

International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693

ISSN Online: 2617-4707

NAAS Rating (2026): 5.29

IJABR 2026; 10(2): 01-09

www.biochemjournal.com

Received: 02-10-2025

Accepted: 20-11-2025

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Dietary supplementation of *Morinda citrifolia* fruit and *Syzygium cumini* leaf enhances growth performance and stress tolerance in white leg shrimp (*Penaeus vannamei*) post larvae

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i2a.7313>

Abstract

This study focused on the evaluation of dietary supplementation of medicinal herbs on growth performance and stress tolerance in Pacific white shrimp, *Penaeus vannamei*. The PL of *Penaeus vannamei* (0.051 g) was distributed into four treatment groups in five replicates. Shrimps were fed with T₀ (Control diet), treatment T₁ (5% noni fruit), treatment T₂, (5% jamun leaf) for 60 days. After the feeding trial, shrimps from each treatment group were challenged with ammonia and salinity stress. The results showed that supplementation of 5% noni fruit in the shrimp diet had a significant difference ($p < 0.05$) in final weight, weight gain, and specific growth rate among all groups. The survival rate and biomass of shrimp showed a significant difference in those groups fed noni and jamun supplemented diets when compared to the control. However, the feed conversion ratio value in the control group was much greater than those of the remaining groups. Moreover, the T₁ and T₂ group also exhibited a significantly higher survival rate in the challenge tests against low salinity or high ammonia. The results suggest that dietary supplementation of noni fruit at the level of 5% modulates growth performance, feed utilization, survival, and resistance to environmental stresses.

Keywords: *Penaeus vannamei*, Noni fruit, Jamun leaves, growth, survival, stress tolerance

1. Introduction

Aquaculture is the fastest-growing food production sector and a critical source of sustainable animal protein; however, global output must increase by approximately 50% by 2050 to meet projected demand. Within this sector, crustacean aquaculture has expanded rapidly in recent decades, driven by strong global market demand. Shrimps and prawns are among the most valuable aquaculture commodities, generating substantial revenue and serving as key protein sources, particularly in tropical countries. Commercial shrimp production is dominated by penaeid species, with *Penaeus vannamei* and *Penaeus monodon* accounting for about 95% of global production in 2015. This dominance has continued, with crustacean aquaculture exceeding 11.2 million tonnes in 2020 and a farm-gate value surpassing USD 81.5 billion. The Pacific white shrimp, *P. vannamei*, remains the leading cultured species, contributing approximately 5.8 million tonnes, or 51.7% of total crustacean aquaculture production (FAO, 2024) [14].

The whiteleg shrimp (*Penaeus vannamei*) is among the most economically important crustacean species in global aquaculture. In Vietnam, particularly in the Mekong Delta, high-density shrimp farming systems have been increasingly adopted due to their substantial economic returns (Trang *et al.*, 2022) [39]. Nevertheless, the intensification and super-intensification of shrimp culture are associated with numerous environmental and health-related challenges (Khoa *et al.*, 2020) [19]. These production systems often exacerbate water pollution, thereby creating favorable conditions for the proliferation of opportunistic and pathogenic bacteria (Lieke *et al.*, 2019; Mirbakhsh *et al.*, 2022) [23, 24]. Furthermore, the intensive and sometimes indiscriminate use of antibiotics for disease prevention and growth enhancement has contributed to the emergence of antibiotic-resistant bacterial strains (Seyfried *et al.*, 2010) [33], as well as the accumulation of antibiotic residues in aquatic

environments (Santos & Ramos, 2016) [32] and shrimp tissues (Romero *et al.*, 2012) [31]. Consequently, there is an urgent need to develop sustainable and environmentally friendly alternatives to conventional chemotherapeutic approaches in aquaculture. Natural products, particularly medicinal plants, have gained considerable attention as promising alternatives due to their availability, cost-effectiveness, environmental safety, and capacity to promote growth and health in aquatic organisms (Awad & Awaad, 2017; Elumalai *et al.*, 2021; Hamed *et al.*, 2021) [4, 13, 17]. As reported by Hai (2015) [40] and Wang *et al.*, plant-based materials can be applied in aquaculture in various forms, including fresh biomass, crude extracts obtained using different solvents, or isolated bioactive compounds, with plant extracts being the most commonly utilized as feed additives.

Immunomodulatory strategies represent a viable alternative to antibiotics for improving disease resistance in shrimp aquaculture by enhancing innate immune function. The extensive use of antibiotics for prophylaxis has accelerated the development of antibiotic-resistant bacteria, compromising farm biosecurity and environmental sustainability (Aoki, 1992) [3]. Consequently, attention has shifted toward plant-based nutraceuticals, including herbs and phytochemicals, as functional feed additives. These compounds not only stimulate immune responses but also enhance growth performance by reducing pathogen burden and optimizing energy allocation (Abreu *et al.*, 2012) [1]. Moreover, herbal nutraceuticals are biodegradable, renewable, and generally safe, supporting their application in sustainable aquaculture systems (Harikrishnan *et al.*, 2011; Abreu *et al.*, 2012) [18, 1]. Numerous plant species have demonstrated immunostimulatory and growth-promoting effects in shrimp, such as *Cynodon dactylon*, *Aegle marmelos*, *Tinospora cordifolia*, *Picrorhiza kurroa*, and *Eclipta alba* in *Penaeus monodon* (Citarasu *et al.*, 2006) [8]; *Cardiospermum halicacabum* in *P. monodon* (Rajasekar *et al.*, 2011) [30]; *Petalonia binghamiae* in *Penaeus vannamei* and *Agati grandiflora*, *Justicia tranquebariensis*, and *Eclipta erecta* in *P. monodon* (Kumaran *et al.*, 2014) [22], highlighting their potential as sustainable alternatives to conventional chemotherapeutics.

Noni (*Morinda citrifolia* L.) is an important medicinal plant extensively cultivated in Southeast Asia and characterized by a high content of nutrients and bioactive compounds, including proteins, vitamins, minerals, carbohydrates, and alkaloids (Singh *et al.*, 2008; Halim *et al.*, 2018) [35, 16]. Numerous studies have documented its antibacterial, antifungal, antioxidant, and anti-inflammatory properties (Krishnaiah *et al.*, 2012; Palu *et al.*, 2012; de Almeida Lopes *et al.*, 2018; Deivi Arunachalam *et al.*, 2021) [20, 27, 9, 10]. Dietary inclusion of noni has been reported to improve growth performance and immune function in terrestrial livestock and poultry species, such as Nicobari fowl, crossbred beef calves, and broiler chickens (Yancey *et al.*, 2013) [46]. However, its application in aquaculture remains underexplored. Emerging evidence indicates that *M. citrifolia* leaf extract enhances immune gene expression in the giant freshwater prawn (*Macrobrachium rosenbergii*) (Halim *et al.*, 2018) [16], while crude fruit extract supplementation improves growth indices and antioxidant capacity in whiteleg shrimp (*Penaeus vannamei*) post-larvae (Moh *et al.*, 2021) [25]. Collectively, these findings highlight *M. citrifolia* as a promising natural feed additive for

improving shrimp health and performance.

Syzygium cumini (L.) Skeels, commonly known as Java plum or jamun, is an important medicinal plant widely used in traditional medicine to treat infectious diseases and is distributed throughout South and Southeast Asia (Morton, 1987) [26]. The leaves contain a wide range of bioactive compounds, including alkaloids, anthocyanins, flavonoids, triterpenoids, tannins, and polyphenols such as gallic and ellagic acids, which exhibit strong antibacterial activity (Chattopadhyay *et al.*, 1998; Timbola *et al.*, 2002; Ayyanar & Subash-Babu, 2012) [7, 38, 5]. These properties support the use of *S. cumini* leaf powder as a natural immunostimulant in shrimp aquaculture. Dietary inclusion of *S. cumini* leaf powder (SCLP) offers a cost-effective and eco-friendly alternative to antibiotics by enhancing non-specific immune responses and resistance to bacterial infections. Consistent with this, Prabu *et al.* reported that jamun leaf powder reduced oxidative stress and enhanced innate immunity in snubnose pompano (*Trachinotus blochii*) following *Vibrio parahaemolyticus* challenge. Accordingly, the present study evaluated the combined efficacy of *Morinda citrifolia* fruit and *S. cumini* leaf powder as natural antioxidants in improving growth performance, alleviating oxidative stress, and enhancing survival of whiteleg shrimp (*Penaeus vannamei*) post-larvae exposed to ammonia and salinity stress.

2. Materials and Methods

2.1 Collection of medicinal herbs

Fresh fruits of *Morinda citrifolia* L. were obtained in sufficient quantity from a commercial supplier. The fruits were thoroughly washed with tap water to remove surface contaminants, cut into small pieces, and sun-dried for approximately 14 days until a constant weight was achieved. The dried material was subsequently ground into a fine powder using a mechanical grinder and stored in airtight containers at room temperature until use. Leaves of Java plum (*Syzygium cumini* (L.) Skeels) were collected from the Junagadh District, Gujarat, India. The leaves were washed with freshwater to remove adhering debris and shade-dried for several days until the moisture content was reduced to approximately 10%. The dried leaves were then pulverized using a laboratory grinder and sieved to obtain a uniform particle size of 100-150 µm. The resulting *S. cumini* leaf powder was stored in clean, airtight containers under dry conditions prior to incorporation into experimental diets. A commercial shrimp feed (Growel Feeds India) with a proximate composition of 40% crude protein, 4% crude lipid, 5% crude fiber, and 11% moisture was used as the basal control diet. The control diet did not contain *M. citrifolia* fruit powder or *S. cumini* leaf powder.

2.2 Experimental animals

Juvenile Pacific whiteleg shrimp (*Penaeus vannamei*) with an initial mean body weight of 5.0-6.0 g were used in the experiment. The shrimp were procured from West Coast Shrimp Hatchery, located in the coastal village of Kotada, Gir Somnath District, Gujarat, India. Live shrimp were transported to the wet laboratory in plastic Sintex™ tanks under continuous aeration to minimize handling stress. Upon arrival, the shrimp were gently transferred to circular fiberglass tanks (300 L capacity) supplied with continuous aeration. The stock was acclimated under laboratory conditions for 14 days and fed a commercial sinking diet

containing 35% crude protein and 6% crude lipid. During the acclimation period, shrimp were monitored daily for general health and abnormal behavior.

2.3 Diet formulation and incorporation of medicinal herbs

Three practical diets were formulated to contain 35% crude protein and 6% crude lipid. The control diet (T₀) contained no herbal supplementation, while the experimental diets were supplemented with either 5% *Morinda citrifolia* fruit powder (T₁) or 5% *Syzygium cumini* leaf powder (T₂) (Table 1). The diets were prepared using soybean meal, fish meal, *Acetes* meal, wheat gluten, groundnut oil cake, sunflower oil cake, wheat flour, de-oiled rice bran, fish oil, soy lecithin, binder, and other additives. All dry ingredients were weighed according to the formulation, thoroughly mixed, and water was added to obtain a homogeneous dough. The dough was transferred to aluminum trays and steam-cooked in an autoclave for 20 min. After cooling to room temperature, vitamin C and butylated hydroxytoluene (BHT) were added to minimize thermal degradation. The dough was then pelletized using a motor-driven pelletizer, and the pellets were oven-dried at 45-50 °C overnight. The dried pellets were packed in airtight polyethylene bags, sealed, and labeled according to dietary treatments. Proximate composition of the experimental diets and feed ingredients was determined following standard AOAC methods (1995) [2].

2.4 Experimental design and feeding trials

A 60-day feeding trial was conducted at the Hands-on Training Center, College of Fisheries Science, Kamdhenu University, Veraval, to evaluate the effects of *Morinda citrifolia* fruit and *Syzygium cumini* leaf powder on the growth and health of Pacific whiteleg shrimp (*Penaeus vannamei*). Shrimp were randomly assigned to three dietary treatments: control (T₀, basal diet without supplementation), 5% *M. citrifolia* fruit powder (T₁), and 5% *S. cumini* leaf powder (T₂), each in triplicate. Shrimp were stocked at approximately 180 individuals per circular fiberglass tank (3.3 × 1.15 × 0.75 m) and fed four times daily. Uneaten feed was removed routinely, and minimal water exchange was performed to maintain water quality. Tanks were continuously aerated and maintained at 28 ± 1 °C and 15 ppt salinity. To reduce stress and mimic natural conditions, tanks were covered with nylon shade netting to limit light exposure. Growth performance was monitored every 15 days by randomly sampling five shrimp per tank to record body weight (BW) and total length (TL). Water quality was maintained within optimal ranges throughout the experiment: dissolved oxygen 5.5-6.0 mg L⁻¹, ammonia 0.2-0.25 mg L⁻¹, nitrite 0.1-0.15 mg L⁻¹, nitrate 0.5-0.6 mg L⁻¹, and pH 7.8-8.3.

2.5 Body growth and growth performance of *P. vannamei* PL determination

Growth of *P. vannamei* post-larvae (PL) was assessed every 15 days throughout the 60-day feeding trial by measuring body weight (BW) and total length (TL). BW was determined using an analytical balance, and TL was measured from the rostrum to the telson using a standard ruler. Growth performance parameters were calculated as follows:

Survival rate (%) = (Final number of shrimp/Initial number of shrimp) × 100

Weight gain (WG, g/shrimp) = Final weight (g) – Initial weight (g)

Daily weight gain (DWG, g/day) = (Final weight – Initial weight)/Days

Specific growth rate (SGR, %/day) = ([ln Final weight – ln Initial weight]/Days) × 100

Feed conversion ratio (FCR) = Feed intake (g)/Weight gain (g)

Biomass (kg/m³) = (Final weight × Final population)/Volume of water

Protein efficiency ratio (PER) = Final biomass (g) - initial biomass (g) /Protein intake

2.6 Salinity stress experiment

After a 60-day feeding trial, 5 individuals in each tank were transferred to a 25-L tank for the salinity stress experiment, with salinity levels decreasing from 15 to 5 ppt by adding dechlorinated tap water. The survival rate of shrimp was calculated at 24-h intervals for 96 h.

2.7 Ammonia stress experiment

Similarly, five shrimp per treatment were allocated to 25-L tanks (5 individuals per replicate) for ammonia stress testing. Fresh seawater was added, and total ammonia nitrogen (TAN) levels were increased using ammonium chloride (NH₄Cl). Based on preliminary experiments and literature reporting elevated TAN in intensive shrimp ponds (up to 46.1 mg L⁻¹; Ciji & Akhtar, 2019), a TAN concentration of 40 mg L⁻¹ (NH₃: 2.79 mg L⁻¹; salinity: 15 ppt; pH: 8.0; temperature: 29 °C) was selected. The test solution was renewed every 24 h, and dead shrimp were recorded throughout the 96-h exposure period.

2.8 Statistical analysis

The data were statistically analyzed by statistical package (SPSS version 16). In this study one-way ANOVA was used to compare the means among all the treatments, and Duncan's multiple range tests (DMRT) were used to determine the significant differences between the means of variant (JL level) among the different treatments (Duncan 1955) [11]. Student's two-tailed t test ($p < 0.05$) was used to compare the significance level of mean values of pre- and post-challenge biochemical and enzymological response in the same treatment. Kaplan Meier test was done for the statistical assay of mortality in addition to one way ANOVA. Comparisons were made at the 5% probability levels.

3. Results

3.1 Growth parameter

The effects of dietary supplementation with medicinal herbs on growth performance, specific growth rate (SGR), feed conversion ratio (FCR), and protein efficiency ratio (PER) of *Penaeus vannamei* were evaluated over a 60-day experimental period. Growth-related parameters were assessed at 15-day intervals, while feed utilization indices

were calculated at the end of the experiment. The results are presented in Tables 1-2 and Figures 1 and 2. At the beginning of the experiment (day 0), shrimp in all treatments (T_0 , T_1 , and T_2) exhibited a uniform mean initial body weight of 0.051 ± 0.00 g, confirming homogeneity among experimental groups. Mean body weight increased progressively in all treatments throughout the culture period, with significant differences observed among treatments at each sampling interval ($p < 0.05$). After 15 days, shrimp fed the T_1 diet exhibited a significantly higher mean weight gain (0.240 ± 0.010 g) compared to T_2 (0.175 ± 0.004 g) and the control group T_0 (0.160 ± 0.007 g). This trend persisted throughout the experiment. At day 30, mean weight gain was highest in T_1 (1.137 ± 0.031 g), followed by T_2 (0.767 ± 0.003 g) and T_0 (0.674 ± 0.006 g). Similarly, at day 45, shrimp in T_1 recorded the greatest mean weight gain (3.293 ± 0.027 g), significantly exceeding those in T_2 (2.051 ± 0.050 g) and T_0 (1.785 ± 0.017 g) ($p < 0.05$). By the end of the 60-day experimental period, final mean body weight differed significantly among treatments ($p < 0.05$). Shrimp

in T_1 attained the highest final mean weight (6.739 ± 0.028 g), followed by T_2 (4.123 ± 0.029 g), while the lowest weight was observed in the control group T_0 (3.559 ± 0.058 g).

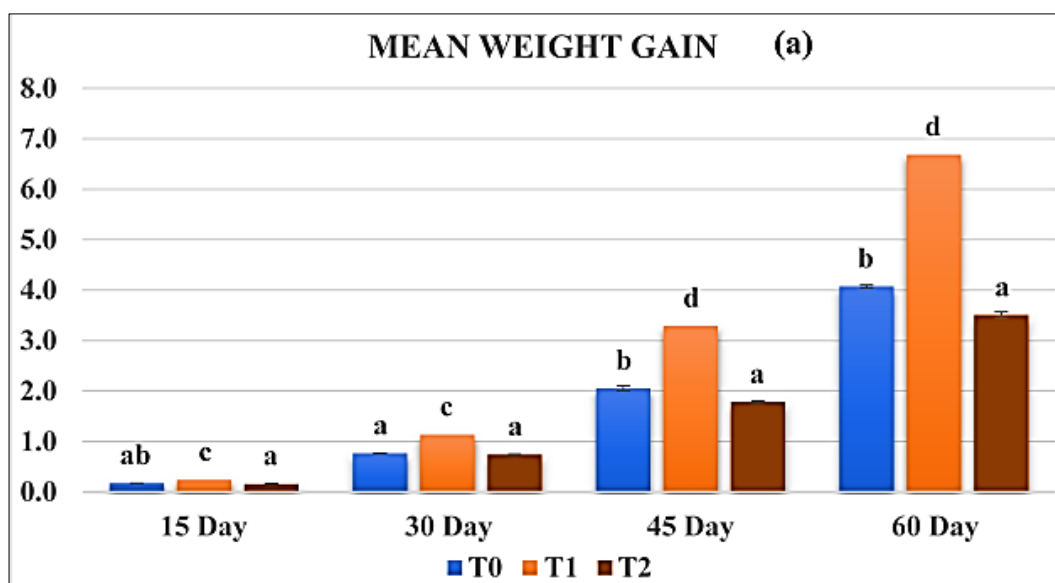
Consistent with the observed growth trends, specific growth rate (SGR) varied significantly among treatments ($p < 0.05$). The highest SGR was recorded in T_1 (6.867 ± 0.004), followed by T_2 (6.376 ± 0.007), whereas T_0 exhibited the lowest SGR (6.228 ± 0.016). Feed utilization efficiency, expressed as feed conversion ratio (FCR), also showed significant differences among treatments ($p < 0.05$). The lowest FCR was observed in T_1 (1.46 ± 0.027), indicating superior feed utilization, followed by T_2 (1.78 ± 0.014). The control treatment T_0 recorded the highest FCR value (1.96 ± 0.025). Protein efficiency ratio (PER) differed significantly among treatments at the end of the experimental period ($p < 0.05$). Shrimp fed the T_1 diet exhibited the highest PER (1.95 ± 0.038), followed by T_2 (1.59 ± 0.014), while the lowest PER was observed in the control group T_0 (1.44 ± 0.019).

Table 1: Growth performance and survival rate of *P. vannamei* fed various experimental diets for 60 days.

Treatment	Weight gain (%)	SGR (%)	FCR	PER	Survival (%)
T_0	3.612 ± 0.12^a	6.438 ± 0.02^b	1.638 ± 0.06^b	1.75 ± 0.07^b	84.00 ± 2.66^a
T_1	6.928 ± 0.09^d	6.902 ± 0.01^d	1.370 ± 0.04^a	2.10 ± 0.06^d	97.33 ± 1.63^c
T_2	4.336 ± 0.08^b	6.256 ± 0.03^a	1.952 ± 0.08^c	1.48 ± 0.06^a	89.33 ± 1.63^{ab}

The survival rate of *Penaeus vannamei* differed significantly among treatments over the 60-day experimental period ($p < 0.05$; Tables 1-2; Fig. 3). Final survival was highest in T_1 ($94.66 \pm 2.49\%$), followed by T_3 ($89.33 \pm 1.63\%$) and T_2

($88.00 \pm 1.33\%$), while the lowest survival was recorded in the control (T_0 ; $81.33 \pm 1.33\%$). Treatments T_2 and T_3 showed significantly higher survival compared to the control.



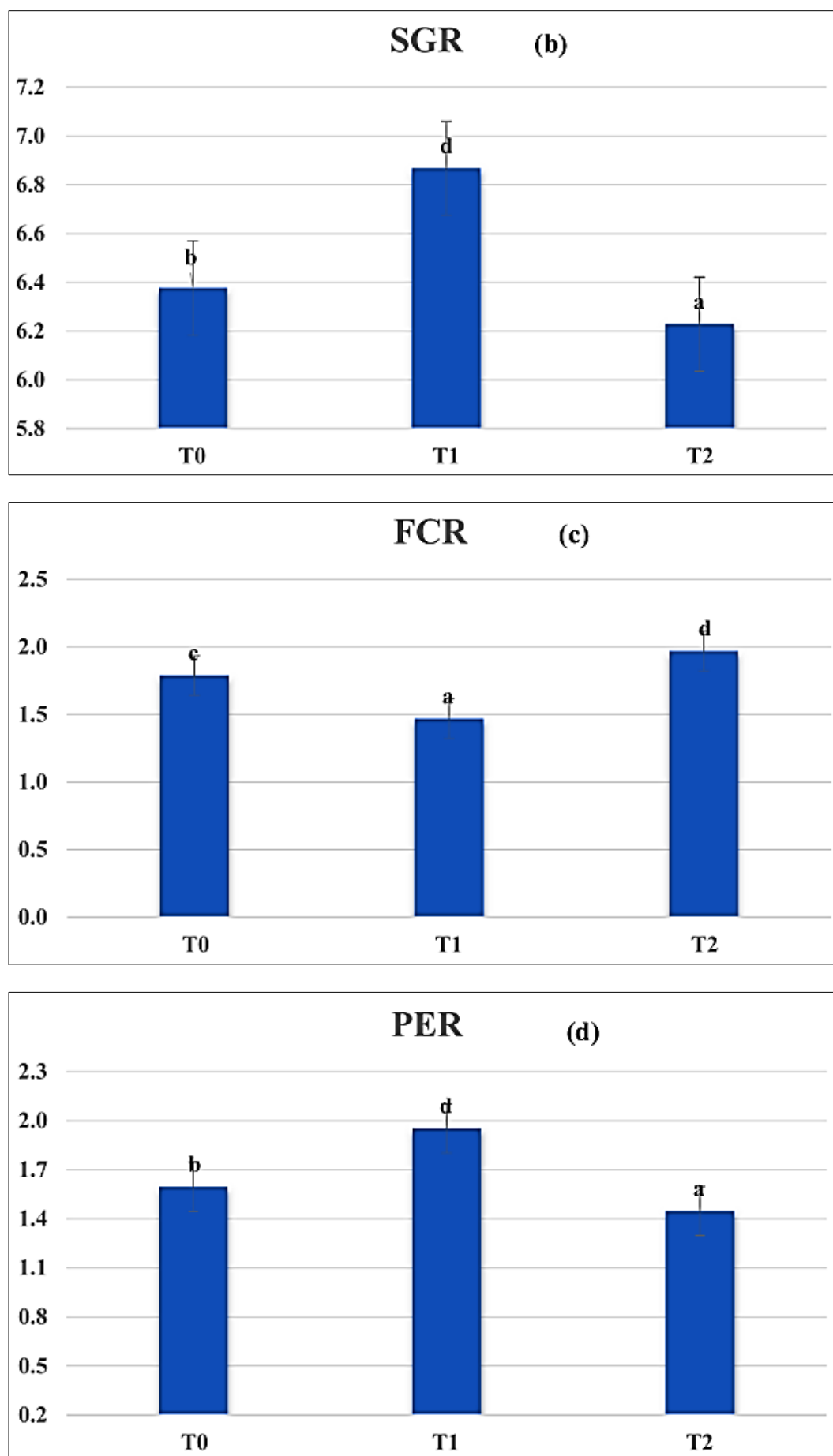


Fig 1: Growth changes in terms of (a) Mean weight gain, (b) Specific growth rate (SGR), (c) Feed conversion ratio (FCR), (d) Protein efficiency ratio (PER) of *P. vannamei* during supplemented feeding trials with *M. citrifolia* fruit and *S. cumini* leaf powder. Significant differences in growth changes are indicated by italic letters.

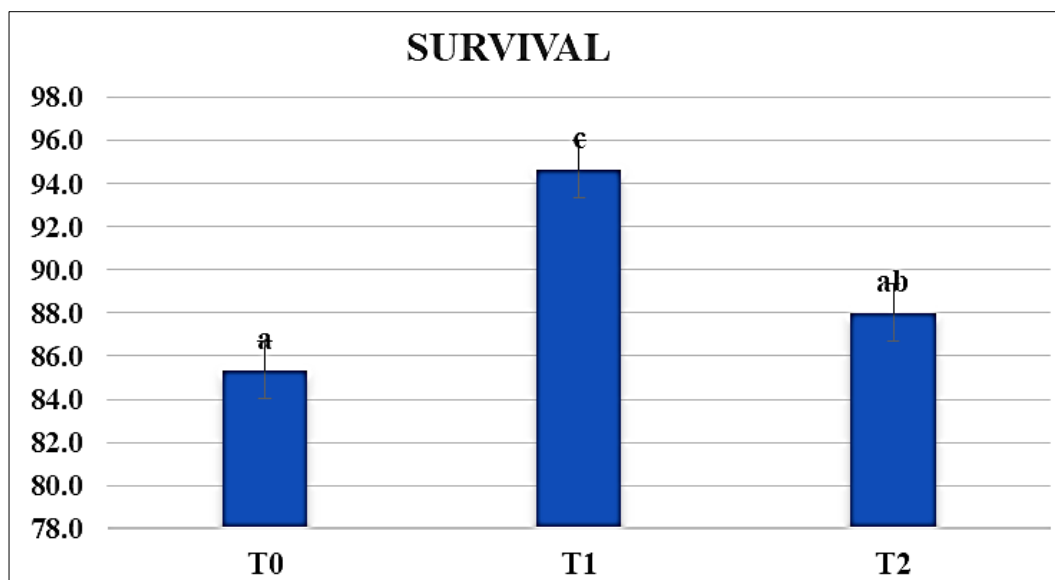


Fig 2: Percentage of survival of *P. vannamei* after feeding trial of medicinal herbs at the end of experiment

3.2 Carcass Composition

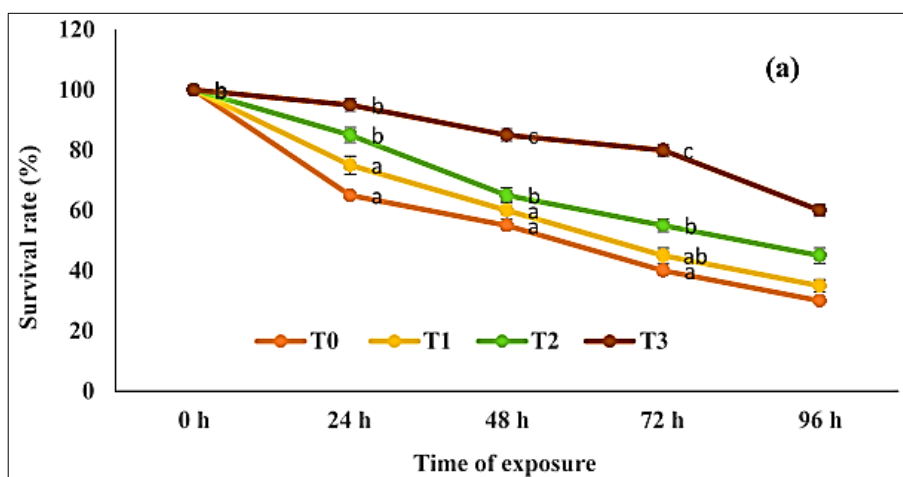
The carcass proximate composition of *Penaeus vannamei* at the end of the experimental period is summarized in Table X. Moisture content did not differ significantly among the Control, T₁, T₂, T₃, and T₄ treatments ($p > 0.05$), with an overall mean of 74.86%. Crude protein content ranged from $19.25 \pm 0.11\%$ in the Control to $20.42 \pm 0.14\%$ in T₃, with significant differences among treatments ($p < 0.05$). Shrimp fed T₂ and T₃ diets showed significantly higher protein

levels compared to the Control, while T₁ and T₄ exhibited intermediate values. Crude lipid content differed significantly among treatments ($p < 0.05$), varying from $1.89 \pm 0.01\%$ (Control) to $2.25 \pm 0.10\%$ (T₃). Lipid content was significantly higher in T₂ and T₃ compared to the Control, whereas T₁ and T₄ were not significantly different. Ash content averaged 3.66% and did not vary significantly among treatments ($p > 0.05$).

Table 1: Proximate composition of *P. vannamei* fed various experimental diets after 60 days.

Treatment	Crude protein (%)	Crude Fat (%)	Moisture (%)	Ash (%)
T ₀	19.25 ± 0.11	2.25 ± 0.10	74.86 ± 0.06	3.66 ± 0.04
T ₁	20.42 ± 0.14	2.18 ± 0.06	74.72 ± 0.01	3.54 ± 0.05
T ₂	19.34 ± 0.05	1.89 ± 0.01	74.56 ± 0.04	3.62 ± 0.06

3.3 Low salinity and high ammonia challenges



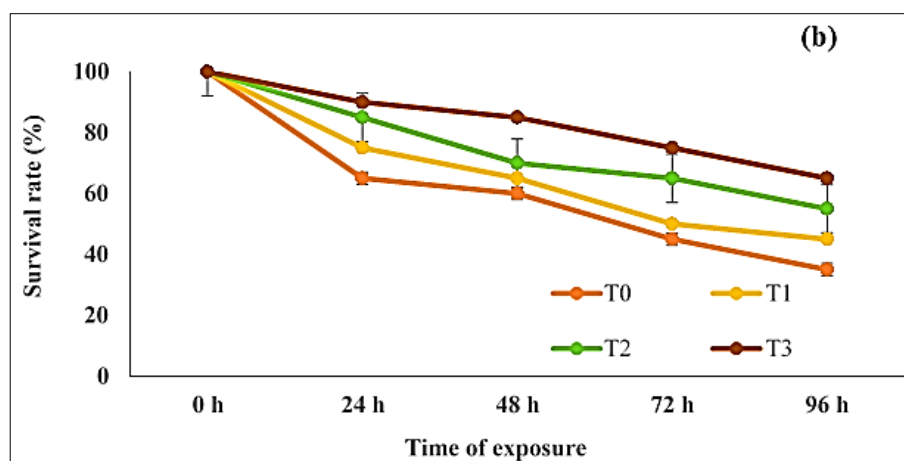


Fig 3: Survival rate (%) of *Penaeus vannamei* fed diets containing *M. citrifolia* fruit and *S. cumini* leaf spowder after exposure to low salinity (a) or high ammonia stress (b). Values shown are mean $\pm$ SD (n = 3). Bars with different letters at the same timepoint indicate significant differences (one-way ANOVA, $p < 0.05$).

The survival rates of the three experimental groups were higher than that of the control group (T₀) after 24 h of exposure to low salinity; however, no significant differences were observed between the T₁ and T₂ groups or between the T₂ and T₃ groups (Fig. 3). Similar results were also observed for 96-h exposure.

3.3. Water quality parameters

The physico-chemical parameters of water were within the optimum range during the entire period of culture. The range of all the physico-chemical parameters were as follows: dissolved oxygen 6.0-6.3 mg L⁻¹, temperature 25.9-27.7 °C, pH 8.1-8.3, ammonia nitrogen 0.05-0.15 mg L⁻¹, nitrate nitrogen 0.81-1.29 mg L⁻¹, nitrite nitrogen 0.074-0.083 mg L⁻¹ and salinity 30-32 ‰ was present throughout the experimental period.

4. Discussion

The present study demonstrates that dietary supplementation with medicinal herbs, specifically noni fruit (*Morinda citrifolia*) and jamun leaf (*Syzygium cumini*), significantly enhanced growth performance, feed utilization efficiency, protein utilization, and survival of *Penaeus vannamei*, confirming their potential as natural growth promoters in shrimp aquaculture. Comparable growth improvements with noni supplementation have been reported in *P. vannamei* (Moh *et al.*, 2021; Phan *et al.*, 2023) [25, 28] and several finfish species, including *Oreochromis niloticus*, *Cyprinus carpio*, and *Pelteobagrus fulvidraco* (Kristiana *et al.*, 2020; Effendi *et al.*, 2022; Wang *et al.*, 2021) [21, 12, 42], indicating broad applicability across aquatic taxa. The enhancement in growth and feed efficiency may be attributed to proxeronine in noni, which is converted to xeronine *in vivo*. Xeronine plays a critical role in protein synthesis, glucose absorption, and metabolic regulation, thereby promoting nutrient utilization and somatic growth (Widjastuti *et al.*, 2019; Sridevi *et al.*, 2013) [45, 36]. In addition, bioactive compounds such as anthraquinones, organic acids, and saponins present in noni lower gut pH and stimulate digestive enzyme activity, enhancing protein digestion, nutrient absorption, protein efficiency ratio (PER), and feed conversion ratio (FCR) (Widianto *et al.*, 2015) [44].

Dietary inclusion of jamun leaf also significantly improved growth indices, feed utilization efficiency, PER, and survival in *P. vannamei*. These findings align with earlier

reports in shrimp, freshwater prawns, and finfish species (Bhavan *et al.*, 2014; Prabu *et al.*, 2021; Giri *et al.*, 2023) [6, 9, 15]. The growth-promoting effects of jamun leaves are likely linked to their rich phytochemical composition, including flavonoids, tannins, and essential oils, which enhance feed palatability, digestion, nutrient absorption, and pathogen resistance. The improved survival rates observed in noni- and jamun-supplemented treatments further indicate their health-promoting and immunostimulatory properties. Similar enhancements in survival have been documented in *P. vannamei* and other aquatic species fed *M. citrifolia* and *S. cumini*-based diets (Bhavan *et al.*, 2014; Phan *et al.*, 2023) [6, 28], although variations reported in some studies suggest that efficacy may depend on inclusion level, processing methods, and culture conditions.

Shrimp fed diets supplemented with noni (*Morinda citrifolia*) fruit extract exhibited significantly higher survival compared to the control. Previous studies have shown that noni fruit contains bioactive compounds with antioxidant and polyphenolic properties that enhance physiological stability and stress tolerance in *Penaeus vannamei* (Moh *et al.*, 2021; Sina *et al.*, 2020) [25, 34]. As crustaceans rely primarily on innate immunity and lack an adaptive immune response, they are highly susceptible to environmental stressors (Wang & Wang, 2012) [43]. In the present study, improved survival following low-salinity and high-ammonia challenge tests indicates enhanced stress resistance in shrimp fed noni-supplemented diets. These findings suggest that dietary noni fruit extract can strengthen non-specific defense mechanisms and improve resilience of whiteleg shrimp under adverse culture conditions.

References

1. Abreu AC, McBain AJ, Simões M. Plants as sources of new antimicrobials and resistance-modifying agents. *Natural Product Reports*. 2012;29(9):1007. DOI:10.1039/c2np20035j.
2. AOAC. Official Methods of Analysis of AOAC International. 16th ed. Vol. 1. Arlington: Association of Official Analytical Chemists; 1995.
3. Aoki T. Chemotherapy and drug resistance in fish farm in Japan. In: Shariff M, Subasinghe RP, Arthur JP, editors. *Diseases in Asian Aquaculture*. Vol. 1. Manila: Asian Fisheries Society; 1992. p. 519-529.

4. Awad E, Awaad A. Role of medicinal plants on growth performance and immune status in fish. *Fish and Shellfish Immunology*. 2017;67:40-54. DOI:10.1016/j.fsi.2017.05.034.
5. Ayyanar M, Subash-Babu P. *Syzygium cumini* (L.) Skeels: a review of its phytochemical constituents and traditional uses. *Asian Pacific Journal of Tropical Biomedicine*. 2012;2(3):240-246. DOI:10.1016/S2221-1691(12)60050-1.
6. Bhavan PS, Mohammedsiddiq S, Srinivasan V, Muralisankar T, Manickam N. Effects of seeds of medicinal plants *Syzygium cumini*, *Phyllanthus emblica*, *Azadirachta indica* and *Ricinus communis* on growth promotion in *Macrobrachium malcolmsonii* early juveniles. *International Journal of Research Studies in Biosciences*. 2014;2(11):95-106.
7. Chattopadhyay D, Sinha BK, Vaid LK. Antibacterial activity of *Syzygium* species. *Fitoterapia*. 1998;69:365-367.
8. Citarasu T, Sivaram V, Immanuel G, Rout N, Murugan V. Influence of selected Indian immunostimulant herbs against white spot syndrome virus infection in black tiger shrimp, *Penaeus monodon*. *Fish and Shellfish Immunology*. 2006;21(4):372-384. DOI:10.1016/j.fsi.2006.01.002.
9. De Almeida Lopes MM, Sanches AG, De Sousa JA, De Oliveira Silva E. Noni—*Morinda citrifolia* L. In: Elsevier eBooks; 2018. p. 319-325. DOI:10.1016/B978-0-12-803138-4.00042-3.
10. Deivi Arunachalam K, Kuruva JK, Pradhoshini KP, Musthafa MS, Faggio C. Antioxidant and antigenotoxic potential of *Morinda tinctoria* Roxb. leaf extract succeeding cadmium exposure in Asian catfish, *Pangasius sutchi*. *Comparative Biochemistry and Physiology Part C: Toxicology and Pharmacology*. 2021;249:109149. DOI:10.1016/j.cbpc.2021.109149.
11. Duncan DB. Multiple range and multiple F-test. *Biometrics*. 1955;11:1-5.
12. Effendi I, Yoswaty D, Syawal H, Austin B, Lyndon AR, Kurniawan R, *et al.* Effects of herbal growth promoters on common carp (*Cyprinus carpio*). *Aquaculture, Aquarium, Conservation and Legislation*. 2022;15(3):1096-1103.
13. Elumalai P, Kurian A, Lakshmi S, Faggio C, Esteban MA, Ringø E. Herbal immunomodulators in aquaculture. *Reviews in Fisheries Science and Aquaculture*. 2021;29(1):33-57. DOI:10.1080/23308249.2020.1779651.
14. FAO. The State of World Fisheries and Aquaculture 2024: Blue Transformation in Action. Rome: Food and Agriculture Organization of the United Nations; 2024. DOI:10.4060/cd0683en.
15. Giri SS, Kim SG, Jung WJ, *et al.* Dietary *Syzygium cumini* leaf extract influences growth performance, immunological responses and gene expression in pathogen-challenged *Cyprinus carpio*. *Fish and Shellfish Immunology*. 2023;138:108830. DOI:10.1016/j.fsi.2023.108830.
16. Halim AM, Prajitno A, Chang CC. Enhancement glutathione peroxidase activity and $\alpha 2$ -macroglobulin gene expression of *Macrobrachium rosenbergii* fed with aqueous *Morinda citrifolia* leaf extract-supplemented diet. *International Journal of Ocean and Aquatic Sciences*. 2018;1(1):9-16. DOI:10.22219/ijota.v1i1.4849.
17. Hamed HS, Ismal SM, Faggio C. Effect of allicin on antioxidant defense system and immune response after carbofuran exposure in Nile tilapia, *Oreochromis niloticus*. *Comparative Biochemistry and Physiology Part C: Toxicology and Pharmacology*. 2020;240:108919. DOI:10.1016/j.cbpc.2020.108919.
18. Harikrishnan R, Balasundaram C, Heo MS. Impact of plant products on innate and adaptive immune system of cultured finfish and shellfish. *Aquaculture*. 2011;317:1-15. doi:10.1016/j.aquaculture.2011.03.039.
19. Khoa TND, Tao CT, Van Khanh L, Hai TN. Super-intensive culture of white leg shrimp (*LitoPenaeus vannamei*) in outdoor biofloc systems. *Aquaculture*. 2020;524:735277. DOI:10.1016/j.aquaculture.2020.735277.
20. Krishnaiah D, Nithyanandam R, Sarbatly R. Phytochemical constituents and activities of *Morinda citrifolia* L. In: InTech eBooks; 2012. DOI:10.5772/26094.
21. Kristiana V, Mukti AT, Agustono. Increasing growth performance of Nile tilapia (*Oreochromis niloticus*) by supplementation of noni *Morinda citrifolia* fruit extract. *AACL Bioflux*. 2020;13(1):159-166.
22. Kumaran T, Viji VT, Velmurugan S, Citarasu T. Influence of selected antiviral herbal active principles against shrimp white spot syndrome virus. *International Journal of Molecular Biology and Biochemistry*. 2014;2(1):41-49.
23. Lieke T, Meinelt T, Hoseinifar SH, *et al.* Sustainable aquaculture requires environmental-friendly treatment strategies for fish diseases. *Reviews in Aquaculture*. 2020;12(2):943-965. doi:10.1111/raq.12365.
24. Mirbakhsh M, Ghaednia B, Zorriehzahra MJ, Esmaeili F, Faggio C. Dietary mixed and sprayed probiotic improves growth performance of juvenile whiteleg shrimp (*LitoPenaeus vannamei* Boone, 1931). *Journal of Applied Aquaculture*. 2023;35(3):823-836. DOI:10.1080/10454438.2022.2032528.
25. Moh JHZ, Waiho K, Fazhan H, *et al.* Effect of noni (*Morinda citrifolia*) fruit extract supplementation on whiteleg shrimp, *Penaeus vannamei*. *Aquaculture Reports*. 2021;21:100798. DOI:10.1016/j.aqrep.2021.100798.
26. Morton JF. Fruits of Warm Climates. Miami: JF Morton; Chapter: Mango (*Mangifera indica* L.). 1987
27. Palu AK, West BJ, Jensen CJ. Noni seed oil topical safety and efficacy. *Journal of Cosmetics, Dermatological Sciences and Applications*. 2012;2(2):74-78. DOI:10.4236/jcdsa.2012.22017.
28. Phan TCT, Nguyen TKL, *et al.* Effects of noni fruit extract on juvenile whiteleg shrimp (*LitoPenaeus vannamei*). *Egyptian Journal of Aquatic Research*. 2023;49(4):549-554. DOI:10.1016/j.ejar.2023.08.003.
29. Prabu DL, Ebenezar S, Chandrasekar S, *et al.* Antioxidant defence system through dietary jamun leaf in *Trachinotus blochii*. *Fish Physiology and Biochemistry*. 2021;47(2):617-637. DOI:10.1007/s10695-021-00935-8.
30. Rajasekar T, Usharani J, Sakthivel M, Deivasigamani B. Immunostimulatory effects of *Cardiospermum halicacabum* against *Vibrio parahaemolyticus* on tiger

- shrimp *Penaeus monodon*. Journal of Chemical and Pharmaceutical Research. 2011;3(5):501-513.
31. Romero J, Gloria C, Navarrete P. Antibiotics in aquaculture—use, abuse and alternatives. In: InTech eBooks; 2012. DOI:10.5772/28157.
 32. Santos L, Ramos F. Detection of antibiotic residues in aquaculture fishes. Trends in Food Science and Technology. 2016;52:16-30. DOI:10.1016/j.tifs.2016.03.015.
 33. Seyfried EE, Newton RJ, Rubert KF, Pedersen JA, McMahon KD. Occurrence of tetracycline resistance genes in aquaculture facilities. Microbial Ecology. 2010;59(4):799-807. DOI:10.1007/s00248-009-9624-7.
 34. Sina H, Dramane G, Tchekounou P, et al. Phytochemical composition and biological activities of *Morinda citrifolia* fruit juice. Saudi Journal of Biological Sciences. 2021;28(2):1331-1335. DOI:10.1016/j.sjbs.2020.11.059.
 35. Singh DR, Sunder J, Srivastava RC. Peptide and mineral profile of *Morinda citrifolia* fruits and leaves. International Journal of Noni Research. 2008;2(1-2):72-78.
 36. Sridevi N, Sasikumar CS, Cherian KM. *Morinda citrifolia* (Noni) - a detailed review. International Journal of Universal Pharmacy and Bio Sciences. 2013;2:494-509.
 37. Sunder J, Jeyakumar S, Sujatha T, Kundu A. Grommune: *Morinda citrifolia*-based herbal tonic for growth and immunity for commercial broilers. Journal of Applied Animal Research. 2014;43(2):137-140. DOI:10.1080/09712119.2014.928628.
 38. Timbola A, Szpoganicz B, Branco A, Monache F, Pizzolatti M. A new flavonol from leaves of *Eugenia jambolana*. Fitoterapia. 2002;73(2):174-176. DOI:10.1016/S0367-326X(02)00009-6.
 39. Trang NT, Tu VH, Son LT, Son NP. Is super-intensive shrimp farming more environmentally friendly: An application of material balance principle in the Mekong Delta. Environment, Development and Sustainability. 2022;25(3):2670-2687. DOI:10.1007/s10668-022-02156-2.
 40. Van Hai N. The use of medicinal plants as immunostimulants in aquaculture: A review. Aquaculture. 2015;446:88-96. DOI:10.1016/j.aquaculture.2015.03.014.
 41. Wang J, Meng X, Lu R, Wu C, Luo Y, Yan X, et al. Effects of *Rehmannia glutinosa* on growth performance, immunological parameters and disease resistance to *Aeromonas hydrophila* in common carp (*Cyprinus carpio* L.). Aquaculture. 2014;435:293-300. DOI:10.1016/j.aquaculture.2014.10.004.
 42. Wang S, Li X, Zhang M, Wang R, Qian Y, Hong M, et al. Effects of fermented noni juice on growth, antioxidant status, immune response, intestinal microbiota, and resistance to *Aeromonas hydrophila* of juvenile yellow catfish *Pelteobagrus fulvidraco* fed a high-fat diet. Aquaculture Nutrition. 2021;27(5):1290-1303. DOI:10.1111/anu.13268.
 43. Wang X, Wang J. Pattern recognition receptors acting in innate immune system of shrimp against pathogen infections. Fish and Shellfish Immunology. 2012;34(4):981-989. DOI:10.1016/j.fsi.2012.08.008.
 44. Widiyanto B, Prayogi HS, Nuryadi N. Pengaruh penambahan tepung buah mengkudu (*Morinda citrifolia* L.) dalam pakan terhadap penampilan produksi itik hibrida. Jurnal Ilmu-Ilmu Peternakan. 2015;25(2):28-35. DOI:10.21776/ub.jiip.2015.025.02.04.
 45. Widjastuti T, Abun N, Setiawan I, Indrawati N. Effects of addition of noni fruit juice (*Morinda citrifolia*) into drinking water on final body weight, carcass percentage, abdominal fat and meat cholesterol of Sentul debu chicken phase growth. IOP Conference Series: Earth and Environmental Science. 2019;334(1):012032. DOI:10.1088/1755-1315/334/1/012032.
 46. Yancey J, Apple J, Kegley E, Godbee R. Effects of *Morinda citrifolia* (Noni) pulp on growth performance and stress responses of growing cattle. The Professional Animal Scientist. 2013;29(4):420-425. DOI:10.15232/S1080-7446(15)30255-2.
 47. Yc CJL. White shrimp *LitoPenaeus vannamei* receiving *Petalonia binghamiae* extract activate immunity and increase resistance against *Vibrio alginolyticus*. Journal of Aquaculture Research and Development. 2014;5(6). DOI:10.4172/2155-9546.1000268.