Bangladesh J. Zool. **50**(2): 143-184, 2022 ISSN: 0304-9027
eISSN: 2408-8455

Review article

WHITELEG SHRIMP *LITOPENAEUS VANNAMEI*: CURRENT STATUS, FUTURE PROSPECTS AND OPPORTUNITIES FOR BANGLADESH AQUACULTURE

Md. Niamul Naser, Manmatha Nath Sarker[1] and Md. Eilious Hosain*

Department of Zoology, Faculty of Biological Sciences, University of Dhaka, Dhaka 1000, Bangladesh

Abstract: Shrimp aquaculture plays the key role in Bangladesh seafood export industry. It includes the species of Tiger prawn *Penaeus monodon*, and Giant river prawn *Macrobrachium rosenbergii*, which have been widely farmed after 1980s. The industry is severely damaged due to diseases outbreaks in hatcheries, nurseries and grow-out ponds since 2000, thus this sector shows shrinkage from global export market. However, the last few decades an alternate aquaculture decapod species, Whiteleg shrimp *Litopenaeus vannamei* has been recognized as the most important in world-seafood export item. Bangladesh aquaculture has very recently been introduced with the Whiteleg shrimp *L. vannamei* for shrimp production boost up. This review focusses on the current state of arts for *L. vannamei* aquaculture techniques and their possible implication to farming in Bangladesh. Recently, several Whiteleg shrimp pilot scale farming were initiated which showed promising production ranged from 5.0 to 8.9 MT/ha. Private entrepreneurs now become interested and it is perceived that the Whiteleg shrimp could gear up shrimp production in near future in terms of better production performance, technology development and extension work besides other indigenous culture-shrimp species. By introducing this shrimp, we forecast that, depending upon the technology adoption in present culture areas, the export frozen seafood earnings from shrimp sector will increase up to 5 to 10 folds from the present. Thus, proper understanding and knowledge based innovative approach for its sustainable rapid extension and strategies is in need. This review suggests the regional reproducible pilot culture program for hatchery, nursery and grow-out under controlled environment ensuring better footprint and low residues impact to natural aquatic systems. Adaptive research should be initiated to develop intensive or super-intensive culture techniques besides the traditional practices in the selected confined areas. The pond culture, biofloc farming, aquamimicry farming and green water raceways could be excellent options for *L. vannamei* culture in Bangladesh.

***Key words*:** Pacific white shrimp, Aquamimicry, Biofloc technology, Flow-through system, IMTA.

INTRODUCTION

Shrimp aquaculture is a billion-dollar food producing industry (Shekhar *et al.*, 2021). The shrimp commodity having high demand in the local and international markets due to its adorable taste and high nutritional values, that is being

*Author for correspondence:< mehosain83@gmail.com>; [1] Former National Consultant at Bangladesh Marine Fisheries Capacity Building Project, Dept of Fisheries, Matshya Bhaban, Dhaka, Bangladesh.
 DOI: https://doi.org/10.3329/bjz.v50i2.62051

exported in the numerous developing countries including Japan, United States of America and European Union. However, shrimp aquaculture industry is recognized for one of the important incomes generating seafood sector which is being supported to shrimp marginal or improvised farmers and shrimp value chain actors across the globe. Shrimp aquaculture production is being directed using few species i.e., whiteleg shrimp *Litopenaeus vannamei*, giant tiger prawn *Penaeus monodon*, oriental river prawn *Macrobrachium nipponense* and giant river prawn *Macrobrachium rosenbergii*; which contributed about of 52.9%, 8% and 2.5% of total crustacean production in 2018, respectively (FAO, 2020).

Pacific white shrimp or king prawn, *L. vannamei* is the most auspicious aquaculture shrimp species. This species is distributed in the Pacific Ocean from Northern Mexico to the coast of Northern Peru, in areas where water temperatures are usually above 20°C throughout the year (Krummenauer *et al.*, 2011). Not surprisingly, currently, *L. vannamei* has been cultured in different saline ecosystems of tropical, subtropical and temperate regions. Culture of this species is heavily affected by low temperature that causes mortality during the coldest months. Thus, the strategy of this shrimp culture in low temperature prone area (e.g., Southern Brazil) restrict to the pond culture periods that involving 6 to 8 months grow-out production. The best growth and survival of this species achieves at temperatures between 28 and 32 °C (Krummenauer *et al.*, 2011). The major aquaculture production of *L. vannamei* is being occurred China, Thailand, Indonesia, Brazil, Ecuador, Mexico, Venezuela, Honduras, Guatemala, Nicaragua, Belize, Vietnam, Malaysia, Taiwan, Pacific Islands, Peru, Colombia, Costa Rica, Panama, El Salvador, the United States of America, India, Philippines, Cambodia, Suriname, Saint Kitts, Jamaica, Cuba, Dominican Republic and Bahamas.

Whiteleg shrimp *L. vannamei* is the best shrimp aquaculture candidate that can breed well in captivity (Jory and Cabrera, 2012). Small sizes postlarvae can be stocked in grow-out phase and having faster growth rates, uniform size could be obtained at the end of cultured when harvest. This species requires comparatively low protein-based feed (20-25%), they have higher adaptation ability in various environmental conditions. In hatcheries, overall survival is comparatively high at 50-60% postlarvae at the end of larvae culture. On contrary, black tiger shrimp *P. monodon* is very susceptible to two of the most fatal shrimp viruses, yellowhead virus (YHV) and white spot syndrome virus (WSSV). Induced breeding of *P. monodon* in captivity is difficult and mostly relies on wild brood stock. In hatcheries, post larval survival is low at 20-30% at the end of larvae culture. This species requires high crude protein feed ~35% (Jory and Cabrera, 2012). In contrast, *L. vannamei* significantly has faster moulting rate than *P. monodon* (Corteel *et al.*, 2012). They also found that total moult cycle duration was around 5 and 6.5 days for 2-g body weight as well as 11 and 12 days for 15-g body weight of *L. vannamei* and *P. monodon*, respectively.

The whiteleg shrimp farming is used less resources and has given higher productivity compared to *P. monodon*. For example, Boyd *et al.* (2017) did find that Whiteleg shrimp production was 43.25-86.5 times higher at 17.3 MT/ha/yr in Thailand when compared to *P. monodon* production was at 0.2-0.4 MT/ha/yr. Also, In Vietnam, *L. vannamei* production was 3.027 times higher at 10.9 MT/ha/yr than that of *P. monodon* production at 3.60 MT/ha/yr. The feed conversion ratio of *L. vannamei* was 1.49 and 1.33 in Thailand and Vietnam; respectively. They also stated that the production of 1 MT of *L. vannamei* has required 0.58 ha land, 5,400 m^3 water, and 1218 kg wildfish in Thailand and 1.76 ha land, 15,100 m^3 water, and 1264 kg wild fish in Vietnam. While, the production of 1 MT of *P. monodon* has required 0.80 ha land, 36,000 m^3 water and 1180 kg wild fish in Vietnam. Similarly, *L. vannamei* production in farms in India had two times higher at 7.86 MT/ha/yr than that of 3.88 MT/ha/yr for *P. monodon* (Boyd *et al.*, 2018). The production of *L. vannamei* is required less land at 0.634 ha/MT compared to 0.716 ha/MT for *P. monodon*. They also stated that *L. vannamei* has required lower water volume usages and water exchanges compared to *P. monodon* production. Similarly, production of 1MT *L. vannamei* has required less wild fish to make fishmeal added in feed at 1209 kg compared to 1611 kg for *P. monodon*. More recently, Nisar *et al.* (2021) accounted that average net returns was 2.55 times higher at $41640.99 ha/yr for *L. vannamei* than *P. monodon* at $16313.13 ha/yr in India. Therefore, these studies are indicated that *L. vannamei* aquaculture industry can bring more benefit along with production and income that also usages lower resources in India, Thailand and Vietnam.

Pacific white shrimp *L. vannamei* is an excellent high-quality animal protein source that contains low-fat and low-cholesterol along with various unsaturated fatty acids, vitamins and minerals (David, 2019). Currently, the annual global production of this shrimp has accounted about 4.4 million MT, which contributing 80% of the total farmed shrimp production, having a market value of about 26.7 billion USD (FAO, 2020). This shrimp industry is considered a substantial profiTable aquaculture farming and commodity business worldwide and created 2.5 million direct jobs and many more indirect (Jory and Darryl, 2018). The shrimp sector is improving the socio-economic condition and livelihood status of various value chain actors including shrimp farmers, equipment, aquafeeds, aqua-medicine and agrochemicals industry and trader, transport and marketing, research and developments and others (Jory and

Darryl, 2018; Kumaran *et al.*, 2021). In recent years, India has been achieved a tremendous success for *L. vannamei* farming. About 12 lakh stakeholders are involved on this sector directly and indirectly for their employment and income generation and better subsistence (Kumaran *et al.*, 2021). This great success of *L. vannamei* aquaculture is consequently due to favourable culture attributes and sustainable modern aquaculture technologies. These are included disease resistance and genetically improve specific pathogen free (SPF) brood stock, higher adaptability to culture conditions and eating various pelleted and live feeds and even small particles, as well as intensive and super-intensive modern culture systems like earthen/concrete ponds culture, recirculating aquaculture system, raceways and microbial/biofloc based systems (Wang *et al.*, 2022).

Currently, whiteleg shrimp *L. vannamei* production has initiated in pilot scale in Bangladesh. It is assuming that this shrimp culture is likely booming in brackish and marine environment conditions of coastal regions in near future. However, the aim of this review was to identify the culture systems of *L. vannamei* for hatchery seed production, nursery phase and grow-out production in assessing the application perspectives in Bangladesh environment. Additionally, this review has identified the research and development work priorities and their experimental variables, and possible required environment features as well as future outlooks in brief. It is believed this review could be helped shrimp entrepreneurs, researchers, policy makers, academicians for proper understanding and protocol setting to develop and adopt *L. vannamei* culture in Bangladesh.

Brief history, research, development of Litopenaeus vannamei aquaculture: Whiteleg shrimp *L. vannamei* is the most important crustacean that are being cultured widely around the world. The aquaculture initiatives of this shrimp had started more than five decades ago. However, this shrimp was introduced widely around the world since the 1970s (Wyban, 2019). The first historical breakthrough on spawning/nauplii production of *L. vannamei* was achieved in Florida since 1973s from a wild-caught mated female, that was shipped from Panama. The commercial culture of *L vannamei* had begun in South and Central America following the better results in pond settings, broodstock maturation technique with adequate nutrition and the discovery of unilateral ablation in Panama in 1976. In the early 1980s, the aquaculture of this species spread around Hawaii, mainland United States of America, and much of Central and South America due to its intensive breeding and culture techniques development. In Asia, this shrimp was introduced between 1978 and 1979 for experimental aquaculture. Taiwan and China were introduced this shrimp since 1996s for commercial aquaculture. Subsequently, this shrimp was introduced to several southeast and south Asian countries between 1997 and 2001; for example, 1997 in Philippines, 1998 in Thailand, 2000 in Vietnam and 2001 in India, Indonesia and Malaysia due to decline of *P. monodon* aquaculture production (Liao and Chien, 2011). Then, it has become a prime cultured shrimp species in Asia.

The high-quality shrimp brood stocked includes specific pathogen free (SPF), specific pathogen resistant (SPR) and specific pathogen tolerant are widely using in commercial shrimp hatcheries for postlarvae production many countries globally. These *L. vannamei* broodstock are played imperative role in increasing shrimp productivity, profitability and sustainability in recent decades. Shrimp has accounted as prime seafood commodity. The first SPF stock of *L. vannamei* was developed in the US by an intensive shrimp farming company in Florida namely American Penaeid (API) (Wyban, 2019). They used the WSSV-Tolerant shrimp (WSSV: white spot syndrome virus) that was derived from the Ecuador (Wyban, 2019). The company acquired a non-SPF Ecuadorian stock and then developed them as SPF shrimp in the spirit of the ICES Code (The International Council for the Exploration of the Sea; Code of Practice to Reduce the Risks of Adverse Effects Arising from the Introduction on Non-indigenous Marine Species) (Lightner, 2011). These SPF shrimp stocked produced high health postlarvae were available to U.S. shrimp farmers, that has significantly augmented shrimp production in U.S. during 1992-1994 (Moss *et al.*, 2003). In the mid-1995, Taura syndrome virus (TSV) was identified in south Texas whiteleg shrimp farm, that had declined shrimp production in Texas from 1994 to 1995. In this devastating situation, the U.S. Marine Shrimp Farming Program (USMSFP) researchers have initiated a selective breeding program to develop TSV-resistant *L. vannamei* (Moss *et al.*, 2003). These authors reported that the cultivation of high-health SPR stocks produced postlarvae with on-farm biosecurity practices have substantially enhanced shrimp production in U.S. from 1998 to the present. Furthermore, National Aquaculture Group (NAQUA), a renowned shrimp company in Saudi Arabia was develop the SPT shrimp stock. NAQUA acquired non-SPF shrimp stocks from Ecuador that carry significant genetic resistance to WSSV. They then cleaned them up to be SPF and began using this SPF/SPT stock in 2014 (Wyban, 2019). These high-quality SPF/SPT broodstock produced postlarvae have given impressive production. Alday-Sanz *et al.* (2020) commented that shrimp stock lines are possibly developed as combined strategies such as SPF+SPR, SPF+SPT or SPF+SPR+SPT in order to help shrimp farmers prevent disease outbreaks in grow-out ponds. The success of these approaches is likely depended on the biosecurity strategy defined for each facility. Currently, shrimp are being cultured using extensive, semi-intensive, intensive and super-intensive, these systems are maintained low, medium, high and extremely high stocking densities, respectively.

Current status of Litopenaeus vannamei aquaculture in Bangladesh: In recent years, the cultivation of king shrimp *L. vannamei* in Bangladesh was an important issue in shrimp industries. Currently, the Department of Fisheries (DoF), Bangladesh Fisheries Research Institute (BFRI) and Non-government Organization include policy makers, academicians, researchers and experts from shrimp processing agencies are working in together for culture strategies, sites and feasibility to sustainable developments. In 2019, Bangladesh government has allowed trial scale production of *L. vannamei*, as the authority has been considered switching from the native tiger prawn *P. monodon* (The Fish Site, 2019). The DoF permitted the first trial take place in ponds covering up to 20 acres in the Cox's Bazar and Khulna districts under the DoF guidelines using imported specific pathogen-free (SPF) shrimp. Dao (2020) reported that government has approved another pilot scale of *L. vannamei* culture for Agri Business Enterprise in Chattogram.

The first consignment of one million *L. vannamei* postlarvae has bought by air from Thailand, these were released in four ponds at BFRI, Paikgachha, Khulna (Roy, 2021). This was a joint venture with MU Seafoods partnered with Sushilan, a local non-government organization (Haque, 2022; Roy, 2021). In this trial, the average production of *L*. vannamei was at 6.761 MT/ha (Haque, 2022). Furthermore, Ali (2022) reported that MU Seafood has cultivated *L. vannamei* in 1.56 hectares of pond area with a controlled environment in Paikgachha, Khulna. The shrimp production was at 8.901 MT/ha, after 90 days of culture period. The figure 1 shows Whiteleg shrimp grow-out production in pond in Bangladesh. NEWAGE (2022) quoted BTTC (Bangladesh Trade and Tariff Commission) *L. vannamei* production report, it was ranged from 5.0 to 8.62 MT in pilot scale culture. BTTC has been seeking commercial cultivation approval for this shrimp. Currently, four companies in Chattogram region (MK Hatchery in Ukhia of Cox's Bazar, Dafa Feed and Agro Products Ltd under Karnaphuli in Chattogram, Niribili Hatchery in the Kalatali area of Cox's Bazar, and Midway Scientific Fisheries Ltd in Khurushkul of Cox's Bazar) and eight companies in Khulna, including MU Sea Foods have been permitted for *L. vannamei* culture (Islam, 2022; The Business Post, 2022). In addition, eight private entrepreneurs are awaiting for getting permission (Islam, 2022; The Business Post, 2022). Therefore, it is perceived that *L. vannamei* culture will be permitted for many aquacultures entrepreneurs in upcoming years. Thus, it is suggested that the culture system of this shrimp should be standardized for Bangladesh shrimp culture environment conditions and perspectives.

Fig. 1. Whiteleg shrimp *Litopenaeus vannamei* grow-out production in pond in Bangladesh, (a-b) a whiteleg shrimp culture pilot project, (c-d) partial harvested *Litopenaeus vannamei*.

Brood-stock rearing and spawning protocol: The white shrimp *L. vannamei* broodstock usually collected from a certified known source. For example, Yang *et al.* (2022) used the Hannan Liyang Inc, Wenchang, China source *L. vannamei* broodstock. Arshadi *et al.* (2020) reared the third-generation (SPF3, domesticated in Hawaii) families of *L. vannamei* in pond (0.1 acre). More recently, BFT system are being used to maturation and rearing of *L. vannamei* broodstock. In the BFT system, *L. vannamei* can be reared with stock at 100 ind. m^{-2} during first six months, then stocking density should be reduced at 50 ind. m^{-2} until the time of harvesting the specimens at 11 months (Magaña-Gallegos *et al.*, 2021). *L. vannamei* broodstock usually fed with fresh-frozen invertebrates that consisted of squid (40%), polychaetes (10%), mussel (40%) and *Artemia*

(10%) (Corral-Rosales *et al.*, 2018). The addition of dehydrated seaweed *Ulva clathrata* (20 g kg^{-1}) in the squid fraction of a formulated fresh diet has increased ablated female survival compared to control feeding group. The broodstock fed with *Ulva* enriched diet has produced more eggs, and nauplii per female, that also increases hatching rates and spawns. Therefore, the dehydrated *U. clathrate* can be added in *L. vannamei* diets that promotes the reproductive performance at commercial hatcheries (Corral-Rosales *et al.*, 2018). Yang *et al.* (2022) did find that *Nereis vexillosa* and *Marphysa maxidenticulata* can be a potential live feed in promoting *L. vannamei* broodstock maturation. These authors showed that the highest gonadal maturation of *L. vannamei* had found when broodstock fed with *M. maxidenticulata.* Additionally, the *N. vexillosa* fed group gave highest gonadal index as well as the progesterone and vitellogenin content in broodstock serum, these were probably due to the higher content of polyunsaturated fatty acids in *N. vexillosa,* particularly C18:2 *n*-6, C18:3 *n*-3, C20:4 *n*-6, and C20:5 *n*-3. They also detected 2.5-8.0 times higher 20:5 *n*-3 content in *N. vexillosa* than those of *M. maxidenticulata*, *Cheilonereis cyclurus*, and *Perinereis aibuhitensis*.

The optimal level of vitamin E and astaxanthin were at 175 mg kg^{-1} and 250 mg kg^{-1}, that has increased *L. vannamei* broodstock growth, survival, maturation and spawning success (Maulana *et al.*, 2017). Xu *et al.* (2017) stated that the optimal arachidonic acid supplementation was at 4.65% of total fatty acids in *L. vannamei* diets that has improved reproductive performance. This level of arachidonic acid is significantly enhanced gonadosomatic index, estradiol level, and fatty acid composition when compared to control. These authors also showed the optimal arachidonic acid supplementation has enhanced spawning rate, multi-spawning rate, average spawning frequency and fecundity of female, diameter of fertilized egg, hatching rate and metamorphosis rate of nauplii at 33 h post spawning compared to control and or a higher arachidonic acid supplementation level at 12.39% of total fatty acids in shrimp diets.

Eyestalk ablation in *L. vannamei* has substantially increased vitellogenin (Vg) gene expression (Arshadi *et al.*, 2020). While an optimal dietary vitamin E at 300 mg kg^{-1} feed are significantly improved reproductive performance include hepatopancreatic index, absolute fecundity, egg diameter, latency period, and Vg gene expression than control. Similarly, Zacarias *et al.* (2019) stated that *L. vannamei* mating success, mortality of female and number of eggs and nauplii per tank per day of non-ablated female have greatly lower than ablated female in commercial hatchery condition. However, non-ablated female has produced higher number of eggs and nauplii per spawned than ablated female, thus non-ablated female can be used in commercial hatcheries (Zacarias *et al.*, 2019).

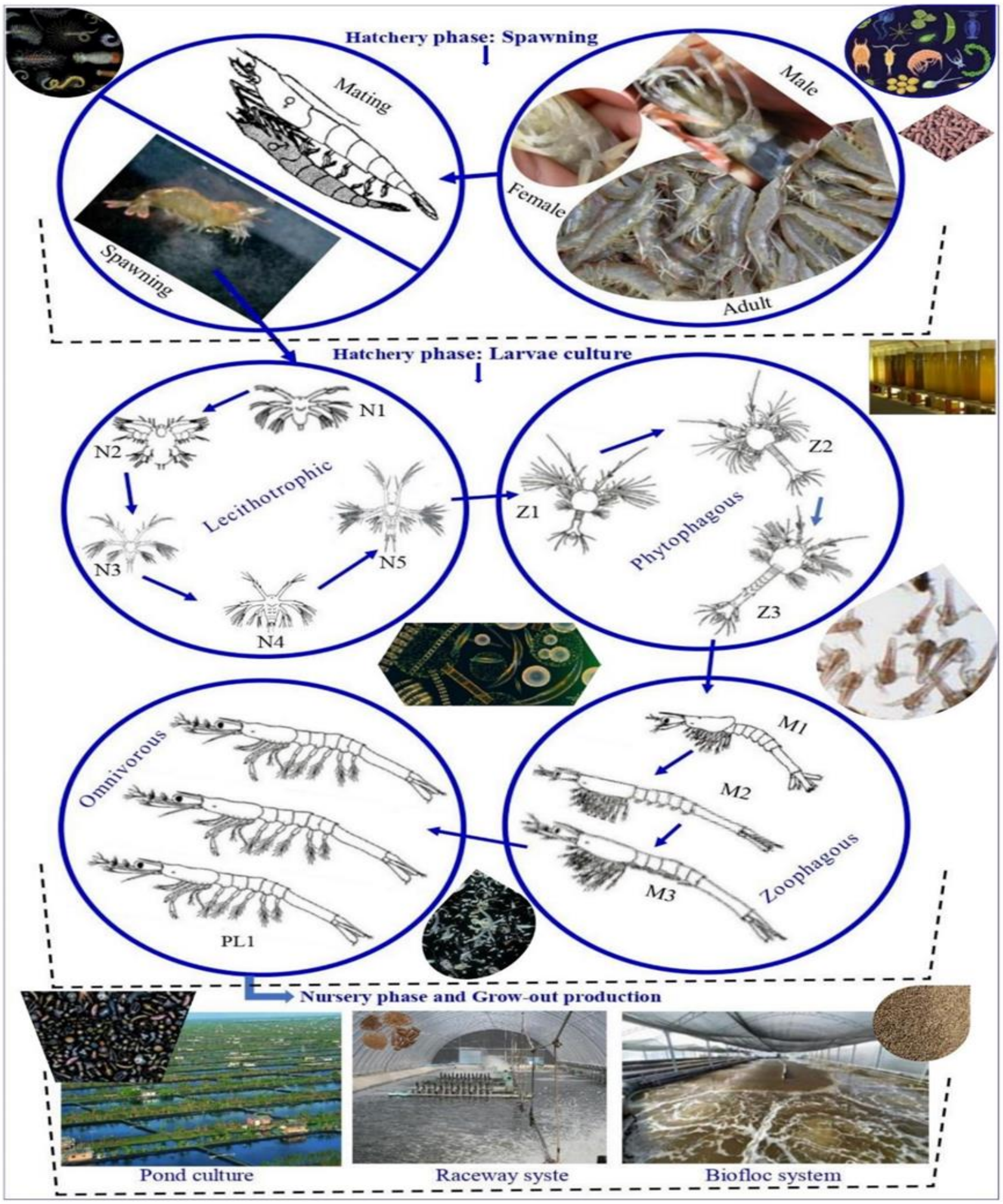

Fig. 2. Schematic diagram of *Litopenaeus vannamei* male and female, spawning, larval stages, postlarvae and majour nursery and grow-out culture systems and some live and pelleted feeds that require for broodstock, larvae culture, nursery phase and grow-out production. Note: N1 to N5: Nauplius1 to nauplius 5; Z1 to Z3: Zoea 1 to zoea 3; M1 to M3: Mysid1 to mysid 3; PL1: Postlarvae 1. The sources of images (Misamore and Browdy, 1996; Rojo-Arreola *et al*., 2020; Wei *et al*., 2014).

Larvae culture: The larvae rearing protocol is prerequisite to initiate aquaculture for any candidate. Whiteleg shrimp *L. vannamei* larval stages includes five nauplius, three zoea, three mysis and postlarvae stages then it becomes a juvenile shrimp (Rojo-Arreola *et al.*, 2020). Larvae culture uses sea water at 35±1 ‰ salinity with the temperature at 28±1 °C (Brito *et al.*, 2001; DAbramo *et al.*, 2006; Sangha *et al.*, 2000). According to DAbramo *et al.* (2006), nauplius stage of *L. vannamei* larval does not require feeds. However, larval feeding should be started at zoea stage using mixed microalgae with *Artemia* or Microbound microparticulate diet or both. While, mysis stage should be added solely *Artemia* or Microbound microparticulate diet until postlarvae (DAbramo *et al.*, 2006). The schematic diagram shows *L. vannamei* male and female, spawning, larval stages and postlarvae (Fig. 2).

The culture technology of Litopenaeus vannamei nursery and grow-out phase: Nursery operation is an intermediate phase between larvae culture and grow-out production, which being produced the advance size postlarvae or juveniles, that enabled the shrimp farmers to obtain three or more crops in a single production year. The grow-out production of *L. vannamei* are being widely performed in different aquaculture systems including pond culture, recirculating aquaculture system, raceway or flow-through system (Fig. 2). More recently grow-out production of whiteleg shrimp has used biofloc system, aquamimicry and integrated multitrophic aquaculture system. The optimal level of different water quality parameters for *L. vannamei* aquaculture is presented in the Table 1.

Table 1. The optimal water quality parameters of *Litopenaeus vannamei* in different culture system

Parameters	References			
	Mohanty *et al.* (2018)	Mendoza-López *et al.* (2017)*	Venkateswarlu (2019)	Towers (2016)
Water temperature (°C)	25-30	25.0-33.0		24-32
Salinity (‰)	15-25	7.0-35.0	12-25	5-35
pH	6-9	7.0-8.0	7.5-8.5	7.4-9.4
Dissolved oxygen (mg L^{-1})	>5	6.0-8.0	>4	3.6-6.5
Ammonia-N (mg L^{-1})	<1.0	1.0	<1.0	0.1-2.4
Nitrite-N (mg L^{-1})	<1.0	0.6	<0.5	
Nitrate-N (mg L^{-1})	<0.8	3.0		
Total suspended solid (mg L^{-1})	500	200.0-600.0		
Transparency (cm)	35 to 45			
Total alkalinity (mg L^{-1})	<140	200.0	>120	
Total hardness (mg L^{-1})			>1000	
Hydrogen sulfide (mg L^{-1})	<0.1		<0.01	
PO_4 (mg L^{-1})		2.0		

Superscript (*) work has described ideal water quality level for BFT system

Pond culture of Litopenaeus vannamei: Pond aquaculture is being widely carried out at the beginning to till now in many countries like India, Malaysia, Myanmar, Indonesia, Thailand, Vietnam, Brazil, Mexico, Costa Rica and USA. This review shows *L. vannamei* survival and feed conversion ratios are varied from 12.2% to 136.2%, and 0.22 to 3, respectively (Table 2). This system can be performed using well water, pond water or riverine/estuarine and or seawater (Table 2). This system requires inorganic and organic fertilizers, vitamins, minerals, and artificial substrates in order to increase natural productivity including phytoplankton, zooplankton and benthos during the pond preparation or periodically which has found beneficial in augmenting the shrimp production. For example, Porchas-Cornejo *et al.* (2014) showed the best growth, productivity and feed conversion ratio in natural productivity pond group than control. In this study, natural productivity was enhanced two weeks before the beginning of the trial by applied of urea and triple super phosphate in enhancing of phytoplankton biomass. In order to enhanced the zooplankton, a 15 L marine water mixture was made including alfalfa (5 kg), fermented with fish oil (50 ml kg^{-1} alfalfa), molasses (0.5 L kg^{-1}), and vitamins (vitamin premix + ascorbic acid; 0.5 g kg^{-1}) for 72 h; after that, this had added to increase zooplankton (Porchas-Cornejo *et al.*, 2014). However, Casillas-Hernández *et al.* (2007) added at a rate of 10 L ha^{-1} commercially available chemical-liquid fertilizer (10% nitrogen (NH_4NO_3), 5% phosphorus (HPO_4) solely. Besides, they also applied additional fertilizers during the experiment when primary productivity in pond water was low in measuring as transparency level at > 40 cm determine with a Secchi disc.

Currently, the pond culture uses sand filtered seawater that are being added activated carbon. Additionally, commercially high-quality probiotics could be supplemented weekly (2 g m^{-3}) in enhancing a heterotrophic microbial community (Arambul-Muñoz *et al.*, 2019). The probiotic mixture should be included *Bacillus subtilis*, *B. lincheniformis*, *B. coagulans*, *Lactobacillus acidophilus* and *Saccharomyces cerevisiae*. The nitrification process could be enhanced in adding 10% of molasses kg^{-1} shrimp feed daily (Arambul-Muñoz *et al.*, 2019). In addition, pond treated with *B. cereus*, shrimp growth and survival as well as overall health includes immunity, total hemocyte count, total protein and lysozyme activity were better than control (Khademzade *et al.*, 2020). The probiotic addition can substantially improve water quality status in eliminating the nitrogenous toxicants ammonia and nitrite, reactive-phosphorus, chemical oxygen demand and presumptive *Vibrio'*s; improved shrimp survival and feed conversion ratio. However, Maia *et al.* (2016) stated that shrimp final weight, survival, yield and feed conversion ratio were similar between molasses adding and molasses with probiotic adding pond culture systems.

Table 2. Growth performance of *Litopenaeus vannamei* in pond culture

S	IW	FG	SGR	FCR	SR	P	CP	CT	Treatments	References
28.32	0.35	15.65		1.58	81.12		110	GP	Control	Khademzad
-	0.31	16.48		1.42	90.90				*P. acidilactici*	e *et al.*
29.40	0.28	17.0		1.23	94.50				*Bacillus cereus*	(2020)
38-43		26.8*	5.8	1.8	68	0.362*	98	GP	With NP	Porchas-
		21.7*	5.4	2.2	66	0.284*			Without NP	Cornejo *et al.* (2014)
33.59	0.001	11.93	9.99	1.12	93.2		98	GP	SD100 ind./m^2	Arambul-
-		9.73	9.77	1.15	91.4				SD 300 ind./m^2	Muñoz *et al.*
33.65		7.65	9.51	1.23	74.0				SD 500 ind./m^2	(2019)
		5.40	9.14	1.44	65.7				SD 700 ind./m^2	
		4.28	8.90	1.50	55.7				SD 900 ind./m^2	
	0.001 1	32.3		1.78	87.3	3325	203	GP	Feeding trays	Casillas-Hernández *et al.* (2007)
		29.5		1.77	87.0	2920			Mechanical feeding dispersion	
22.5-		15.55		1.40	87.3	7.9*	110	GP	SD 750 ind./m^2	Tantu *et al.*
22.9		16.33		1.36	82.9	10.7*			SD1000 ind./m^2	(2020)
		15.48		1.55	79.1	12.2*			SD 1200 ind./m^2	
11.7-	0.07	23.55		0.94	75.8	3068.5			SF protocol	Ullman *et*
11.93		24.65		1.04	72.2	3032.5			SF protocol+15%	*al.* (2019)
		28.66		0.98	66.9	3294.3			AD feeding system	
		35.91		1.14	73.9	4568.8			Timer feeding	
0.52-	0.02	7.58	7.07	1.35	78.36	1.19*	84	GP	LS (Tamazula)	Héctor
0.88		7.25	7.02	1.51	77.55	1.12*			LS (El Pitahayal)	Manuel
		6.78	6.94	1.58	79.55	1.08*			LS (El Terahuito)	Esparza-
		7.20	7.01	1.48	76.35	1.10*			LS (La Trinidad)	Leal *et al.*
34.0		8.85	7.25	1.38	85.55	1.51*			Seawater (control)	(2009)
38-47		12.93		1.68	86.89		112	GP	Feed at 25% CP	Martinez-
		12.12		1.66	88.76				Feed at 40% CP	Cordova *et al.* (2002)
0.7		19.3	2.3	3.0	47.0	3449	112	GP	PL15 (39 PL/m^2, 03)	Green
		5.5	3.1	1.9	82.3	988	55		PL25 (23 PL/m^2, 03)	(2008)
		9.0	4.7	1.2	99.2	2462	65		PL25 (28 PL/m^2, 03)	
		20.5	2.5	1.9	94.4	1379	134		PL15 (7 PL/m^2, 04)	
		14.4	2.6	1.6	136.2	2674			PL15 (13 PL/m^2, 04)	
		17.1	2.5	1.8	94.1	4966			PL15 (30 PL/m^2, 04)	
4-16	0.12	7.98		2.03	93.0	742	75	GP	SD10 ind./m^2 (FC)	Krummenau
		7.67		2.27	86.0	1649			SD 25 ind./m^2 (FC)	er *et al.*
		6.67		2.43	82.0	2187			SD 40 ind./m^2 (FC)	(2010)
	0.17	12.94		1.72	94.0	1220			SD 10 ind./m^2 (SC)	
		10.88		1.86	91.0	2475			SD 25 ind./m^2 (SC)	
		9.34		1.92	79.0	2951			SD 40 ind./m^2 (SC)	
	0.12	14.53		1.94	91.0	1322	150		SD 10 ind./m^2 (LC)	
		13.05		2.03	84.0	2740			SD 25 ind./m^2 (LC)	
		13.21		2.12	80.0	4227			SD 40 ind./m^2 (LC)	
21.1-	2.09	11.28		1.51	84.88	8875	112	GP	MO addition	Maia *et al.*
22		10.69		1.53	75.05	8228			CP and MO	(2016)
15-19		21.2		1.4	82	8750	122		P1 (SD 50 ind./m^2)	Balakrishna
		18.9		1.34	92	9813	121		P2 (SD 56 ind./m^2)	n *et al.*
		19.6		1.38	81	8138	119		P5 (SD 51 ind./m^2)	(2011)
		17.5		1.35	80	8591	118		P6 (SD61 ind./m^2)	
5.79-	0.02	15.58	8.40	0.88	91.59	1455	79	GP	Monoculture	de Oliveira
6.32		12.86	8.14	1.18	74.59	1039			Polyculture with mullets	Costa *et al.* (2013)
45.56	0.008	15.7	2.38	1.8	91.0	2853	115	GP	SM feed 38% CP	Ghorbani
		15.6	2.38	1.76	92.0	2865			Com. feed 39% CP	Vaghei *et al.* (2017)

Note: S: salinity (‰); IW: initial weight (g); FG: final weight (g); SGR: specific growth rate (%day^{-1}); FCR: feed conversion ratio, SR: survival rate (%); CP: culture period; CT: culture type, GP: grow-out production; NP: nursery phase; P: Production (kg/ha); Values* in FGs are weight gain; Values* in P (kg) are production/m^2; NP: natural productivity; SF: Standard feeding; AD: Acoustic demand; LS: Low salinity; CP: commercial probiotics; FC: First cycle; SC: Second cycle; LC: Long cycle.

Table 2. Growth performance of *Litopenaeus vannamei* in pond culture (continued)

S	IW	FG	FCR	SR	P	CP	CT	Treatments	References
15-24		15.0	I .97	67.0	3525	112	GP	Direct stocking PL_{10}	de Yta *et al.*
	0.018	13.9	2.03	77.0	3747			Stocking 10 days NS	(2004)
	0.038	12.8	2.12	79.0	3533			Stocking 20 days NS	
22-25			1.13	81.0	8215	109	GP	Probiotics	Wang *et al.*
			1.35	48.6	4985			Control	(2005)
11		17.88	1.37	60.0	17143	112	GP	Farm 1	Fakhri *et al.*
20		14.36	1.3	85	18333			Farm 2	(2015)
13-22		21	1.33	91	1778	105-	GP	Pond 1	Junda (2018)
		22.7	1.4	90	1881	112		Pond 2	
		23	1.35	90	2910			Pond 3	
		23	1.28	89	2507			Pond 4	
		21.5	1.34	90	2010			Pond 5	
		23	1.28	88	3664			Pond 6	
		23	1.3	90	2231			Pond 7	
	0.07	1.06				35		PL (WW)	Otoshi *et al.*
		4.97				35		PL (PW)	(2011)
	5.85	13.89				42		Juvenile (WW)	
		16.55				42		Juvenile (PW)	
	13.84	17.25				35		Sub adult (WW)	
		17.79				35		Sub adult (PW)	
	32.79	36.11				42		Adult shrimp (WW)	
		37.47				42		Adult shrimp (PW)	
41.8	0.98	6.3	2.95	42.9	651.9	79	GP	92 shrimps/m^2	Junior *et al.*
46.0		9.4	1.44	12.2	332.0			14 shrimps/m^2	(2021)
61.1		6.9	0.22	39.3	219.0			8 shrimps/m^2	
36	0.16	11.17	1.71	88.3	1451	102	GP	Pink shrimp	Peixoto *et al.*
42-	0.002	12.52	1.11	96.6	1790	133	GP	*L. vannamei*	(2003)
42.5		12.88		48.3	1866			F: S30 ind./m^2	Martinez-
41-		12.61		63.5	2402			F(S30+O10+C8) ind./m^2	Cordova and
41.5		13.45		61.2	2469			F(S30+O10+C10) ind./m^2	Martinez-
		13.69		63.1	2592			F (S30+O16+ C8) ind./m^2	Porchas (2006)
		14.88		59.7	2665			F(S30+O16+C10) ind./m^2	
		12.34		63.2	2356			Se: S 30 ind./m^2	
		12.23		61.9	2271			Se (S30+O10+ C8) ind./m^2	
		12.97		66.7	2595			S (S30+O10+C10) ind./m^2	
		13.26		67.3	2677			Se (S30+O16+C8) ind./m^2	
		13.11		65.2	2564			Se (S30+O16+C10) ind./m^2	
0.52-61			0.22-3.0	12.2-136.2					Range

Note: S: salinity (‰); IW: initial weight (g); FG: final weight (g); SGR: specific growth rate (%day^{-1}); FCR: feed conversion ratio, SR: survival rate (%); CP: culture period; CT: culture type, GP: grow-out production; NP: nursery phase, SM: soybean meal, Com: Commercial, NS: Nursed shrimp, WW: Well water, PW: Pond water, F: First, S: Shrimp, O: Oyster, C: Clam, Se: Second

It also rises dissolved oxygen level, ammonifying bacteria, and protein mineralizing bacteria (Khademzade *et al.*, 2020; Wang *et al.*, 2005). Moreover, a commercial probiotic having total bacterial counting at 10^9 CFU mL^{-1} that contain *Bacillus* sp., yeast, *Saccharomyces cerevisiae*, *Nitrosomonas* sp. and *Nitrobacter* sp. The addition of these consignment of that probiotic in *L. vannamei* pond culture had given 1.6 times higher production than control (Wang *et al.*, 2005). Pond should be stocked nursed *L. vannamei* postlarvae

(PL)/juveniles that is likely enhanced the shrimp production performance. Although, de Yta *et al.* (2004) have achieved comparable growth performance when added 10 days nursed PL of whiteleg shrimp either pond or enclosed greenhouse and 20 days nursed PL of whiteleg shrimp in greenhouse at stocking density of 35 PL m^{-2}. Survival was higher when whiteleg shrimp PL nursed with greenhouse at 10 or 20 days than those stocked directly. Not significantly, but slightly higher yield was in 10 days nursed with greenhouse room than other two groups, this was due to uniform harvest size. Thus, pond grow-out should be stocked 10 days indoor nursed PL (de Yta *et al.*, 2004). Currently, several modern nursery systems have developed that include RAS, biofloc system, static greenhouse or flow-through/raceway which will be discussed in the specific section in this review.

An optimal stocking density can bring numerous benefits include higher growth, survival, productivity as well as improving overall health status and reducing stress condition in an aquaculture system. A higher stocking density has increased total ammonia, nitrate and total phosphorus (Arambul-Muñoz *et al.*, 2019). According to these authors, *L. vannamei* growth has gradually decreased as increased the stocking density, while survival began in decreasing trend drastically after stocking density at 300 ind. m^{-2}. The good shrimp survivals (79-94%) were among 10, 25 and 40 ind. m^{-2} stocking density in terms of short cycles (75 days) and long cycles (150 days) (Krummenauer *et al.*, 2010). Shrimp harvest weight had decreased with increasing of stocking density at 50 ind. m^{-2} to 61 ind. m^{-2} and these range of stocking density did not different the survival while shrimp productivity was higher at 56 ind. m^{-2} stocking density (Balakrishnan *et al.*, 2011). More recently, several researches tested very high stocking density of *L. vannamei* at 100, 300, 500, 700 and 900 ind. m^{-2} (Arambul-Muñoz *et al.*, 2019), and 750, 1000 and 1200 ind. m^{-2} (Tantu *et al.*, 2020), 150, 300 and 450 ind. m^{-2} (Krummenauer *et al.*, 2010); but these studies gave in contrasting results. For example, whiteleg shrimp growth and survival have decreased with increasing of stocking densities (Arambul-Muñoz *et al.*, 2019; Krummenauer *et al.*, 2011). In contrast, Tantu *et al.* (2020) stated comparable *L. vannamei* production performance among various stocking densities. However, pond based super intensification of Whiteleg shrimp are warranted more studies to explore growth, health status, diseases and stress parameters as well as farm economics and water quality management.

This review shows *L. vannamei* can be cultured using a wide range of salinities between 0.52 and 61‰ in earthen pond condition (Table 2). Whiteleg shrimp growth, survival, production and feed conversion ratio was not different with low salinity (0.52-0.88‰) in various ionic composition and survival can be considered as well (76.35 to 79.55%) (Esparza-Leal *et al.*, 2009). But these survivals were lower than that of 85.55% in seawater at 34.0‰ salinity, and growth performance was greatly higher at seawater than low salinity groups (Esparza-Leal *et al.*, 2009). Green (2008) conducted some experiments in culturing of *L. vannamei* in freshwater supplemented with major ions to a final salinity of 0.7‰. Among these experiments, one study exhibited worst shrimp survival (47.0%), and others experiments had revealed the better survival (83.3-136.3%). These studies were considered as viable in terms of growth, production and survival. Thus, *L. vannamei* can be cultured using freshwater with mineral supplementation to market proximity where Whiteleg shrimp having high demand.

Whiteleg shrimp can culture with low and high protein feed. In addition, shrimp growth, survival, productivity and feed conversion ratio were not different between low and high protein feed at 25 and 40% crude protein (Martinez-Cordova *et al.*, 2002). *L. vannamei* is able to utilize the soybean meal-based feed contained 42% crude protein, this feed has given similar shrimp survival, growth, production, feed conversion ratio and protein efficiency ratio when compared to commercial feed contained at 38% crude protein (Ghorbani Vaghei *et al.*, 2017). Polyculture of shrimp and mullet in earthen ponds system has significantly decreased shrimp production and promoting the mullet growth (de Oliveira Costa *et al.*, 2013). Martinez-Cordova and Martinez-Porchas (2006) examined the feasibility of a polyculture of whiteleg shrimp *L. vannamei*, giant oyster *Crassostrea gigas*, and black clam *Chione fluctifraga* in earthen ponds condition. They showed that a combine stocking density (shrimp 30 m^{-2} + oyster 16 m^{-2} + clam 10 m^{-2}) has significantly reduced total ammonium nitrogen and chlorophyll-a than lower stocking density groups. *L. vannamei* polyculture with mollusks was likely beneficial for shrimp productive performance. In this polyculture condition, the *C. fluctifraga* was likely a good candidate and may have substantial potentiality than that of *C. gigas* (Martinez-Cordova and Martinez-Porchas, 2006). Based on these current research, *L. vannamei* polyculture with fish or mollusks were feasible and having enormous potentiality in shrimp industry.

Raceways/ flow-through culture for Litopenaeus vannamei: A raceway/flow-through system is an artificial tank setting that has inlet and outlet to receive the water and pass way. The culture tank receives water continuously from a higher located point using an inlet water flow, and then the outlet flows back into water reservoirs/pond/lake/rivers or the sea. This aquaculture system is widely used for finfish and shellfish production, broodstock maintenance, breeding and spawning, seed production, eggs hatching, larval rearing, nursery operation of fish and shrimp. The details of *L. vannamei* production performance in raceway system is given in the Table 3. Cohen *et al.* (2005) showed an excellent shrimp survival, growth and feed conversion ratio after 50 days nursing in a greenhouse-enclosed raceways intensification. In the raceway system, the concentration of ammonia-N was not exceeded 2.0 mg L^{-1} during this period, whereas the nitrite-N spike exceeded 26.4 mg L^{-1} at the end of study (Cohen *et al.*, 2005). *L. vannamei* final weight, survival, yield and feed conversion ratio were better in raceway system design with foam fractionator and 3.35% daily water exchange than that raceway without foam fractionator and 9.37% daily water exchange (Mishra *et al.*, 2008).

Whiteleg shrimp weight and growth rate were higher when shrimp fed with 40% crude protein diet than those fed with 30% crude protein feed (Correia *et al.*, 2014). While, shrimp and feed conversion ratio have unaffected after 62 days nursery period. Samocha *et al.* (2004) conducted five-week nursery with low salinity (18-2.6‰) groundwater using raceway, in which they obtained excellent *L. vannamei* survival (98.1%), FCR, and yield with a stocking density of about 20,000 postlarvae m^{-2}. Izquierdo *et al.* (2006) showed that substitution of fish oil by olive oil in diets for *L. vannamei* reared in mesocosms have not affected growth or survival. These authors also stated that *L. vannamei* survival and growth was better reared in mesocosms than those reared in clear water flow-through and fed an olive oil diet. Whereas, docosahexaenoic acid or an arachidonic acid enrichment of non-fish oil diet have improved *L. vannamei* survival those reared in clear water flow-through system.

Pacific Whiteled shrimp *L. vannamei* survival was found to be higher in commercial feed contained 35% crude protein compared to feed that contained 40% crude protein (Prangnell *et al.*, 2022). While shrimp growth, yield and feed conversion ratio were not affected by high protein feed. But, the addition of high protein feed (40% CP) have increased nitrite and nitrate concentrations, and alkalinity consumption in a biofloc dominated raceway system (Prangnell *et al.*, 2022). *L. vannamei* survival, growth and productivity were greatly higher in raceways pond using nanobubble aeration system (Rahmawati *et al.*, 2020). This system has increased dissolved oxygen, and decreased total virus-bacteria. A lower stocking density at 970 ind. m^{-2} in recirculating raceway had a higher survival (82%) than 48% at higher stocking density of 2132 ind. m^{-2} (Reid and Arnold, 1992), while these stocking densities have not affected productivity. The better *L. vannamei* growth, survival and feed conversion ratio was in lower stocking density groups (SD at 29 or 88 ind. m^{-2}) than the higher stocking density groups (SD at 176 and 264 ind. m^{-2}) (Roy *et al.*, 2020). These authors have stated that the performance of *L. vannamei* was not different when shrimp

Table 3. Growth performance of *Litopenaeus vannamei* in raceways culture system

S	IW	FG	SGR	FCR	SR	P	CP	CT	Treatments	References
26.69-	4.70	27.22		1.59	93.13	8.21	77	GP	CF at 35% CP	Prangnell *et*
33.65		28.80		1.72	83.35	7.79			CF at 40% CP	*al.* (2022)
	0.09	15.10		1.1	95	8.7	81	GP	Nanobubble	Rahmawati *et*
		12.70		1.5	78	4.4			Diffuser aerator	*al.* (2020)
27.3-		1.12		0.86	97.5	4.25	50	NP	Raceway 1	Cohen *et al.*
29.7		1.01		0.98	106.0	4.33			Raceway 2	(2005)
25-27	0.006	1.91		1.03	96.2	7.23	71	NP	FF and 3.35% DWE	
		2.00		1.03	96.2	7.23			FF and 3.35% DWE	Mishra *et al.*
		1.73		1.50	68.9	4.33			Without FF and 9.37% DWE	(2008)
		1.43		1.50	68.9	4.33			Without FF and 9.37% DWE	
31.2-	0.001	0.94	11.03	1.75	82.29		62	NP	CF at 30% CP	Correia *et al.*
31.5		1.03	11.19	2.15	84.13				CF at 40% CP	(2014)
16-35		10.8			48	11.4	146	GP	SD at 2132 ind./m^2	Reid and Arnold
		14			82	11	173	GP	SD at 970 ind./m^2	(1992)
1.8-2.6	0.0025	0.1117		0.7	98.1		35	NP	SD at 19800 ind./m^2	Samocha *et*
	0.091	0.3770		1.22	81.8		20	NP	SD at 2670 ind./m^2	*al.* (2004)
2.1	0.65	21.6		1.7	81.3		69	GP	SD at 29 ind./m^2	Roy *et al.*
		17.4		2.3	75.1				SD at 88 ind./m^2	(2020)
		14.5		4.1	53.1				SD at 176 ind./m^2	
		13.6		5.4	43.9				SD at 264 ind./m^2	
2.1	0.65	20.0		3.3	47.9		65	GP	Diets at 5% fish meal	
		19.3		2.8	53.9				Diets at 10% FM	
		22.0		2.6	47.8				Diets at 20% FM	
		17.4		2.6	65.5				Control	
32.48-	1.12	10.04	3.91	2.28	91.7		56	GP	DMM 0% in diet	Ju *et al.*
32.84	1.06	11.06	4.11	2.13	95.8				DMM 3% in diet	(2012)
	1.09	10.12	3.93	2.21	97.9				DMM 6% in diet	
	1.10	10.88	4.07	2.27	87.5				DMM 9% in diet	
	1.08	10.28	3.96	2.22	95.8				DMM 12% in diet	
	1.08	7.03	3.18	2.63	100				Commercial feed	
35	1.98	11.48		1.85	94.4		72	GP	DM at 4.8 g/kg feed	Façanha *et al.*
		12.03		1.82	93.1				DM at 6.2 g/kg feed	(2018)
		11.92		1.73	97.8				DM at 7.2 g/kg feed	
		12.14		1.76	96.7				DM at 8.1 g/kg feed	
		12.42		1.71	95.0				DM at 9.2 g/kg feed	
32-35	0.71	7.88	4.34	1.24	96.0		56	NP	Fish oil mesocosms	Izquierdo *et*
		7.40	4.15	1.27	96.3				Olive oil mesocosms	*al.* (2006)
		3.75	2.97	4.66	56.7				Olive oil flow-through	
		3.73	2.93	2.80	76.0				Docosahexaenoic	
		2.96	2.55	3.00	81.7				Arachidonic acid	
32.48-	1.6	9.1		1.97	83.3		56	GP	Control	Ju *et al.*
32.84		9.1		2.17	70.8				Lutein	(2010)
		8.8		2.40	66.7				Fucoxanthin	
		9.3		2.45	75.0				Astaxanthins	
		8.8		2.52	66.7				Glucosamine	
		8.0		2.29	77.1				Carotenoid mix	
		9.0		2.45	87.5				Phytosterol mix	
		9.4		2.78	72.9				Bromophenol mix	
		8.0		2.45	55.4				Combination	
		5.1		3.83	65.2				Commercial feed	

Note: S: salinity (‰); IW: initial weight (g); FG: final weight (g); SGR: specific growth rate (%day^{-1}); FCR: feed conversion ratio, SR: survival rate (%); CP: culture period; CT: culture type, GP: grow-out production; CF: commercial feed; NP: nursery phase; FF: Foam fractionator; DWE: daily water exchange; DMM: defatted microalgae meal; DM: dietary methionine; FM: Fish meal

fed with various fish meal contained at 5, 10 and/or 20% in diets. In this study, shrimp survival was varying between 47.8% and 65.6%, these was likely due to a higher stocking density at 264 shrimp m^{-2} (Roy *et al.*, 2020).According to Ju *et al.* (2012) defatted microalgae meal (a by-product of astaxanthin production from *Haematococcus pluvialis* that contained 40.3% crude protein and 0.9%

crude lipid) could a valuable alternative protein and pigmentation ingredient in shrimp feed. The addition of a 3% defatted microalgae meal in diet has greatly increased the shrimp growth and improved feed conversion ratio compared to control (Ju *et al.*, 2012). While, shrimp production performance was similar among 6, 9 or 12% adding defatted microalgae meal in shrimp diets, these diets have ensured the higher shrimp production performance than those fed with a commercial feed (Ju *et al.*, 2012). The addition of dietary methionine at 8.1 and 9.1 g kg^{-1} feed have significantly increased shrimp body weight compared with 4.8 to 7.2 g kg^{-1} feed groups in the raceway systems (Façanha *et al.*, 2018). The supplementation of the bioactive compounds (lutein, fucoxanthin, astaxanthins, glucosamine, carotenoid mix, phytosterol mix, bromophenol) have not significantly improved whiteleg shrimp growth performance (Ju *et al.*, 2010).

Recirculating Aquaculture System (RAS) for Litopenaeus vannamei: Recirculation aquaculture system (RAS) is basically employed on mechanical and biological filters that attribute to reduce heat and water demand through water reuse, and this system is notably more mechanize and expensive in operation (Bregnballe, 2015; Yogev and Gross, 2019). Currently, *L. vannamei* are being cultured using RAS for commercial nursery and grow-out production and or experimental aquaculture usages in order to determine ideal stocking density, feed type, the functioning light in aquaculture systems and effect of probiotic supplementation etc. (Table 4). For example, Cárdenas *et al.* (2015) showed that the addition of 4 and 8% of brown seaweed meal and/or green seaweed meal in *L. vannamei* pellet feed has provided adequate growth and higher survival compared to the control diet and 8% of brown seaweed meal and or 4% of green seaweed meal based shrimp feed. This study is confirmed a significantly higher apparent digestibility coefficients for dry matter and crude protein when shrimp feeds were added brown or green seaweed meal compared to control diet. Esparza-Leal *et al.* (2015) observed that a higher growth of *L. vannamei* was at stocking density 1500 and 3000 ind. m^{-3} than those of stocking density at 6000 and 9000 ind. m^{-3}. While survival was unaffected among all stocking density groups and all these stocking density groups have ensured excellent shrimp survivals (85-91.8%) in nursery phase. Similarly, Suantika *et al.* (2018) did find that an increasing of stocking density has significantly decreased growth and survival of *L. vannamei* in grow-out production. Thus, the optimal shrimp density could be at 500 PL m^{-3} compared to 750 and 1000 PL m^{-3}, which also ensures the best feed conversion ratio. Recently, *L. vannamei* grow-out production performance has comparable between RAS and hybrid system (combination of RAS and carbon adding zero-water discharge system) (Chen *et al.*, 2020; Suantika *et al.*, 2020), and this

Table 4. Growth performance of *Litopenaeus vannamei* in recirculation aquaculture system

S	IW	FG	SGR	FCR	SR	CP	CT	Treatments	References
33	1.42	3.42	3.03	1.91	73.33	29	FE	Control	Cárdenas *et al.* (2015)
		3.61	3.23	1.77	84.44			NG4 %	
		3.71	3.30	1.92	55.56			NG8 %	
		3.64	3.25	1.90	64.44			NK4 %	
		3.69	3.22	1.78	93.33			NK8 %	
5		14.87	7.12	1.32	70.0	84	GP	SD 500 PL/m^3	Suantika *et al.* (2018)
		12.94	6.95	1.45	53.67			SD 750 PL/m^3	
		11.32	6.79	2.05	44.0			SD 1000 PL/m^3	
5		14.86	7.12	1.32	70.0	84	GP	RAS	Suantika *et al.* (2020)
		12.06	7.05	1.54	70.0			Hybrid	
29.5-29.6		10.32	6.84		48.90	36	GP	SA RAS	Chen *et al.* (2020)
		9.75	6.80		44.36			Control	
30.7-31.2	0.004	1.37	2.73	1.01	53.1	50	NP	SD1500 PL/m^3	Tierney *et al.* (2020)
		1.52	3.03	0.99	50.3			SD1500 PL/m^3+S	
		1.25	2.50	1.08	53.8			SD 3000 PL/m^3	
		1.36	2.71	1.04	52.0			SD 3000 PL/m^3+S	
15.7-15.9	1.2	25.0	3.5	1.4	74.1	84	GP	Full light	Fleckenstein *et al.* (2019)
		24.2	3.4	1.8	57.2			Partial light	
		19.9	3.2	2.1	62.0			No extra light	
Seawater	0.009	1.26	11.8	1.1	85.0	42	NP	SD1500 PL/m^3	Esparza-Leal *et al.* (2015)
		0.85	10.8	0.9	91.8			SD 3000 PL/m^3	
		0.66	10.2	1.2	88.3			SD 6000 PL/m^3	
		0.51	9.7	1.0	89.3			SD 9000 PL/m^3	
34.68-35.06	3.5	12.54		1.76	92.13	53	GP	Shrimp and Mullet	Legarda *et al.* (2019)
		12.58		1.87	91.50			Shrimp	
20	1.13	12.6		2.1	76.2	87	GP	No probiotics (P)	Kesselring *et al.* (2019)
		14.9		1.6	78.1			P continuously	
		14.8		1.7	76.2			Alternating 1week P, 1 week control,	
		14.9		1.7	75.2			Alternating 2 weeks P, 2 weeks control	
		15.5		1.6	76.2			Alternating 2 weeks P, 1 week control	
27.2	1.92	17.85		1.6	93.11	70	GP	RAS with BFT	Xu *et al.* (2020)
0.6	0.082	13.9		1.61	56.3	133	GP	Shrimp and tomato in a RAS	Mariscal-Lagarda et al. (2012)
14.8-15.1	2.9	21.1		1.6	77.5	86	GP	100% least salt	Fleckenstein *et al.* (2022)
		20.7		1.5	84.3			97.5% least cost salt	
		21.9		1.4	81.1			95% least cost salt	
		21.7		1.5	79.2			90% least cost salt	
		22.2		1.4	76.7			80% least cost salt	
		21.9		1.4	82.3			75% least cost salt	

Note: S: salinity (‰) IW: initial weight (g); FG: final weight (g); SGR: specific growth rate (%day-1); FCR: feed conversion ratio, SR: survival rate (%); CP: culture period; CT: culture type, GP: grow-out production; NP: nursery phase; FE: feed experiment; NG4 %: 8 % inclusion of commercial green seaweed meal in shrimp diet; NG8 %: 8 % inclusion of commercial green seaweed meal in shrimp diet; NK4 %: 4 % inclusion of commercial brown seaweed meal in shrimp diet; NK8 %: 4 % inclusion of commercial brown seaweed meal in shrimp diet; S: substrate; SA: Sucrose Addition.

technology did not give better shrimp survivals (44.36-70%). Mariscal-Lagarda *et al.* (2012) have been conducted an integrated culture of white shrimp *L. vannamei* and tomato *Lycopersicon esculentum* using low salinity (0.65‰) groundwater in RAS setting; in which, good shrimp growth, yield and feed conversion ratio had achieved. Although, shrimp survival (56.3%) was inadequate in considering a viable aquaculture, this was likely due to low salinity (0.65‰) groundwater using RAS. Therefore, periodical mineral adding low salinity shrimp-tomato integration RAS could be initiated to improve shrimp survival. Adding different level of least cost salt at 100, 97.5, 95, 90, 80, and 75% in RAS system when *L. vannamei* cultured, these were provided comparable growth, survival, biomass production and feed conversion ratio after 86 days grow-out culture (Fleckenstein *et al.*, 2022). Although least cost salt has substantial influences on DO, pH, salinity, and turbidity; but these were not impacted shrimp performance (Fleckenstein *et al.*, 2022). This study also shows that adding to least cost salt is substantially reduced the cost in artificial sea salt mixtures-based aquaculture technology. Xu *et al.* (2020) stated that RAS-biofloc technology was viable for *L. vannamei* that has recorded better growth, survival (93.11%), yield and feed conversion ratio after 70 days grow-out culture. Furthermore, in a laboratory setting, the integration of Pacific white shrimp *L. vannamei* and white mullet *Mugil curema* in a biofloc based RAS was viable in terms of growth, production, feed conversion ratio and survival (Legarda *et al.*, 2019). Also, this technology is ensured an excellent shrimp and mullet survivals (>90%). Therefore, this technology is warranted more researches in large scale commercial application with analyzing of economic viability to understand their feasibility in aquaculture industry. Whiteleg shrimp *L. vannamei* growth was greatly higher at 24 hours lighting and 12 hours lighting groups than no extra lighting RAS (Fleckenstein *et al.*, 2019), while shrimp survival was substantially better as well as growth was slightly good at 24 hours lighting group than 12 hours lighting RAS. Therefore, indoor aquaculture should provide adequate lighting during operation.

Biofloc technology (BFT) for Litopenaeus vannamei : A BFT system is an environment friendly because it can improve water quality conditions and, for some species, can provide instant food, nutrition and healthcare to culture species (Ahmad *et al.*, 2017; Hosain *et al.*, 2021a,b,c). Bioflocs are particles consisting of a mixture of bacteria, algae, uneaten food, zooplankton that may provide a constant supply of nutrition to the farmed animals. Moreover, there are additional benefits to the animal including better growth and feeding efficiencies as well as immunity and disease resistance (Ahmad *et al.*, 2017; Panigrahi *et* al., 2018; 2019). Biofloc contains proteins, lipids, minerals, vitamins, amino acids, and fatty acids as well as enzymes, immunostimulants and natural probiotics (Ahmad *et al.*, 2017; Hosain *et al.*, 2021c).

Now, *Litopeneaus vannamei* BFT based system are being practiced in fresh, brackish and marine water environments (Table 5). The most of the brackish water BFT based studies have been carried out in moderate to higher saline levels brackish water, while few are deal in fresh or low salinity (Table 5). A higher growth, survival and production of white leg shrimp has found in 25‰ salinity based BFT compared to 2-4‰ BFT (Maica *et al.*, 2012). The low salinity (1-7‰) brackish water BFT is found feasible to *L. vannamei*. Liu *et al.* (2014) reported the better survival, FCR and production of *L. vannamei* was in polyculture BFT systems with spotted scat (*Scatophagus argus*) and water spinach (*Ipomoea aquatica*) than control groups at low salinity (1‰) brackish water BFT, where maize starch has added to nitrogen ratio of 15. A survival at 72.73% has found in 4‰ salinity BFT system (Maica *et al.*, 2012). Artificial brackish water with salinity 4‰ based BFT system has provided higher growth, survival and production of *L. vannamei* postlarvae, in which CN ratio of 10 was maintained by adding molasses (Zacarias *et al.*, 2019). A higher growth, survival and better FCR of *L. vannamei* have obtained in 7‰ salinity based BFT system than control, PKE was added to maintain CN ratio of 15. In a 5‰ based BFT system, *L. vannamei* production performance has better in glucose and molasses carbon based BFTs than starch adding BFT system (Huang *et al.*, 2022).

A total of 12 different carbon sauces have been added when culturing whiteleg shrimp is BFT systems, while the C-N ratios were between 6 and 22 (Table 5). Sucrose, molasses and glycerol carbon based heterotrophic BFT systems have a higher removal of nitrate-N than chemoautotrophic system, when *L. vannamei* was cultured (Ray and Lotz, 2014). A higher growth of *L. vannamei* has been remained in wheat flour BFT than molasses, tapioca BFT and clear-water system, while survival was similar, these carbon sources were added to nitrogen ratio of 20 at 26‰ salinity based BFT (Rajkumar *et al.*, 2016). This study detected a higher number of total heterotrophic bacteria in three carbon sources BFTs than control. Tinh *et al.* (2021) reported the addition of corn starch in BFT system has resulted in significantly higher whiteleg shrimp growth rate, production, average body weight, and lower FCR compared to molasses addition. Two different mixtures of molasses and wheat bran (50+50 and 75+25) % and molasses were used to create a zero-water exchange BFT for *L. vannamei* in which C-N ratio had 16 (Zhao *et al.*, 2016). These authors reported a higher growth had in the mixtures of 50% molasses and 50% wheat bran than molasses and the 75% molasses and 25% wheat bran while survival shows no differences among the groups. Similarly, a mixture of molasses and rice bran (50+50) % carbon source was added to nitrogen ratio at 12 to 15 for the *L. vannamei* juvenile production (Effendi *et al.*, 2016).Result shows that PLs growth, production, survival and FCR were better at BFT system than that of periphyton based system. The C-N ratio of 12 is suiTable in terms of good water quality, higher shrimp performance, and better FCR and production compared to C-N ratios of 15 and 18, when molasses was added for *L. vannamei* juveniles cultured in

Table 5. Growth performance of *Litopenaeus vannamei* in biofloc system

S	FG	SGR	SR	FCR	P (Kg m^{-3})	CS	CN R	Treatments	References
26.6-26.9	9.84		97.33	1.29	2.81			Control	Xu *et al.* (2016)
	9.75		97.50	1.30	2.79	MO	6	C-N-adjust	
	9.99		95.50	1.27	2.83	MO	12	C-N-12	
	9.20		97.83	1.40	2.64	MO	15	C-N-15	
	9.03		95.67	1.47	2.53	MO	18	C-N-18	
32.98-33.76	6.26	2.61	84.38	1.75				Control	Khanjani and Sharifinia (2022)
	6.65	2.79	91.67	1.45		MO	10	C-N-10	
	6.88	2.88	94.79	1.33		MO	14	C-N-14	
	6.67	2.80	91.67	1.44		MO	18	C-N-18	
	6.44	2.70	88.02	1.58		MO	22	C-N-22	
2-25	1.87	5.13	22.50	0.86	91.25[a]	MO	6	2‰ BFT	Maica *et al.* (2012)
	1.94	5.23	72.73	0.87	154.61[a]	MO	6	4‰ BFT	
	2.06	5.37	97.50	0.81	220.53[a]	MO	6	25‰ BFT	
4	0.8	7.0	87.5		0.15	MO	10	K: Mg (1:5.4)	Zacarias *et al.* (2019)
	0.7	6.4	81.2		0.12	MO	10	K: Mg (1:4.65)	
	0.7	6.6	89.8		0.14	MO	10	K: Mg (1:3.77)	
	1.7	9	65.0		0.22	MO	10	Control: K: Mg (1:4.57)	
26.7	6.80	3.24	78.3	1.71		WB, MO	20	One time feeding	Nery *et al.* (2019)
	7.35	3.34	79.8	1.56		WB, MO	20	Two times feeding	
	8.07	3.46	81.8	1.38		WB, MO	20	Three times feeding	
	6.52	3.18	85.2	1.82		WB, MO	20	Four times feeding	
7	3.55	3.64	84.6	1.86				Control	Syamala *et al.* (2017)
	4.99	4.56	88.6	1.61		PKE	15	PKE	
25	5.97	4.10	86.9					Control	Rajkumar *et al.* (2016)
	6.64	4.25	82.2			MO	20	Molasses	
	7.25	4.43	85.6			TF	20	Tapioca flour	
	8.49	4.57	90.3			WF	20	Wheat flour	
25	2.5		96	1.3		CS	12	Corn starch	Tinh *et al.* (2021)
	1.3		90	2.6		MO	12	Molasses	
5	12.04	4.23	100		1.09	Gl	20	Glucose	Huang *et al.* (2022)
	11.22	4.13	100		1.01	MO	20	Molasses	
	4.47	1.86	48.2		0.39	St	20	Starch	
19.8-19.9	10.5		81.7	1.8	2.2	MO	6	Control commercial (CS) 20‰	Pinto *et al.* (2020)
	11.2		82.0	1.7	2.4	MO	6	CS: low-cost prepared salt mixture (PS)=10:10‰	
	12.8		56.0	2.4	1.8	MO	6	CS:PS = 5:15‰	
	4.3		12.0	16.4	0.2	MO	6	CS:PS = 20:0‰	
26.08	0.44		92.71	1.76		MO	20	One time feeding	Peixoto *et al.* (2018)
	0.43		90.87	1.75		MO	20	Two times feeding	
	0.56		88.51	1.50		MO	20	Three times feeding	
	0.43		89.84	1.67		MO	20	Four times feeding	
37.23-38.49	9.98		94.79	1.08	3.4	MO	20	TSS 100-300 mg L^{-1}	Gaona *et al.* (2017)
	8.85		84.17	1.21	2.98	MO	20	TSS 300-600 mg L^{-1}	
	7.60		20.73	5.28	0.65	MO	20	TSS 600-1000 mg L^{-1}	
33.0-33.5	15.0		83.3	1.4	2.3	MO	15	Na_2CO_3 based BFT	Furtado *et al.* (2011)
	14.3		85.0	1.4	2.2	MO	15	Ca $(OH)_2$ based BFT	
	14.2		80.0	1.5	1.8	MO	15	$NaHCO_3$ based BFT	
	12.0		80.0	3.0	1.3	MO	15	Control/BFT	
	0.64	8.84	52.17	2.04	0.29	MO	15	0‰ salinity	Moura *et al.* (2021)
	1.21	11.30	96.67	0.71	1.11	MO	15	3‰ salinity	
	1.19	11.25	97.0	0.84	1.10	MO	15	6‰ salinity	
	1.14	11.09	95.67	0.89	1.03	MO	15	10‰ salinity	
	1.24	11.40	92.83	0.84	1.10	MO	15	13‰ salinity	

Note: S: salinity (‰); FG: final weight (g); SGR: specific growth rate (%day^{-1}); FCR: feed conversion ratio, SR: survival rate (%); CS: carbon sources; CN R: Carbon to nitrogen ratio; MO: Molasses; TF: Tapioca flour, WF: Wheat flour, Gl: Glucose; St: Starch

Table 5. Growth performance of *Litopenaeus vannamei* in biofloc system (continued)

S	FG	SGR	SR	FCR	P (Kg m^{-3})	CS	CN R	Treatments	References
35.0-	1.6		95.8	1.1		RB	20	RB and 25 mg L^{-1} TSS	Vilani *et al.*
35.4	1.3		94.2	1.2		RB	20	RB and 100 mg L^{-1} TSS	(2016)
	1.3		93.4	1.3		MO	20	MO and 25 mg L^{-1} TSS	
	1.2		91.9	1.4		MO	20	MO and 100 mg L^{-1} TSS	
1			51.1	5.64	0.292			SM and fed 100%	Liu *et al.*
			56.6	4.43	0.304			SP and fed100%	(2014)
			95.6	1.02	0.495	MS	15	SP and fed 100% in BFT	
			94.3	1.15	0.423	MS	15	SP and fed 80% in BFT	
22.5	16.66		59.53	1.96	21.74[b]			Control	Llario *et al.*
	17.48		65.7	1.91	23.0	SU	15	HB treatment	(2019)
	17.83		66.19	1.81	21.07	SU	15	Low bacteria treatment	
26.5-	8.52		98.5	1.55	2.46	MO	9	SI 35% CP feed with CN 9	Xu *et al.*
26.9	8.75		98.6	1.52	2.48	MO	12	SI 35% CP feed CN 12	(2018)
	8.24		98.8	1.62	2.39	MO	15	SI 35% CP feed CN 15	
	8.09		96.0	1.71	2.27	MO	18	SI 35% CP feed CN 18	
	9.84		97.3	1.29	2.81	MO	9	HI 35% CP feed CN 9	
	9.99		96.5	1.27	2.83	MO	12	HI 35% CP feed CN 12	
	9.20		97.8	1.40	2.64	MO	15	HI 35% CP feed CN 15	
	9.03		95.6	1.47	2.53	MO	18	HI 35% CP feed CN 18	
18.93-	12.04	6.55		1.34	2.72	MO	6	SD 300 ind. m^{-3}	Liu *et al.*
18.99	9.94	5.93		1.49	2.99	MO	6	SD 400 ind. m^{-3}	(2017)
	6.98	4.71		1.71	2.63	MO	6	SD 500 ind. m^{-3}	
10.84-	0.66		95.70	1.18		WB, MO	10	SD1500 ind. m^{-2}	Silva *et al.*
11.77	0.52		94.90	1.34		WB, MO	10	SD 3000 ind. m^{-2}	(2015)
	0.56		54.26	2.19		WB, MO	10	SD 4500 ind. m^{-2}	
	0.34		46.26	3.99		WB, MO	10	SD 6000 ind. m^{-2}	
31.0-33.0	18.0	1.03	83.96	0.76		MO+RB	12-15	Biofloc system	Effendi *et al.* (2016)
	20.5	1.09	74.48	3.43				PB system	
31.8-	9.52	1.08	90.06					Control	Zhao *et al.*
32.3	10.78	1.48	91.48			MO	16	100% MO	(2016)
	11.36	1.69	89.56			MO+WB	16	50% MO + 50% WB	
	10.22	1.35	87.56			MO+WB	16	75% MO + 25% WB	
43±2	8.78		88.20	2.03		RBP		RBP + FZ (Fr 90 g kg^{-1}) BFT	Leite *et al.* (2020)
	9.17		88.1	1.55		RBP		RBP + (Fr 110 g kg^{-1}) BFT	
	9.32		87.3	1.55		RBP		RBP + FZ (Fr 150 g kg^{-1}) BFT	
	9.52		82.1	1.56		RBP		RBP + FZ (Fr 200 g kg^{-1}) BFT	
	9.04		83.2	1.56		RBP		RBP + FZ (Fr 250 g kg^{-1}) BFT	
	8.75		88.1	1.55		MO		MO based BFT	
	7.74		81.3	1.67				Control	
15.0-18.4			88.7	1.63	2.8	SU added when NO_2-N was above 2 mg L^{-1}		Low solids	Ray *et al.* (2011)

Note: S: salinity (‰); FG: final weight (g); SGR: specific growth rate (%day^{-1}); FCR: feed conversion ratio, SR: survival rate (%); CS: carbon sources; CN R: Carbon to nitrogen ratio; RB: rice bran; MS: Maize starch; SM: Shrimp monoculture; SP: Shrimp polyculture; RBP: Rice by product, HB: High bacteria, PB: Periphyton based system; FZ: Fertilizer; Fr: fiber

brackish water BFT system (Xu *et al.*, 2016; Xu *et al.*, 2018). Similarly, the C-N ratio 12 has been found optimal for those the less and more expensive feed containing protein levels at 35.80 and 36.10% (Xu *et al.*, 2018). These authors suggested that less expensive feed with C-N ratio of 12 could be used in BFT systems, this can be reduced feed cost and ensured economic viability. More recently, Khanjani and Sharifinia (2022) showed the higher *L. vannamei* final weight, productivity and survival had in molasses adding to nitrogen ratio at 14 based BFT than those molasses to nitrogen ratios at 10, 18 and 22 based BFT systems.

In BFT system, three times feeding frequency is optimal for *L. vannamei* grow-out phase that has given the best growth compared to those of one and four times feeding groups, and this group survival had higher than one and two times feeding groups and similar to four times feeding treatment (Nery *et al.*, 2019). Similarly, three times feeding frequency has resulted better growth for *L. vannamei* nursery phase, but survival was not different among the feeding frequency of one, two, three or four times a day (Peixoto *et al.*, 2018). Whiteleg shrimp culturing BFT system should be maintained the total suspended solids (Gaona *et al.*, 2017). These authors showed that the low (100-300 mg L^{-1}) and medium (400-600 mg L^{-1}) TSSs based BFT systems have improved water quality conditions and reducing feed cost, augment production, growth and survival as well as ensure overall animal health. In contrast, the higher solids (600-1000 mg L^{-1}) based BFT system had decreased whiteleg shrimp productivity, growth and survival (Gaona *et al.*, 2017). Overall, BFT system is a tremendous technology for whiteleg shrimp. This technology has ensured excellent survivals and better FCRs and higher productivity in those successful BFT systems. This systems requirs optimal carbon sources, C-N ratio and TSS level to maximize the shrimp production.

Aquamimicry shrimp farming: Aquamimicry is a newly developed modern shrimp culture technique, it attempts to create a better balance between biofloc production and live feeds include microalgae, rotifers, cladocerans, copepods, amphipods etc. (Khanjani *et al.*, 2022; Nisar *et al.*, 2022; Romano, 2017). This system relies on organic carbon source without providing a specific carbon to nitrogen ratio and probiotic (Khanjani *et al.*, 2022; Romano, 2017). The system is often adding *Bacillus* sp. probiotics with fermented rice or wheat bran regularly (Romano, 2017). This author suggested a dose of fermented carbon source at 50-100 ppm for first two weeks then it could be reduced at following order 4>2 ppm as daily addition throughout the culture cycle. The Aquamimicry system should be maintained an ideal turbidity around 30-40 (measured using a Secchi disk) (Romano, 2017). The shrimp stocking density can be at 30-100 ind. m^{-2} (Romano, 2017). Addition of fermented carbon source with probiotics involves in blooming the bacteria, phytoplankton and zooplankton (Nisar *et al.*, 2022; Romano, 2017; Zeng *et al.*, 2020). This system is usually stimulated in increasing of copepods blooming thus it is often known as biofloc-copefloc system (Santhanam and Perumal, 2020).

This system does not require any chemical addition thus it is a completely organic shrimp farming. The Aquamimicry system was started in 2013 by two renowned shrimp farmers Mr. Sutee Prasertmark and Mr. Veerasan Prayotamornkul in Thailand (Zeng *et al.*, 2020). Currently, this innovative shrimp farming system is adopted in many countries i.e., Bangladesh, Brazil, Brunei, China, Ecuador, Egypt, India, Korea, Malaysia, Mexico, Peru, Singapore, Sri Lanka, USA, and Vietnam. This system increases shrimp production as well as provides good water quality conditions and wellbeing to culture animals (Zeng *et al*., 2020). This aquaculture system is still in its initial stage and does not have much experimental research in optimizing the best organic carbon sources or its optimal administration level for shrimp or fish culture. Therefore, more researches are needed to optimize its system design and operation protocol includes suiTable carbon sources and its optimal level in semi-intensive and intensive shrimp production using pond setting.

Integrated multitrophic aquaculture system: Integrated multi-trophic aquaculture (IMTA) is resembled to polyculture, where multi-trophic aquatic species include plant, fishes, shrimp, mollusks and echinoderms do exist together in a farming condition within a culture mesocosm and or a separate mesocosm. This system is involved in improving of farm efficiency with more benefits such as increases productivity and profit, reduces waste, and provides ecosystem services along with bio-remediation. For example, whiteleg shrimp (SD at 300 ind. m^{-3}) and Nile tilapia *Oreochromis niloticus* (SD at 344 ind. m^{-3}) have been integrated with heterotrophic and mature biofloc systems (Martins *et al*., 2020). In which, shrimp production performance was unaffected by two systems and ensuring excellent survival (>88%) while tilapia production was two times higher in heterotrophic BFT system. Significantly higher sludge including total suspended solids and settleable solids as well as less bacterial community diversity and Vibrionaceae were in heterotrophic BFT system (Martins *et al*., 2020).

Integration of *L. vannamei*, mullet *Mugil liza* and sea lettuce *Ulva fasciata* in a biofloc system could be a viable system, in which shrimp and mullet growth and survival were unaffected while total yield was better in IMTA system than control (Legarda *et al*., 2021). Mullet *Mugil curema* stocked at 10-20% of *L. vannamei* biomass in the IMTA systems that substantially increased mullet growth and survival compared to mullet stocked at 30% of *L. vannamei* biomass (Legarda *et al*., 2020). Whereas, shrimp performance includes shrimp final weight, growth rate, feed conversion ratio and production were comparable between those treatments. Brito *et al.* (2016a) indicated that integration of *L. vannamei* with red seaweed *Gracilaria birdiae* in the BFT system has decreased dissolved inorganic nitrogen, nitrate-N and *Vibrio* density. This system is significantly increased shrimp overall performance including growth and productivity as well as crude protein content in whole body shrimp. Ge *et al.* (2019) demonstrated that the integration of *L. vannamei* (500 shrimp m^{-3}) and green seaweed *Ulva prolifera* (800 mg L^{-1}) with 10% water exchange improve the water quality and enhance shrimp growth. Contreras-Sillero *et al.* (2020) showed that polyculture of *L. vannamei* and sea cucumber *Holothuria inornata* in a BFT based recirculation system was feasible, and this system provide the excellent growth, survival and productivity.

Prospects and future outlooks of Litopenaeus vannamei production in Bangladesh: Whiteleg shrimp *L. vannamei* can bring more prospects in coastal aquaculture in Bangladesh due to its ease culture technology and ability to grown in low salinity freshwater to high salinity marine environments, high market demand and its deliciousness and adorability to shrimp consumers. The development of *L. vannamei* aquaculture will help to enhance the high demand shrimp commodity, and having prospects its business in local and international markets. Despite these possibilities, the shrimp sector has some constraints when culturing in Bangladesh environments. For example, sustainable aquaculture production of this shrimp requires quality seeds that rely on specific pathogen free (SPF) and specific pathogen tolerant (SPT) broodstocks to overcome mass shrimp mortality owing to diseases. Furthermore, shrimp should be cultured using highly intensive or super intensive culture system. Also, the nitrogenous toxicants should be eliminated in *L. vannamei* culture systems. Moreover, the *L. vannamei* culture technology should be adopted using of environment friendly controlled aquaculture technology to ensure not to entire as new footprint of *L. vannamei* as well as their aquaculture residues (pollutants and aquaculture chemicals) in coastal estuarine environments. Therefore, the reproducible research should be warranted in hatcheries, nurseries, grow-out production and high-quality broodstock developments. The Table 6 is summarized and presented the current global progress and future research and development works for *L. vannamei* in Bangladesh in brief.

The feasibility of modern aquaculture of *L. vannamei* as well as some traditional Bangladesh shrimp culture technologies should be compared with emphasized of shrimp production performance, carcass quality, benefit-cost analysis to identify the viable technology for local shrimp farmers. The larvae culture technology will be adopted by buying of SPF, SPR and SPT stocks from several countries. The broodstock developments in government and non-government satellite hatcheries with cohort breeding protocol of respective broodstock of SPR, SRT and SPT for in each hatchery should be initiated using several stocks available in worldwide. Additionally, the hybrid broodstock of whiteleg shrimp should be developed with combined strategies such as SPF+SPR, SPF+SPT or SPF+SPR+SPT (proposed by Alday-Sanz *et al.*, 2020). The broodstock developing activities could be initiated and managed with accordance of proper scientific methods and biosecurity farming conditions to avoid the inbreeding problem with emphasized of higher growth and diseases resistant traits. The satellite nursery station should be established with modern indoor aquaculture system to ensure advanced shrimp juvenile in enhancing the Whiteleg shrimp production in Bangladesh.

The grow-out production of *L. vannamei* should be used confined outdoor pond or indoor modern aquaculture system to ensure high-quality *L. vannamei* shrimp production and not to escape in natural environments. Additionally, more experimental researches are needed on larval phase, nursery, grow-out production and broodstock feed and feeding regimes, and various stocking densities with enzyme activities and diseases challenges and carcass quality when used locally available feed or newly develop feed for *L. vannamei* in Bangladesh. Furthermore, these researches will be monitored the physio-chemical features including salinity, temperature, pH, TAN, nitrite-N, nitrate-N, TSS and VSS. The effect of tank colour on larval performance should also be explored. Moreover, all aquaculture production experiments will be examined *L. vannamei* physiology in particularly digestive enzyme activity, immunity and diseases resistances with various pathogen challenge tests during culture protocol development in Bangladesh. The studies of probiotics addition in aquaculture systems and their impacts on culture environments and shrimp production performance researches are suggested in controlled indoor and out-door systems.

In Bangladesh, the outdoor earthen ponds within the controlled environment of *L. vannamei* grow-out culture could be a great option. This system should be developed based on reproducible research findings or using feasible technologies as early as possible. Then, the developed viable technology should be demonstrated throughout the coastal regions where brackish and marine waters are available. During this pilot program, shrimp carcass quality and overall health status including immunity, diseases resistance and robustness will be examined. Additionally, the aquaculture attributes such as monoculture, intensification, polyculture with locally available finfishes, shellfishes could be initiated and its benefit-cost ratio will be estimated. Finally, the developed technology will be disseminated among the shrimp farmers.

Boosting seafood export earnings of Bangladesh: Historically, the exported shrimp commodities have been increased gradually from 13631.0 to 54891.0 MT between 1985-86 and 2010-11(Table 7). The following decade, the frozen seafood export from Bangladesh showed a declining trend and fallen to 30036.18 MT in 2019-20. While, the prawn and shrimp farming area and its production have accounted for 2,76,492 ha and 669 kg ha^{-1}, and 2,57,888 ha and 998 kg ha^{-1} for 2010-11 and 2019-20, respectively (DoF, 2020; FRSS, 2012). Herein, the prawn

Table 6. Global recent progress of *Litopenaeus vannamei* aquaculture as well as future research, development and implication studies for Bangladesh

Issues	Recent key progress of white leg shrimp aquaculture	Future key research and development
Larvae culture	Various genera of microalgae i.e., *Chaetoceros, Tetraselmis, Isochrysis, Thalassiosira, Dunaliella, Amphipora, Spirulina* are commonly used in *L. vannamei* larvae culture in shrimp hatcheries[1].	More research should be warranted in adding of microalgae in order to develop the mass larvae culture of *L. vannamei* in Bangladesh.
	The supplementation of artificial diet with live feeds to the *L. vannamei* larvae culture has increased larval production performance and viability[2].	The researchers are needed to develop the artificial diet supplementation-based mass larvae culture technology of white leg shrimp in Bangladesh
Post larvae culture	The BFT based post larvae culture is considered more viable to *L. vannamei* juvenile production, in which different BFT system attributes i.e., carbon sources, C-N ratios, total suspended solid levels etc. have been standerdized[3].	More researches are recommended to identify the optimal carbon sources, C-N ratio, TSS levels using locally available cheaper carbon sources adding BFT nursery system
	More recently, one strategy, the addition of microalgae and rotifer (*Brachionus plicatilis*) in BFT system was more viable in terms of production performance and body composition of *L. vannamei* compared to sole BFT system[4].	The addition of live feeds for *L. vannamei* nursery phase should be initiated using microalgae and zooplankton. The developed technology should be implemented in hatcheries to ensure advanced size post larvae for shrimp farmers.
Grow-out	Currently, many investigations have been assayed the viability of BFT based grow-out production in indoor or commercial pond for many species of penaeid shrimps in globally that are considered environment-friendly viable technology[3].	More BFT based researches should be undertaken in indoor and commercial pond, in which the optimal carbon sources, C-N ratio, TSS levels, feed and feeding regime etc. could be optimized.
	More recently, BFT based integrated multitrophic aquaculture (IMTA) or polyculture of *L. vannamei* and finfishes, shellfishes (oyster, clam), sea cucumber and seaweed have been gained considerable attention, and the interventions, development, and expansion are likely flourished rapidly[5].	The BFT based IMTA or polyculture system of *L. vannamei* and locally available salinity tolerance finfishes, shellfishes and seaweed should be tested to examine the feasibility of this system.
	The aquamimicry shrimp farming system is a viable technique that are practicing by *L. vannamei* and *P. monodon* farmers in many countries[6].	The aquamimicry shrimp farming system should be developed for *L. vannamei* and *P. monodon* production in Bangladesh.
Broodstock development	Nowadays, *L. vannamei* is a key aquaculture shrimp and most of the production come from this species because ease of domestication and associated implementation of highly effective selective breeding programmes focused on growth and disease tolerance[7].	More researches are need to developed the improving and quality broodstock with emphasized on growth and disease tolerance traits for Bangladesh.
References	(González-Davis *et al.*, 2012; IBA *et al.*, 2014; Jamali *et al.*, 2015; Piña *et al.*, 2006; Tam et al., 2021)[1], (Brito *et al.*, 2001; Medina-Reyna *et al.*, 2000; DAbramo *et al.*, 2006; Sangha *et al.*, 2000)[2], (Abakari et al., 2021; El-Sayed, 2021; Khanjani and Sharifinia, 2020; Robles-Porchas et al., 2020)[3], (Brito et al., 2016; de Andrade et al., 2021; Silva et *al.*, 2021)[4], (Brito *et al.*, 2018; Costa *et al.*, 2021; Hoang *et al.*, 2020; Holanda *et al.*, 2020; Lima *et al.*, 2021; Liu *et al.*, 2014; Pinheiro *et al.*, 2020; Poli *et al.*, 2019; Sarkar *et* al., 2021)[5], (Ahmed, 2017; Zeng et al., 2020)[6], (Marin-Riffo et al., 2021)[7].	

M. rosenbergii and shrimp *P. monodon* production per hectare have not improved during the decade. However, the *L. vannamei* production was higher at 5.0 to 8.9 MT ha^{-1}, i.e. 5 to 9 times more in pilot scale grow-out ponds in Bangladesh, compared to the present production rate of 998 kg ha^{-1} (DoF 2020).

Table 7. Exported of frozen seafood commodities include prawn, shrimp and fishes from 1985-86 to 2019-20. Exported live fish data excluded. (DoF,2002, 2007 and 2020)

Year	Prawn and shrimp		Fish		Total		1 USD equivalence to BDT
	Export (MT)	BDT (Million)	Export (MT)	BDT (Million)	Export (MT)	BDT (Million)	
1985-86	13631.0	2693.0	5017.0	365.0	18648.0	3058.0	26.0
1990-91	17985.0	4512.9	5702.0	414.0	23687.0	4926.9	33.0
1994-95	26277.0	10457.0	9267.0	1802.6	35544.0	12259.6	40.20
2000-01	29713.0	18852.0	7965.0	948.9	37678.0	19800.9	50.82
2005-06	49317.0	26984.0	17429.0	2941.4	66746.0	29925.4	61.39
2010-11	54891.0	35682.0	33112.0	9111.0	88003.0	44793.0	69.18
2015-16	40726.0	35987.0	18561.0	4373.0	59287.0	40360.0	77.67
2019-20	30036.18	29489.0	21915.52	6250.0	51951.7	35739.0	84.78

Based on the *L. vannamei* cultivation success in Bangladesh, this shrimp can boost up production from the coastal Bangladesh and can help in export earnings. In this stand point, if Bangladesh cultivate about 10% of shrimp culture area (27,000 ha) with *L. vannamei*, the projected production will be about 2,70,000 MT from two consecutive cycles in a year (calculation using the minimal production at 5 MT ha^{-1} under two cycle per year, that obtained a pilot scale culture in Bangladesh). Moreover, this shrimp production (2,70,000 MT) can be added great amount of money with the value of 1,35,000 million BDT to the national economy that will 4.57 times higher than that of current export earnings (BDT 29,489.0 million in 2019-20; Average shrimp price BDT 500/kg). Additionally, these shrimp commodity export earnings value could be about USD 1319.50 (1 USD = BDT 102.34). Hence, the export earnings could boost from 5 to 10 folds from the present scenario, that will depend upon the management techniques as well as expansion of shrimp culture area in the coastal region.

CONCLUSION

This review shows the Pacific white shrimp *L. vannamei* could be a potential shrimp species in the coastal region of Bangladesh. This shrimp has more reliable aquaculture attributes like easy to culture in various environment conditions and technologies. This species able to tolerate a wide range of salinity in aquaculture conditions. Postlarval survival is significantly higher during hatchery phase. This species can be grown in higher stocking densities, and they are eating various feed and feed particles in culture environments. The specific diseases resistance strains of this species are available in several countries. This shrimp can be cultured in numerous indoor and outdoor aquaculture systems i.e., earthen pond culture, tank culture, limited/zero discharge recirculating aquaculture system, clear-water or green water raceways, biofloc and aquamimicry culture system. For instance, the reproducible researches are needed to examine the culture profitability in Bangladesh coastal environment conditions. Hopefully, the current knowledge on culture technology could be very helpful for strategies and aquaculture systems design and development studies in various *L. vannamei* culture stations. Therefore, more researches and development activities of this shrimp are warranted. The outcomes of these research and development works could be helpful to enhance the shrimp production in Bangladesh, which will support to the increasing protein demand of rapid growing human populations globally and will create many job opportunities.

LITERATURE CITED

ABAKARI, G., LUO, G., KOMBAT, E.O. and ALHASSAN, E.H. 2021. Supplemental carbon sources applied in biofloc technology aquaculture systems: types, effects and future research. *Rev. Aquac.* **13**, 1193–1222.

AHMAD, I., RANI, A.M.B., VERMA, A.K. and MAQSOOD, M. 2017. Biofloc technology : an emerging avenue in aquatic animal healthcare and nutrition. *Aquac. Int.* **25**, 1215–1226.

ALDAY-SANZ, V., BROCK, J., FLEGEL, T.W., MCINTOSH, R., BONDAD-REANTASO, M.G., SALAZAR, M. and SUBASINGHE, R. 2020. Facts, truths and myths about SPF shrimp in Aquaculture. *Rev. Aquac.* **12**, 76–84.

ALI, S. 2022. No greenlight for Vannamei shrimp production hurting exports. Bus. Standerd 1–7.

ARAMBUL-MUÑOZ, E., PONCE-PALAFOX, J.T., SANTOS, R.C.D.L., ARAGÓN-NORIEGA, E.A., RODRÍGUEZ-DOMÍNGUEZ, G. and CASTILLO-VARGASMACHUCA, S.G. 2019. Influence of stocking density on production and water quality of a photoheterotrophic intensive system of white shrimp (*Penaeus vannamei*) in circular lined grow-out ponds, with minimal water replacement. *Lat. Am. J. Aquat. Res.* **47**, 449–455.

ARSHADI, A., GHARAEI, A. and MIRDAR HARIJANI, J. 2020. Effect of dietary vitamin E on reproductive performance and vitellogenin gene expression in broodstock of *Litopenaeus vannamei. Iran. J. Fish. Sci.* **19**, 2475–2492.

AVNIMELECH, Y. 1999. Carbon/nitrogen ratio as a control element in aquaculture systems. *Aquaculture* **176**, 227–235.

BALAKRISHNAN, G., PEYAIL, S. 1, KUMARAN, R., THEIVASIGAMANI, A., SAVJI, K.A., CHOKKAIAH, M. and NATARAJ, P. 2011. Growth of cultured Whiteleg Shrimp *Litopenaeus vannamei* (Boone 1931) in different Stocking Density. *Adv. Appl. Sci. Res.* **3**, 107–113.

BOYD, C.E., MCNEVIN, A.A., DAVIS, R.P., GODUMALA, R. and MOHAN, A.B.C. 2018. Production methods and resource use at *Litopenaeus vannamei* and *Penaeus monodon* farms in India compared with previous findings from Thailand and Vietnam. *J. World Aquac. Soc.* **49**, 551–569.

BOYD, C.E., MCNEVIN, A.A., RACINE, P., TINH, H.Q., MINH, H.N., VIRIYATUM, R., PAUNGKAEW, D. and ENGLE, C. 2017. Resource use assessment of Shrimp, *Litopenaeus vannamei* and *Penaeus monodon*, production in Thailand and Vietnam. *J. World Aquac. Soc.* **48**, 201–226.

BREGNBALLE, J. 2015. A Guide to Recirculation Aquaculture, FAO and Eurofish Report.

BRITO, L.O., CARDOSO JUNIOR, L. DE O., LAVANDER, H.D., ABREU, J.L. DE, SEVERI, W. and GÁLVEZ, A.O. 2018. Bioremediation of shrimp biofloc wastewater using clam, seaweed and fish. *Chem. Ecol.* **34**, 901–913.

BRITO, L.O., CHAGAS, A.M., DA SILVA, E.P., SOARES, R.B., SEVERI, W. and GÁLVEZ, A.O. 2016a. Water quality, *Vibrio* density and growth of Pacific white shrimp *Litopenaeus vannamei* (Boone) in an integrated biofloc system with red seaweed *Gracilaria birdiae* (Greville). *Aquac. Res.* **47**, 940–950.

BRITO, L.O., DOS SANTOS, I.G.S., DE ABREU, J.L., DE ARAÚJO, M.T., SEVERI, W. and GÀLVEZ, A.O. 2016b. Effect of the addition of diatoms (*Navicula* spp.) and rotifers (*Brachionus plicatilis*) on water quality and growth of the Litopenaeus vannamei postlarvae reared in a biofloc system. *Aquac. Res.* **47**, 3990–3997.

BRITO, R., ROSAS, C., CHIMAL, M.E. and GAXIOLA, G. 2001. Effect of different diets on growth and digestive enzyme activity in *Litopenaeus vannamei* (Boone, 1931) early post-larvae. *Aquac. Res.* **32**, 257–266.

CÁRDENAS, J.V., GÁLVEZ, A.O., BRITO, L.O., GALARZA, E.V., PITTA, D.C. and RUBIN, V.V. 2015. Assessment of different levels of green and brown seaweed meal in experimental diets for Whiteleg shrimp (*Litopenaeus vannamei*, Boone) in recirculating aquaculture system. *Aquac. Int.* **23**, 1491–1504.

CASILLAS-HERNÁNDEZ, R., NOLASCO-SORIA, H., GARCÍA-GALANO, T., CARRILLO-FARNES, O. and PÁEZ-OSUNA, F. 2007. Water quality, chemical fluxes and production in semi-intensive Pacific white shrimp (*Litopenaeus vannamei*) culture ponds utilizing two different feeding strategies. *Aquac. Eng.* **36**, 105–114.

CHEN, Z., CHANG, Z., ZHANG, L., WANG, J., QIAO, L., SONG, X. and LI, J. 2020. Effects of carbon source addition on microbial community and water quality in recirculating aquaculture systems for *Litopenaeus vannamei. Fish. Sci.* **86**, 507–517.

COHEN, J.M., SAMOCHA, T.M., FOX, J.M., GANDY, R.L. and LAWRENCE, A.L. 2005. Characterization of water quality factors during intensive raceway production of juvenile *Litopenaeus vannamei* using limited discharge and biosecure management tools. *Aquac. Eng.* **32**, 425–442.

CONTRERAS-SILLERO, M.E., PACHECO-VEGA, J.M., VALDEZ-GONZÁLEZ, F.J., DE LA PAZ-RODRÍGUEZ, G., CADENA-ROA, M.A., BAUTISTA-COVARRUBIAS, J.C. and GODÍNEZ-SIORDIA, D.E. 2020. Polyculture of White shrimp (*Penaeus vannamei*) and sea cucumber (*Holothuria inornata*) in a biofloc system. *Aquac. Res.* **51**, 4410–4420.

CORRAL-ROSALES, D.C., PALACIOS, E., RICQUE-MARIE, D. and CRUZ-SUÁREZ, L.E. 2018. Enhancement of reproductive performance in shrimp *Litopenaeus vannamei* (Boone, 1931) by supplementation of *Ulva clathrata* meal in maturation diet in two commercial hatcheries. *Aquac. Res.* **49**, 1053–1059.

CORREIA, E.S., WILKENFELD, J.S., MORRIS, T.C., WEI, L., PRANGNELL, D.I. and SAMOCHA, T.M. 2014. Intensive nursery production of the Pacific white shrimp *Litopenaeus vannamei* using two commercial feeds with high and low protein content in a biofloc-dominated system. *Aquac. Eng.* **59**, 48–54.

CORTEEL, M., DANTAS-LIMA, J.J., WILLE, M., ALDAY-SANZ, V., PENSAERT, M.B., SORGELOOS, P. and NAUWYNCK, H.J. 2012. Moult cycle of laboratory-raised *Penaeus* (*Litopenaeus*) *vannamei* and *P. monodon*. Aquac. Int. 20, 13–18.

CRAB, R., DEFOIRDT, T., BOSSIER, P. and VERSTRAETE, W. 2012. Biofloc technology in aquaculture: Beneficial effects and future challenges. *Aquaculture* **356–357**, 351–356.

DABRAMO, L.R., PEREZ, E.I., SANGHA, R. and PUELLO-CRUZ, A. 2006. Successful culture of larvae of *Litopenaeus vannamei* fed a microbound formulated diet exclusively from either stage PZ2 or M1 to PL1. *Aquaculture* **261**, 1356–1362.

DAVID, F. 2019. A worldwide reliable indicator to differentiate wild vs. farmed Penaeid shrimps based on 207 fatty acid profiles. *Food Chem.* **292**, 247–252.

DE ANDRADE, R.J.V., DOS SANTOS, E.P., DE ALMEIDA COSTA, G.K., CAMPOS, C.V.F. DA S., DA SILVA, S.M.B.C., GÁLVEZ, A.O. and BRITO, L.O. 2021. Effect of different frequencies of the addition of *Brachionus plicatilis* on the performance of *Litopenaeus vannamei* in a nursery biofloc system with rice bran (anaerobic and aerobic) as an organic carbon source. *Aquaculture* **540**. https://doi.org/10.1016/j.aquaculture.2021.736669

DE OLIVEIRA COSTA, L.C., XAVIER, J.A.A., DE MATOS NEVES, L.F., DE AZAMBUJA, A.M.V., JUNIOR, W.W. and FIGUEIREDO, M.R.C. 2013. Polyculture of *Litopenaeus vannamei* shrimp and *Mugil platanus* mullet in earthen ponds. *Rev. Bras. Zootec.* **42**, 605–611.

DE SCHRYVER, P., CRAB, R., DEFOIRDT, T., BOON, N. and VERSTRAETE, W. 2008. The basics of bio-flocs technology: The added value for aquaculture. *Aquaculture* **277**, 125–137.

DE YTA, A.G., ROUSE, D.B. and DAVIS, D.A. 2004. Influence of nursery period on the growth and survival of *Litopenaeus vannamei* under pond production conditions. *J. World Aquac. Soc.* **35**, 357–365.

EFFENDI, I., SUPRAYUDI, M.A., SURAWIDJAJA, E.H., SUPRIYONO, ZAIRIN, E. and SUKENDA, M. 2016. Production performance of white shrimp (*Litopenaeus vannamei*) under sea floating net cages with biofloc and periphyton juvenile. *AACL Bioflux* **9**, 823–832.

EL-SAYED, A.F.M. 2021. Use of biofloc technology in shrimp aquaculture: a comprehensive review, with emphasis on the last decade. *Rev. Aquac.* **13**, 676–705.

EMERENCIANO, M.G.C., MARTÍNEZ-PORCHAS, L.R.M.-C.M. and MIRANDA-BAEZA, A. 2017. Biofloc technology (BFT): A Tool for water quality management in aquaculture. Intech. https://doi.org/http://dx.doi.org/10.5772/66416

DoF, 2002. Fishery statistical yearbook of Bangladesh 2001-2002. Fisheries Resources Survey System, Department of Fisheries. Department of Fisheries. Bangladesh : Ministry of Fisheries. p. 41.

DoF, 2007. Fisheries statistical yearbook of Bangladesh 2007-2008 (July 2007- June 2008). Twenty Fifth Edition Fisheries Resources Survey System. Department of Fisheries Ministry of Fisheries and Livestock. p. 49.

DoF, 2020. Yearbook Of Fisheries Statistics of Bangladesh 2019-20. Fisheries Resources Survey System (FRSS), Department of Fisheries. Bangladesh: Ministry of Fisheries and Livestock. p. 141.

ESPARZA-LEAL, H.M., CARDOZO, A.P. and WASIELESKY, W. 2015. Performance of *Litopenaeus vannamei* postlarvae reared in indoor nursery tanks at high stocking density in clear-water versus biofloc system. *Aquac. Eng.* 68, 28–34.

ESPARZA-LEAL, H.M., VALENZUELA-QUIÑÓNEZ, W., PONCE-PALAFOX, J.T., BELTRÁN, H.C. and FIGUEROA, J.L.A. 2009. The effect of low salinity water with different ionic composition on the growth and survival of *Litopenaeus vannamei* (Boone, 1931) in intensive culture. *J. Appl. Aquac.* **21**, 215–227.

FAÇANHA, F.N., SABRY-NETO, H., FIGUEIREDO-SILVA, C., OLIVEIRA-NETO, A.R. and NUNES, A.J.P. 2018. Minimum water exchange spares the requirement for dietary methionine for juvenile *Litopenaeus vannamei* reared under intensive outdoor conditions. *Aquac. Res.* **49**, 1682–1689.

FAKHRI, M., BUDIANTO, B., YUNIARTI, A. and HARIATI, A.M. 2015. Variation in water quality at different intensive Whiteleg shrimp, *Litopenaeus vannamei*, farms in East Java, Indonesia. *Nat. Environ. Pollut. Technol.* **14**, 65–70.

FAO, 2020. The State of World Fisheries and Aquaculture 2020. Sustainibility in action, Food and Agriculture Organization of the United Nations, Rome. https://doi.org/10.4060/ca9229en

FLECKENSTEIN, L.J., TIERNEY, T.W., FISK, J.C. and RAY, A.J. 2022. Using alternative low-cost artificial sea salt mixtures for intensive, indoor shrimp (*Litopenaeus vannamei*) production. *Aquac. Reports* **24**, 101147.

FLECKENSTEIN, L.J., TIERNEY, T.W., FISK, J.C. and RAY, A.J. 2019. Effects of supplemental LED lighting on water quality and Pacific white shrimp (*Litopenaeus vannamei*) performance in intensive recirculating systems. *Aquaculture* **504**, 219–226.

FRSS, 2012. Fisheries Statistical Yearbook of Bangladesh. Fisheries Resources Survey System (FRSS), Department of Fisheries, Bangladesh. p. 46.

FURTADO, P.S., POERSCH, L.H. and WASIELESKY, W. 2011. Effect of calcium hydroxide, carbonate and sodium bicarbonate on water quality and zootechnical performance of shrimp *Litopenaeus vannamei* reared in bio-flocs technology (BFT) systems. *Aquaculture* **321**, 130–135.

GAONA, C.A.P., DE ALMEIDA, M.S., VIAU, V., POERSCH, L.H. and WASIELESKY, W. 2017. Effect of different total suspended solids levels on a *Litopenaeus vannamei* (Boone, 1931) BFT culture system during biofloc formation. *Aquac. Res.* **48**, 1070–1079.

GE, H. XING, NI, Q., LI, JIAN, LI, JI TAO, CHEN, ZHAO, Z. and ZHEN, F. 2019. Integration of white shrimp (*Litopenaeus vannamei*) and green seaweed (*Ulva prolifera*) in minimum-water exchange aquaculture system. *J. Appl. Phycol.* **31**, 1425–1432.

GHORBANI VAGHEI, R., ABOLHASANI, M.H., GHORBANI, R. and MATINFAR, A. 2017. Production of soybean meal-based feed and its effect on growth performance of western white shrimp (*Litopenaeus vannamei*) in earthen pond. *Iran. J. Fish. Sci.* **16**, 578–586.

GOMES VILANI, F., SCHVEITZER, R., DA FONSECA ARANTES, R., DO NASCIMENTO VIEIRA, F., MANOEL DO ESPÍRITO SANTO, C. and QUADROS SEIFFERT, W. 2016. Strategies for water preparation in a biofloc system: Effects of carbon source and fertilization dose on water quality and shrimp performance. *Aquac. Eng.* **74**, 70–75.

GONZÁLEZ-DAVIS, O., PONCE-RIVAS, E., SÁNCHEZ-SAAVEDRA, M.D.P., MUÑOZ-MÁRQUEZ, M.E. and GERWICK, W.H. 2012. Bioprospection of microalgae and cyanobacteria as biocontrol agents against *Vibrio campbellii* and their use in White Shrimp *Litopenaeus vannamei* culture. *J. World Aquac. Soc.* **43**, 387–399.

GOU, J., HONG, C.U., DENG, M., CHEN, J., HOU, J., LI, D. and HE, X. 2019. Effect of carbon to nitrogen ratio on water quality and community structure evolution in suspended growth bioreactors through biofloc technology. *Water* **11**, 1640. https://doi.org/10.3390/w11081640

GREEN, B.W. 2008. Stocking strategies for production of *Litopenaeus vannamei* (Boone) in amended freshwater in inland ponds. *Aquac. Res.* **39**, 10–17.

HAQUE, A. 2022. Whiteleg shrimp cultivation sees success in Khulna. Bus. Standerd https://www.tbsnews.net/economy/Whiteleg-shrimp-cu.

HOANG, M.N., NGUYEN, P.N. and BOSSIER, P. 2020. Water quality, animal performance, nutrient budgets and microbial community in the biofloc-based polyculture system of white shrimp, *Litopenaeus vannamei* and gray mullet, *Mugil cephalus*. *Aquaculture* **515**, 734610.

HOLANDA, M., SANTANA, G., FURTADO, P., RODRIGUES, R.V., CERQUEIRA, V.R., SAMPAIO, L.A., WASIELESKY, W. and POERSCH, L.H. 2020. Evidence of total suspended solids control by *Mugil liza* reared in an integrated system with pacific white shrimp *Litopenaeus vannamei* using biofloc technology. *Aquac. Reports* **18**. https://doi.org/10.1016/j.aqrep.2020.100479

HOSAIN, M.E., AMIN, S.M.N., ARSHAD, A., KAMARUDIN, M.S. and KARIM, M. 2021a. Effects of carbon sources on the culture of giant river prawn in biofloc system during nursery phase. *Aquac. Reports* **19**, 100607.

HOSAIN, M.E., AMIN, S.M.N., KAMARUDIN, M.S., ARSHAD, A., KARIM, M. and ROMANO, N. 2021b. Effect of salinity on growth, survival, and proximate composition of *Macrobrachium rosenbergii* post larvae as well as zooplankton composition reared in a maize starch based biofloc system. *Aquaculture* **533**, 736235.

HOSAIN, M.E., AMIN, S.M.N., KAMARUDIN, M.S., ARSHAD, A. and ROMANO, N. 2021c. Effects of C- N ratio on growth, survival and proximate composition of *Macrobrachium rosenbergii* post larvae reared under a corn starch based zero- exchange brackish water biofloc system. *Aquaculture* **52**, 3015-3025.

HUANG, H.H., LIAO, H.M., LEI, Y.J. and YANG, P.H. 2022. Effects of different carbon sources on growth performance of *Litopenaeus vannamei* and water quality in the biofloc system in low salinity. *Aquaculture* **546**, 737239.

IBA, W., RICE, M.A. and WIKFORS, G.H. 2014. Microalgae in Eastern Pacific White Shrimp, *Litopenaeus vannamei* (Boone 1931) hatcheries: A Review on roles and culture environments. *Asian Fish. Sci.* **27**, 212–233.

ISLAM, M.N. 2022. Trial farming of vannamei shrimp to begin in Chattogram. Daily Star.MAy 22, 2022.https://www.thedailystar.net/business/economy/news/trial-vannamei-shrimp-farming-begin-ctg-3029651 Accessed on 10 June 2022.

IZQUIERDO, M., FORSTER, I., DIVAKARAN, S., CONQUEST, L., DECAMP, O. and TACON, A. 2006. Effect of green and clear water and lipid source on survival, growth and biochemical composition of Pacific white shrimp *Litopenaeus vannamei. Aquac. Nutr.* **12**, 192–202.

JAMALI, H., AHMADIFARD, N. and ABDOLLAHI, D. 2015. Evaluation of growth, survival and body composition of larval white shrimp (*Litopenaeus vannamei*) fed the combination of three types of algae. *Int. Aquat. Res.* **7**, 115–122.

JORY, D. and CABRERA, T. 2012. Marine shrimp. In: Lucas, J.S., Southgate, P.C. (Eds.), Aquaculture: Farming Aquatic Animals and Plants. Blackwell Publishing Ltd, Oxford. pp. 476–513.

JORY, DARRYL, E. 2018. Current production, challenges and the future of shrimp farming. *Glob. Aquac. Alliance,* 1–8.

JU, Z.Y., DENG, D.F. and DOMINY, W. 2012. A defatted microalgae (*Haematococcus pluvialis*) meal as a protein ingredient to partially replace fishmeal in diets of Pacific white shrimp (*Litopenaeus vannamei*, Boone, 1931). *Aquaculture* **354–355**, 50–55.

JU, Z.Y., FORSTER, I., CONQUEST, L., DOMINY, W., KUO, W.C. and DAVID HORGEN, F. 2008. Determination of microbial community structures of shrimp floc cultures by biomarkers and analysis of floc amino acid profiles. *Aquac. Res.* **39**, 118–133.

JU, Z.Y., FORSTER, I.P. and DOMINY, W.G. 2010. Effects of supplementing bioactive compounds to a formulated diet on sensory compounds and growth of shrimp, *Litopenaeus vannamei* (Boone, 1931). *Aquac. Res.* **41**, 1421–1431.

JUNDA, M. 2018. Development of intensive shrimp farming, *Litopenaeus vannamei* in land-based ponds: Production and management. *J. Phys. Conf. Ser.* **1028**. https://doi.org/10.1088/1742-6596/1028/1/012020

JUNIOR, A.P.B., FLICKINGER, D.L. and HENRY-SILVA, G.G. 2021. Sedimentation rates of nutrients and particulate material in pond mariculture of shrimp (*Litopenaeus vannamei*) carried out with different management strategies. *Aquaculture* **534**, 736307.

KESSELRING, J.C., GRUBER, C., STANDEN, B. and WEIN, S. 2019. Continuous and pulse-feeding application of multispecies probiotic bacteria in Whiteleg shrimp, *Litopenaeus vannamei. J. World Aquac. Soc.* **50**, 1123–1132.

KHADEMZADE, O., ZAKERI, M., HAGHI, M. and MOUSAVI, S.M. 2020. The effects of water additive *Bacillus cereus* and *Pediococcus acidilactici* on water quality, growth performances, economic benefits, immunohematology and bacterial flora of Whiteleg shrimp (*Penaeus vannamei* Boone, 1931) reared in earthen ponds. *Aquac. Res.* **51**, 1759–1770.

KHANJANI, M.H., MOZANZADEH, M.T. and FÓES, G.K. 2022. Aquamimicry system: a sutiable strategy for shrimp aquaculture – a review. *Ann. Anim. Sci.* **22**, 1201–1210.

KHANJANI, M.H., SAJJADI, M.M., ALIZADEH, M. and SOURINEJAD, I. 2017. Nursery performance of Pacific white shrimp (*Litopenaeus vannamei* Boone, 1931) cultivated in a biofloc system: the effect of adding different carbon sources. *Aquac. Res.* **48**, 1491–1501.

KHANJANI, M.H. and SHARIFINIA, M. 2022. Biofloc technology with addition molasses as carbon sources applied to *Litopenaeus vannamei* juvenile production under the effects of different C/N ratios. *Aquac. Int.* **30**, 383–397.

KHANJANI, M.H. and SHARIFINIA, M. 2020. Biofloc technology as a promising tool to improve aquaculture production. *Rev. Aquac.* **12**, 1836–1850.

KRUMMENAUER, D., CAVALLI, R.O., BALLESTER, E.L.C. and WASIELESKY, W. 2010. Feasibility of pacific white shrimp *Litopenaeus vannamei* culture in southern Brazil: Effects of stocking density and a single or a double CROP management strategy in earthen ponds. *Aquac. Res.* **41**, 240–248.

KRUMMENAUER, D., PEIXOTO, S., CAVALLI, R.O., POERSCH, L.H. and WASIELESKY, W. 2011. Superintensive culture of white shrimp, *Litopenaeus vannamei*, in a biofloc technology system in Southern Brazil at different stocking densities. *J. World Aquac. Soc.* **42**, 726–733.

KUMARAN, M., SUNDARAM, M., MATHEW, S., ANAND, P.R., GHOSHAL, T.K., KUMARARAJA, P., ANANDARAJA, R., ANAND, S. and VIJAYAN, K.K. 2021. Is Pacific white shrimp (*Penaeus vannamei*) farming in India sustainable? A multidimensional indicators-based assessment. *Environ. Dev. Sustain.* **23**, 6466–6480.

LEGARDA, E.C., ARANHA MARTINS, M., MOREIRA PEREIRA, P.K., SIQUEIRA CARNEIRO, R.F., PINHEIRO, I.C., SEIFFERT, W.Q., MACHADO, C., DE LORENZO, M.A. and VIEIRA, F. DO N. 2020. Shrimp rearing in biofloc integrated with different mullet stocking densities. *Aquac. Res.* **51**, 3571–3581.

LEGARDA, E.C., DA SILVA, D., MIRANDA, C.S., PEREIRA, P.K.M., MARTINS, M.A., MACHADO, C., DE LORENZO, M.A., HAYASHI, L. and DO NASCIMENTO VIEIRA, F. 2021. Sea lettuce integrated with Pacific white shrimp and mullet cultivation in biofloc impact system performance and the sea lettuce nutritional composition. *Aquaculture* **534**, 736265.

LEGARDA, E.C., POLI, M.A., MARTINS, M.A., PEREIRA, S.A., MARTINS, M.L., MACHADO, C., DE LORENZO, M.A. and DO NASCIMENTO VIEIRA, F. 2019. Integrated recirculating aquaculture system for mullet and shrimp using biofloc technology. *Aquaculture* **512**, 734308.

LEITE, J.S., MELO, C.S.B. and NUNES, A.J.P. 2020. Utilization of rice byproducts as carbon sources in high-density culture of the Pacific white shrimp, *Litopenaeus vannamei*. *Rev. Bras. Zootec.* **49**, e20190039. https://doi.org/10.37496/RBZ4920190039

LIAO, I.C. and CHIEN, Y. 2011. The Pacific White Shrimp, *Litopenaeus vannamei*, in Asia: The World's Most Widely Cultured Alien Crustacean, B.S. Galil et al. (eds.), In the Wrong Place - Alien Marine Crustaceans: Distribution, Biology and Impacts. Nature-Springer Series in Invasion Ecology 6. https://doi.org/10.1007/978-94-007-0591-3

LIGHTNER, D. V. 2020. Bangladesh government grants permission for vannamei pilot farms. SeafoodSource https://www.seafoodsource.com/news/aquaculture/ban.

LIGHTNER, D. V. 2011. Status of shrimp diseases and advances in shrimp health management, in: Diseases in Asian Aquaculture. pp. 121–133.

LIMA, P.C.M., SILVA, A.E.M., SILVA, D.A., SILVA, S.M.B.C., BRITO, L.O. and GÁLVEZ, A.O. 2021. Effect of stocking density of *Crassostrea* sp. in a multitrophic biofloc system with *Litopenaeus vannamei* in nursery. *Aquaculture* **530**, 735913.

LIU, G., ZHU, S., LIU, D., GUO, X. and YE, Z. 2017. Effects of stocking density of the white shrimp

Litopenaeus vannamei (Boone) on immunities, antioxidant status, and resistance against *Vibrio harveyi* in a biofloc system. *Fish Shellfish Immunol.* **67**, 19–26.

LIU, L., HU, Z., DAI, X. and AVNIMELECH, Y. 2014. Effects of addition of maize starch on the yield, water quality and formation of bioflocs in an integrated shrimp culture system. *Aquaculture* **418–419**, 79–86.

LLARIO, F., FALCO, S., SEBASTIÁ-FRASQUET, M.T., ESCRIVÁ, J., RODILLA, M. and POERSCH, L.H. 2019. The role of *Bacillus amyloliquefaciens* on *Litopenaeus vannamei* during the maturation of a biofloc system. *J. Mar. Sci. Eng.* **7**, 1–17.

MAIA, E. DE P., MODESTO, G.A., BRITO, L.O., GALVEZ, A.O. and GESTEIRA, T.C.V. 2016. Intensive culture system of *Litopenaeus vannamei* in commercial ponds with zero water exchange and addition of molasses and probiotics. *Rev. Biol. Mar. Oceanogr.* **51**, 61–67.

MAICA, P.F., BORBA, M.R. DE and JR, W.W. 2012. Effect of low salinity on microbial floc composition and performance of *Litopenaeus vannamei* (Boone) juveniles reared in a zero-water-exchange super-intensive system. *Aquac. Res.* **43**, 361–370.

MAGAÑA-GALLEGOS, E., ARÉVALO, M., CUZON, G. and GAXIOLA, G. 2021. Effects of using the biofloc system and eyestalk ablation on reproductive performance and egg quality of *Litopenaeus vannamei* (Boone, 1931) (Decapoda: Dendrobranchiata: Penaeidae). *Anim. Reprod. Sci.* **228**, 1–10.

MARÍN-RIFFO, M.C., RAADSMA, H.W., JERRY, D.R., COMAN, G.J. and KHATKAR, M.S. 2021. Bioeconomic modelling of hatchery, grow-out and combined business of Australian black tiger shrimp *Penaeus monodon* farming. *Rev. Aquac.* **13**, 1695–1708.

MARISCAL-LAGARDA, M.M., PÁEZ-OSUNA, F., ESQUER-MÉNDEZ, J.L., GUERRERO-MONROY, I., DEL VIVAR, A.R. and FÉLIX-GASTELUM, R. 2012. Integrated culture of white shrimp (*Litopenaeus vannamei*) and tomato (*Lycopersicon esculentum* Mill) with low salinity groundwater: Management and production. *Aquaculture* **366–367**, 76–84.

MARTINEZ-CORDOVA, L.R., CAMPAÑA-TORRES, A. and PORCHAS-CORNEJO, M.A. 2002. The effects of variation in feed protein level on the culture of white shrimp, *Litopenaeus vannamei* (Boone) in low-water exchange experimental ponds. *Aquac. Res.* **33**, 995–998.

MARTINEZ-CORDOVA, L.R. and MARTINEZ-PORCHAS, M. 2006. Polyculture of Pacific white shrimp, *Litopenaeus vannamei*, giant oyster, *Crassostrea gigas* and black clam, *Chione fluctifraga* in ponds in Sonora, Mexico. *Aquaculture* **258**, 321–326.

MARTINS, M.A., POLI, M.A., LEGARDA, E.C., PINHEIRO, I.C., CARNEIRO, R.F.S., PEREIRA, S.A., MARTINS, M.L., GONÇALVES, P., SCHLEDER, D.D. and DO NASCIMENTO VIEIRA, F. 2020. Heterotrophic and mature biofloc systems in the integrated culture of Pacific white shrimp and Nile tilapia. *Aquaculture* **514**, 734517.

MARÍN-RIFFO, M.C., RAADSMA, H.W., JERRY, D.R., COMAN, G.J. and KHATKAR, M.S. 2021. Bioeconomic modelling of hatchery, grow-out and combined business of Australian black tiger shrimp *Penaeus monodon* farming. *Rev. Aquac.* **13**, 1695–1708.

MAULANA, F., ARFAH, H., ISTIFARINI, M. and SETIAWATI, M. 2017. Supplementation of astaxanthin and vitamin E in feed on the development of gonads white shrimp broodstock. *J. Akuakultur Indones.* **16**, 124–135.

MEDINA-REYNA, C. E. and CHAVEZ-SANCHEZ, C.A.M.P. 2000. Evaluation of a microbound spray-dried feed for the rearing of penaeid shrimp larvae. *N. Am. J. Aquac.* **62**, 73–77.

MENDOZA-LÓPEZ, D.G., CASTAÑEDA-CHÁVEZ, M.R., LANGO-REYNOSO, F., GALAVIZ-VILLA, I., MONTOYA-MENDOZA, J., PONCE-PALAFOX, J.T., ESPARZA-LEAL, H.M. and ARENAS-FUENTES, V. 2017. The effect of biofloc technology (BFT) on water quality in white shrimp *Litopenaeus vannamei* culture: A review. *Rev. Bio Ciencias* **4**, 1–15.

MISAMORE, M.J. and BROWDY, C.L. 1996. Mating behavior in the white shrimps *Penaeus setiferus* and *P. vannamei* a generalized model for mating in *Penaeus*. J. Crustac. Biol. 16, 61–70.

MISHRA, J.K., SAMOCHA, T.M., PATNAIK, S., SPEED, M., GANDY, R.L. and ALI, A.M. 2008. Performance of an intensive nursery system for the Pacific white shrimp, *Litopenaeus vannamei*, under limited discharge condition. *Aquac. Eng.* **38**, 2–15.

MOHANTY, R.K., AMBAST, S.K., PANIGRAHI, P. and MANDAL, K.G. 2018. Water quality suitability and water use indices: Useful management tools in coastal aquaculture of *Litopenaeus vannamei*. *Aquaculture* **485**, 210–219.

MOSS, S.M., ARCE, S.M., MOSS, D.R. and OTOSHI, C.A. 2003. Disease prevention strategies for Penaeid Shrimp Culture. *Anonime* 1–12.

MOURA, P.S. DE, WASIELESKY, W., SERRA, F. DA P., BRAGA, A. and POERSCH, L. 2021. Partial seawater inclusion to improve *Litopenaeus vannamei* performance in low salinity biofloc systems. *Aquaculture* **531**, 735905.

NERY, R.C., COSTA, C.B., RODRIGUES, F., SOARES, R., BEZERRA, R. DE S. and PEIXOTO, S. 2019. Effect of feeding frequency on growth and digestive enzyme activity in *Litopenaeus vannamei* during the grow-out phase in biofloc system. *Aquac. Nutr.* **25**, 577–584.

NEW AGE, 2022. BTTC seeks commercial production approval for Vannamei shrimps. New AGE 1–5.

NISAR, U., PENG, D., MU, Y. and SUN, Y. 2022. A Solution for sustainable utilization of aquaculture waste: A comprehensive review of biofloc technology and aquamimicry. *Front. Nutr.* **8**, 1–15.

NISAR, U., ZHANG, H., NAVGHAN, M., ZHU, Y. and MU, Y. 2021. Comparative analysis of profitability and resource use efficiency between *Penaeus monodon* and *Litopenaeus vannamei* in India. *PLoS One* **16**, 1–19.

OTOSHI, C.A., MOSS, D.R. and MOSS, S.M. 2011. Growth-enhancing effect of pond water on four size classes of pacific white shrimp, *Litopenaeus vannamei. J. World Aquac. Soc.* **42**, 417–422.

PANIGRAHI, A., SARANYA, C., SUNDARAM, M., VINOTH KANNAN, S.R., DAS, R.R., SATISH KUMAR, R., RAJESH, P. and OTTA, S.K. 2018. Carbon: Nitrogen (C:N) ratio level variation influences microbial community of the system and growth as well as immunity of shrimp (*Litopenaeus vannamei*) in biofloc based culture system. *Fish Shellfish Immunol.* **81**, 329–337.

PANIGRAHI, A., SUNDARAM, M., CHAKRAPANI, S., RAJASEKAR, S., SYAMA DAYAL, J. and CHAVALI, G. 2019. Effect of carbon and nitrogen ratio (C:N) manipulation on the production performance and immunity of Pacific white shrimp *Litopenaeus vannamei* (Boone, 1931) in a biofloc-based rearing system. *Aquac. Res.* **50**, 29–41.

PEIXOTO, S., SILVA, E., COSTA, C.B., NERY, R.C., RODRIGUES, F., SILVA, J.F., BEZERRA, R. and SOARES, R. 2018. Effect of feeding frequency on growth and enzymatic activity of *Litopenaeus vannamei* during nursery phase in biofloc system. *Aquac. Nutr.* **24**, 579–585.

PEIXOTO, S., WASIELESKY, W. and LOUZADA, L. 2003. Comparative analysis of pink shrimp, *Farfantepenaeus paulensis*, and pacific white shrimp, *Litopenaeus vannamei*, culture in extreme Southern Brazil. *J. Appl. Aquac.* **14**, 101–111.

PIÑA, P., VOLTOLINA, D., NIEVES, M. and ROBLES, M. 2006. Survival, development and growth of the Pacific white shrimp *Litopenaeus vannamei* protozoea larvae, fed with monoalgal and mixed diets. *Aquaculture* **253**, 523–530.

PINHEIRO, I., CARNEIRO, R.F.S., VIEIRA, F. DO N., GONZAGA, L.V., FETT, R., COSTA, A.C. DE O., MAGALLÓN-BARAJAS, F.J. and SEIFFERT, W.Q. 2020. Aquaponic production of *Sarcocornia ambigua* and Pacific white shrimp in biofloc system at different salinities. *Aquaculture* **519**, 734918.

PINTO, P.H.O., ROCHA, J.L., DO VALE FIGUEIREDO, J.P., CARNEIRO, R.F.S., DAMIAN, C., DE OLIVEIRA, L. and SEIFFERT, W.Q. 2020. Culture of marine shrimp (*Litopenaeus vannamei*) in biofloc technology system using artificially salinized freshwater: Zootechnical performance, economics and nutritional quality. *Aquaculture* **520**, 734960.

POLI, M.A., LEGARDA, E.C., DE LORENZO, M.A., PINHEIRO, I., MARTINS, M.A., SEIFFERT, W.Q. and NASCIMENTO VIEIRA, F. 2019. Integrated multitrophic aquaculture applied to shrimp rearing in a biofloc system. *Aquaculture* **511**, 1–6.

PORCHAS-CORNEJO, M.A., MARTÍNEZ-PORCHAS, M., MARTÍNEZ-CÓRDOVA, L.R., RAMOS-TRUJILLO, L. and BARRAZA-GUARDADO, R. 2014. Consumption of Natural and Artificial Foods by Shrimp (*Litopenaeus vannamei*) Reared in Ponds with and without Enhancement of Natural Productivity. *Isr. J. Aquac. Bamidgeh*, **64**, 2012.709

PRANGNELL, D.I., CASTRO, L.F., ALI, A.S., BROWDY, C.L. and SAMOCHA, T.M. 2022. The performance of juvenile *Litopenaeus vannamei* fed commercial diets of differing protein content, in a super-intensive biofloc-dominated system. *J. Appl. Aquac.* **34**, 1–22.

RAHMAWATI, A.I., SAPUTRA, R.N., HIDAYATULLAH, A., DWIARTO, A., JUNAEDI, H., CAHYADI, D., SAPUTRA, H.K.H., PRABOWO, W.T., KARTAMIHARJA, U.K.A., SHAFIRA, H., NOVIYANTO, A. and ROCHMAN, N.T. 2020. Enhancement of *Penaeus vannamei* shrimp growth using nanobubble in indoor raceway pond. *Aquac. Fish.* **6**, 277–282.

RAJKUMAR, M., PANDEY, P.K., ARAVIND, R., VENNILA, A., BHARTI, V. and PURUSHOTHAMAN, C.S. 2016. Effect of different biofloc system on water quality, biofloc composition and growth performance in *Litopenaeus vannamei* (Boone, 1931). *Aquac. Res.* **47**, 3432–3444.

RAY, A.J., DILLON, K.S. and LOTZ, J.M. 2011. Water quality dynamics and shrimp (*Litopenaeus vannamei*) production in intensive, mesohaline culture systems with two levels of biofloc management. *Aquac. Eng.* **45**, 127–136.

RAY, A.J. and LOTZ, J.M. 2014. Comparing a chemoautotrophic-based biofloc system and three heterotrophic-based systems receiving different carbohydrate sources. *Aquac. Eng.* **63**, 54–61.

REID, B. and ARNOLD, C.R. 1992. The intensive culture of the Penaeid Shrimp *Penaeus vannamei* Boone in a Recirculating Raceway System. *J. World Aquac. Soc.* **23**, 146–153.

ROBLES-PORCHAS, G.R., GOLLAS-GALVÁN, T., MARTÍNEZ-PORCHAS, M., MARTÍNEZ-CORDOVA, L.R., MIRANDA-BAEZA, A. and VARGAS-ALBORES, F. 2020. The nitrification process for nitrogen removal in biofloc system aquaculture. *Rev. Aquac.* 12, 2228–2249.

RODRÍGUEZ, E.O., LÓPEZ-ELÍAS, J.A., AGUIRRE-HINOJOSA, E., GARZA-AGUIRRE, M.D.C., CONSTANTINO-FRANCO, F., MIRANDA-BAEZA, A. and NIEVES-SOTO, M. 2012. Evaluation of the nutritional quality of *Chaetoceros muelleri* schütt (Chaetocerotales: Chaetocerotaceae) and *Isochrysis* sp. (Isochrysidales: Isochrysidaceae) grown outdoors for the larval development of *Litopenaeus vannamei* (Boone, 1931) (Decapoda: Penaei. Arch). *Biol. Sci.* **64**, 963–970.

ROJO-ARREOLA, L., GARCÍA-CARREÑO, F., ROMERO, R. and DOMINGUEZ, L.D. 2020. Proteolytic profile of larval developmental stages of *Penaeus vannamei*: An activity and mRNA expression approach. PLoS One 15, 1–16.

ROMANO, N. 2017. Aquamimicry: A revolutionary concept for shrimp farming. *Global Seafood Alli.* 1–8.

ROY, D. 2021. Experimental vannamei shrimp cultivation underway producers aim to revive exports. Dly. Star.

ROY, L.A., TEICHERT-CODDINGTON, D., BECK, B.H., DAHL, S., JAMES, J., GUO, J. and DAVIS, D.A. 2020. Evaluation of stocking density and dietary fish meal inclusion for intensive tank production of Pacific White Shrimp *Litopenaeus vannamei* cultured in low-salinity waters of Western Alabama. *N. Am. J. Aquac.* **82**, 345–353.

SAMOCHA, T.M., LAWRENCE, A.L., COLLINS, A., CASTILLE, F.L., BRAY, W.A., DAVIES, C.J., LEE, P.G. and WOOD, G.F. 2004. Production of the Pacific White Shrimp, *Litopenaeus vannamei* in high-density greenhouse- enclosed raceways using low salinity groundwater. *J. Appl. Aquac.* **15**, 1–19.

SANGHA, R.S., CRUZ, A.C.P., CHAVEZ-SANCHEZ, M.C. and JONES, D.A. 2000. Survival and growth of *Litopenaeus vannamei* (Boone) larvae fed a single dose of live algae and artificial diets with supplements. *Aquac. Res.* **31**, 683–689.

SANTHANAM, P. and PERUMAL, P. 2020. Biofloc-copefloc : A novel technology towards sustained aquaculture. *J. Indian Soc. Coast. Agric.* **2**, 43–50.

SARKAR, S., REKHA, P.N., PANIGRAHI, A., DAS, R.R., RAJAMANICKAM, S. and BALASUBRAMANIAN, C.P. 2021. Integrated brackishwater farming of red seaweed *Agarophyton tenuistipitatum* and Pacific white shrimp *Litopenaeus vannamei* (Boone) in biofloc system: a production and bioremediation way out. *Aquac. Int.* **29**, 2145–2159.

SHEKHAR, M.S., KATNENI, V.K., JANGAM, A.K., KRISHNAN, K., KAIKKOLANTE, N. and VIJAYAN, K.K. 2021. The Genomics of the farmed shrimp: Current status and application. *Rev. Fish. Sci. Aquac.* **29**, 654–665.

SILVA, D.A., DE LIMA, P.C.M., DA SILVA, A.E.M., DE OLIVEIRA FILHO, P.R.C., DA SILVA, S.M.B.C., OLIVERA GÁLVEZ, A. and BRITO, L.O. 2021. Effects of adding rotifers on the water quality, plankton composition and growth of Pacific white shrimp, *Litopenaeus vannamei* juvenile, when cultured with biofloc technology. *Aquac. Res.* **52**, 4380–4393.

SILVA, E., SILVA, J., FERREIRA, F., SOARES, M., SOARES, R. and PEIXOTO, S. 2015. Influence of stocking density on the zootechnical performance of *Litopenaeus vannamei* during the nursery phase in a biofloc system. *Bol. do Inst. Pesca* **41**, 777–783.

SUANTIKA, G., SITUMORANG, M.L., NURFATHURAHMI, A., TAUFIK, I., ADITIAWATI, P., YUSUF, N., AULIA, R. 2018. Application of indoor recirculation aquaculture system for White Shrimp (*Litopenaeus vannamei*) growout super-intensive culture at low salinity condition. *J. Aquac. Res. Dev.* **09**. https://doi.org/10.4172/2155-9546.1000530

SUANTIKA, G., SITUMORANG, M.L., SAPUTRA, F.I., PUTRI, S.L.E., PUTRI, S.P., ADITIAWATI, P., FUKUSAKI, E. 2020. Metabolite profiling of Whiteleg shrimp *Litopenaeus vannamei* from super-intensive culture in closed aquaculture systems: a recirculating aquaculture system and a hybrid zero water discharge–recirculating aquaculture system. *Metabolomics* **16**, 1–11.

SYAMALA, K., LAKRA, W.S., CHADHA, N.K., SAHU, N.P. and PRASAD, K.P. 2017. Effect of de-oiled oil palm kernel meal based biofloc system on growth and digestive enzyme activity of pacific white shrimp, *Litopenaeus vannamei. Int. J. Curr. Microbiol. Appl. Sci.* **6**, 1806–1816.

TAM, L.T., VAN CONG, N., THOM, L.T., HA, N.C., HANG, N.T.M., VAN MINH, C., VIEN, D.T.H. and HONG, D.D. 2021. Cultivation and biomass production of the diatom *Thalassiosira weissflogii* as a live feed for white-leg shrimp in hatcheries and commercial farms in Vietnam. *J. Appl. Phycol.* **33**, 1559–1577.

TANTU, A.G., SALAM, S. and ISHAK, M. 2020. Vaname shrimp cultivation (*Litopenaeus vannamei*) on high stocking densities in controlled ponds. *J. Aquac. Res. Dev.* **11**, 1–6.

THE BUSINESS POST, 2022. Vannamei shrimp trial farming gets permission again https://businesspostbd.com/news/vannamei-shrimp-tr.

THE FISH SITE, 2019. Bangladesh considers switching shrimp species. https://thefishsite.com/articles/bangladesh-consid.

TIERNEY, T.W., FLECKENSTEIN, L.J. and RAY, A.J. 2020. The effects of density and artificial substrate on intensive shrimp *Litopenaeus vannamei* nursery production. *Aquac. Eng.* **89**. https://doi.org/10.1016/j.aquaeng.2020.102063

TINH, T.H., KOPPENOL, T., HAI, T.N., VERRETH, J.A.J. and VERDEGEM, M.C.J. 2021. Effects of carbohydrate sources on a biofloc nursery system for Whiteleg shrimp (*Litopenaeus vannamei*). *Aquaculture* **531**. 735795. https://doi.org/10.1016/j.aquaculture.2020.735795

TOWERS, L. 2016. Management of intensive Vannamei shrimp ponds. *Fish Site*, 1–11.

ULLMAN, C., RHODES, M., HANSON, T., CLINE, D. and DAVIS, D.A. 2019. Effects of four different feeding techniques on the pond culture of Pacific White Shrimp, *Litopenaeus vannamei. J. World Aquac. Soc.* **50**, 54–64.

Venkateswarlu, V., P.S.P.A. and P.B. 2019. A study on water quality parameters in shrimp *L. vannamei* semi-intensive grow out culture farms in coastal districts of Andhra Pradesh, India. *Int. J. Fish. Aquat. Stud.* **7**, 394–399.

WANG, H., TENG, M., LIU, P., ZHAO, M., WANG, S., HU, J., BAO, Z. and ZENG, Q. 2022. Selection signatures of Pacific White Shrimp *Litopenaeus vannamei* revealed by whole-genome resequencing analysis. *Front. Mar. Sci.* **9**, 1–9.

WANG, Y.B., XU, Z.R. and XIA, M.S. 2005. The effectiveness of commercial probiotics in northern white shrimp *Penaeus vannamei* ponds. *Fish. Sci.* **71**, 1036–1041.

WEI, J., ZHANG, X., YU, Y., HUANG, H., LI, F. and XIANG, J. 2014. Comparative transcriptomic characterization of the early development in Pacific white shrimp *Litopenaeus vannamei. PLoS One* **9**, 1–13.

WYBAN, J. 2019. Selective Breeding of *Penaeus vannamei*: Impact on World Aquaculture and Lessons for Future. *J. Coast. Res.* **86**, 1–5.

XU, H., ZHANG, Y., LUO, K., MENG, X., LUAN, S., CAO, B., CHEN, B., LIANG, M. and KONG, J. 2017. Arachidonic acid in diets for early maturation stages enhances the final reproductive performances of Pacific white shrimp (*Litopenaeus vannamei*). *Aquaculture* **479**, 556–563.

XU, W., XU, Y., SU, H., HU, X., YANG, K., WEN, G. and CAO, Y. 2020. Characteristics of ammonia removal and nitrifying microbial communities in a Hybrid Biofloc-RAS for intensive *Litopenaeus vannamei* culture: A pilot-scale study. *Water* **12**, 1–17.

XU, W.J., MORRIS, T.C. and SAMOCHA, T.M. 2016. Effects of C/N ratio on biofloc development, water quality, and performance of *Litopenaeus vannamei* juveniles in a biofloc-based, high-density, zero-exchange, outdoor tank system. *Aquaculture* **453**, 169–175.

XU, W.J. and PAN, L.Q. 2013. Enhancement of immune response and antioxidant status of *Litopenaeus vannamei* juvenile in biofloc-based culture tanks manipulating high C/N ratio of feed input. *Aquaculture* **412–413**, 117–124.

YANG, D., WANG, C., KOU, N., XING, J., LI, X., ZHAO, H. and LUO, M. 2022. Gonadal maturation in *Litopenaeus vannamei* fed on four different polychaetes. *Aquac. Reports* **22**, 100920.

YOGEV, U. and GROSS, A. 2019. Reducing environmental impact of recirculating aquaculture systems by introducing a novel microaerophilic assimilation reactor: Modeling and proof of concept. *J. Clean. Prod.* **226**, 1042–1050.

ZACARIAS, S., CARBONI, S., DAVIE, A. and LITTLE, D.C. 2019. Reproductive performance and offspring quality of non-ablated Pacific white shrimp (*Litopenaeus vannamei*) under intensive commercial scale conditions. *Aquaculture* **503**, 460–466.

ZACARIAS, S., SCHVEITZER, R., ARANTES, R., GALASSO, H., PINHEIRO, I., ESPIRITO SANTO, C., VINATEA, L. 2019. Effect of different concentrations of potassium and magnesium on performance of *Litopenaeus vannamei* postlarvae reared in low-salinity water and a biofloc system. *J. Appl. Aquac.* **31**, 85–96.

ZENG, S., KHORUAMKID, S., KONGPAKDEE, W., WEI, D., YU, L., WANG, H., DENG, Z., WENG, S., HUANG, Z., HE, J. and SATAPORNVANIT, K. 2020. Dissimilarity of microbial diversity of pond water, shrimp intestine and sediment in Aquamimicry system. *AMB Express*, **10**. https://doi.org/10.1186/s13568-020-01119-y

ZHAO, D., PAN, L., HUANG, F., WANG, C. and XU, W. 2016. Effects of different carbon sources on bioactive compound production of biofloc, immune response, antioxidant level, and growth performance of *Litopenaeus vannamei* in zero-water exchange culture tanks. *J. World Aquac. Soc.* **47**, 566–576.

(Manuscript received on 30 June 2022 revised on 26 August, 2022)