture (2019) 250–263, https://doi.org/10.1016/j.aquaculture.2018.10.023.

[137] H.S. Murthy, P. Li, A.L. Lawrence, D.M. Gatlin, Dietary β-glucan and nucleotide effects on growth, survival and immune responses of pacific white shrimp, Litopenaeus vannamei, J. Appl. Aquacult. (2009) 160–168, https://doi.org/10.1080/10454430903113644.

[138] L.Q. Luan, N.T. Vu, N.T. Nghia, N.H.P. Thao, Synergic degradation of yeast β-glucan with a potential of immunostimulant and growth promotor for tiger shrimp, Aquacult Rep (2021) 100858, https://doi.org/10.1016/j.aqrep.2021.100858.

[139] C. Pooljun, P. Jariyapong, T. Wongtawan, I. Hirono, S. Wuthisuthimethavee, Effect of feeding different types of β-glucans derived from two marine diatoms (Chaetoceros muelleri and Thalassiosira weissflogii) on growth performance and immunity of banana shrimp (Penaeus merguiensis), Fish Shellfish Immunol. (2022) 512–519, https://doi.org/10.1016/j.fsi.2022.09.047.

[140] M. Rajeish, M.M. Dechamma, M.K. Mani, P. Rai, I. Karunasagar, P. Bossier, I. Karunasagar, B. Maiti, Different expression pattern of thrombospondin gene in the presence and absence of β-glucan fed Penaeus monodon challenged with white spot syndrome virus, Fish Shellfish Immunol. Reports (2021) 100020, https://doi.org/10.1016/j.fsirep.2021.100020.

[141] M. Labieniec, T. Gabryelak, G. Falcioni, Antioxidant and pro-oxidant effects of tannins in digestive cells of the freshwater mussel Unio tumidus, Mutat. Res., Genet. Toxicol. Environ. Mutagen. (2003) 19–28, https://doi.org/10.1016/S1383-5718(03)00115-3.

[142] R.-H. Lu, C.-B. Qin, F. Yang, W.-Y. Zhang, Y.-R. Zhang, G.-K. Yang, L.-P. Yang, X.-L. Meng, X. Yan, G.-X. Nie, Grape seed proanthocyanidin extract ameliorates hepatic lipid accumulation and inflammation in grass carp (Ctenopharyngodon idella), Fish Physiol. Biochem. (2020) 1665–1677, https://doi.org/10.1007/s10695-020-00819-3.

[143] K. Peng, H. Zhao, G. Wang, B. Chen, W. Mo, Y. Huang, Effect of condensed tannins on growth performance, intestinal immune capacity and bacterial microbiomes of Lateolabrax japonicus, Aquacult. Res. (2021) 5321–5331, https://doi.org/10.1111/are.15402.

[144] J. Yao, P. Chen, E. Ringø, G. Zhang, Z. Huang, X. Hua, Effect of diet supplemented with rapeseed meal or hydrolysable tannins on the growth, nutrition, and intestinal microbiota in grass carp (Ctenopharyngodon idellus), Front. Nutr. (2019), https://doi.org/10.3389/fnut.2019.00154.

[145] G. Orso, M.M. Solovyev, S. Facchiano, E. Tyrikova, D. Sateriale, E. Kashinskaya, C. Pagliarulo, H.S. Hoseinifar, E. Simonov, E. Varricchio, M. Paolucci, R. Imperatore, Chestnut shell tannins: effects on intestinal inflammation and dysbiosis in zebrafish, Animals-Basel (2021) 1538.

[146] K. Starčević, L. Krstulović, D. Brozić, M. Maurić, Z. Stojević, Ž. Mikulec, M. Bajić, T. Mašek, Production performance, meat composition and oxidative susceptibility in broiler chicken fed with different phenolic compounds, J. Sci. Food Agric. (2015) 1172–1178, https://doi.org/10.1002/jsfa.6805.

[147] G. Biagi, I. Cipollini, B.R. Paulicks, F.X. Roth, Effect of tannins on growth performance and intestinal ecosystem in weaned piglets, Arch. Anim. Nutr. (2010) 121–135, https://doi.org/10.1080/17450390903461584.

[148] H. Do Huu, H.M. Sang, N.T. Thanh Thuy, Dietary β-glucan improved growth performance, Vibrio counts, haematological parameters and stress resistance of pompano fish, Trachinotus ovatus Linnaeus, 1758, Fish Shellfish Immunol. (2016) 402–410, https://doi.org/10.1016/j.fsi.2016.03.161.