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RECENT DEVELOPMENTS IN AQUACULTURE – A REVIEW

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Abstract

Towards the sustainable aquaculture production, more recent technologies have been developed in the past few years. The application of effectives microbes (EM) in controlling water quality, the application of biofloc technology, aquamimicry, black soldier fly (BSF) as supplemental protein feed, application of triploidy, polyploidy, vaccines, probiotic and prebiotic, Internet of Things (IoT) in monitoring the water quality in the farm operation, monosex culture and neo-female application also being applied in the aquaculture operation. The developments of these recent technologies were towards achieving the sustainable aquaculture production, prevention of the disease outbreak, help in increasing the yield of crops harvested as well as towards the green environmental developments. This review paper emphasizes the most recent technologies developed in aquaculture in the past few years until these days. The developments of the new technology in aquaculture also in order to support the sustainable development goals (SDGs) proposed by the United Nation focused on SDG1 (no poverty) and SDG2 (zero hunger) from the increase of aquaculture production achieved through the recent developed technology. Ultimately, this review paper can generate new knowledge and information to the aquaculturist and aquafarmers on the new technologies and developments in aquaculture which could help benefit in the cultures operation and increase production in the near future.

Key words: recent technologies, effective microbes, BSF, sustainability, environments, SDG goals

To ensure the sufficient seafood supply, aquaculture practices is the only way towards the safety and sustainable supply of seafood production (Yue and Shen, 2022). On top of that, aquaculture faces serious challenges such as environmental pollution, requiring a lot of workers, and disease outbreak where the new developed technology is a must to increase the aquaculture and fish production and towards its sustainability (Yue and Shen, 2022).

The development of biotechnology in fisheries and aquaculture is growing faster where it has been identified to help in increasing the fisheries production in the fisheries and aquaculture sector (Lakra and Ayyappan, 2003). El-Gayar (2008) identified that the application of advances in information technology (IT) such as computerized models, artificial intelligence, image processing and geographical information systems help for the better management of aquaculture facility and also become one of the regional planning in aquaculture development. Meanwhile the development of biotechnology included the application of synthetic hormone in fish breeding, monosex culture, polyploid, molecular biology, transgenesis and introduction of marine natural products where all of this development helps to revolutionize the aquaculture industry as well as playing a major role in biodiversity conservation (Lakra and Ayyappan, 2003). Besides that, the new technology such as genome editing, offshore farming, recirculating aquaculture systems, oral vaccination, Internet of Things may become the solution for more sustainable and profitable aquaculture production (Yue and Shen, 2022).

This review paper briefly introduces and emphasizes the most recent technology developments in aquaculture industry. The application of these new and mostly recent technologies helps increase the aquaculture production and profitability, helps for the better management of aquaculture industry as well as for the sustainable aquaculture production in the near future and also in supporting the sustainable developments goals (SDGs) towards no poverty and zero hunger. Figure 1 shows the new and most recent technologies developed that are discussed in this review paper.

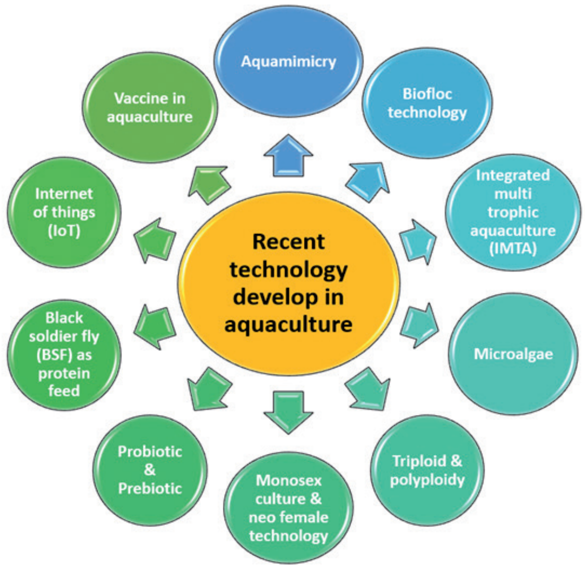

Figure 1. The most recent technologies developed in aquaculture

Aquamimicry

Aquamimicry is a new system that requires the addition of organic carbon without providing a specific C:N ratio. In this system, it provides a natural condition for the blooming of phytoplankton and zooplankton especially copepods (Khanjani et al., 2022 a). The appearance of these planktonic organisms acts as the supplementary food for the shrimp and through the proliferation of beneficial bacteria in aquamimicry system, it helps stabilize the water condition, and accelerate the growth performance of the shrimp as well (Khanjani et al., 2022 a). Aquamimicry stimulates the natural condition in the shrimp farming by stimulating the beneficial microbial to growth, flourishing the planktonic organisms such as phytoplankton and zooplankton especially copepods that can be used as supplementary food sources in the shrimp culture as well as helps in maintaining the good water quality condition (Romano, 2017). Aquamimicry will mimic the condition in the natural environments which help in creating the environmental stability and also help reducing the feeding cost (Panigrahi et al., 2019). In the aquamimicry system, the efficiency of the system depends on the carbon sources such as rice bran, soybean, and meal with the combination of probiotics bacteria usually from *Bacillus* sp. that help in enhancing the bloom of zooplankton especially copepods (Khanjani et al., 2022 a). The application of the fermented carbon sources (source of prebiotic derivatives such as oligosaccharides) with the probiotic (*Bacillus* sp.) helps in maintaining a good water quality and also helps in the recycling of the nitrogenous waste in the aquaculture system by the *Bacillus* sp. bacteria, thus helping to reduce the application of therapeutics and towards greener aquaculture technology (Deepak et al., 2020; Zeng et al., 2020).

In the aquamimicry system there is no requirement to adjust the C:N ratio as it only depends on the inclusion of the fermented carbon source and more probiotics can be added during the shrimp growth out condition which identified different with biofloc (BFT) system (Catalani, 2020). The addition of the fermented carbon sources is essential to develop the aquamimicry condition and flourish the zooplankton as in aquamimicry, the appearances of zooplankton such as copepod is more important in developing this system (Catalani, 2020). Rice bran is the most preferable as fermented carbon source as it is cheaper, easily obtained from markets, and contains high fiber and nutritional value (Deepak et al., 2020).

Aquamimicry technology is more dependent on the natural products especially copepod as the live feed sources to the shrimp which is known as "copefloc" technology (Deepak et al., 2020). Copepods have higher nutritional value than rotifer and are rich in fatty acids such as polyunsaturated fatty acids (PUFA) including arachidonic acid, eicosapentaenoic, high carotenoids, peptides, vitamins and minerals which are identified important for growth and developments of shrimp (Satoh et al., 2009; Taher et al., 2017). The appearance of copepod in the shrimp nursery culture system helped in improving the post-larvae (PL) growth performance, immune system and enhanced the feed conversion efficiency in the shrimp *Penaeus vannamei* PL (Abbaszadeh et al., 2022). In aquamimicry system, the rice bran was fermented with the probiotic and was added with water and hydrolyzing enzyme for 24 hours of fermentation. Fermentation was conducted at the rate 500 to 100 kg/ha and after a week the bloom of the live feed such as copepod can be observed (Khanjani et al., 2022 a). Figure 2 shows the advantages of the aquamimicry technology.

Figure 2. The advantages of aquamimicry technology in the aquaculture system

Biofloc technology

Biofloc is the most popular technology being applied worldwide in the aquaculture system as it is an environmentally friendly technology that helps in zero water exchange and also helps in reducing the frequent water exchange in the culture system (Avnimelech, 2007). Biofloc is an advanced technology that helps to sustain the aquaculture production by increasing the yield of shrimp production, supplemented animal diet, helps in promoting bioremediation and biodegradation process in order to maintain the water quality as well as reducing the amount of water exchange (Khanjani et al., 2022 c). In the biofloc technology, there are a lot of microorganisms which identified have their own function such as help in improving water quality, act as supplementary food source, create probiotic properties, and also become the main player for the successes of the aquatic farm system (Khanjani et al., 2022 c). Biofloc consists of varieties of microorganism such as heterotrophic bacteria, algae, fungi, protozoa, nematode and detritus that conglomerate together and produce a symbiotic process to help maintain the water quality and help support the high density of shrimp culture (Manan et al., 2017). In biofloc system, heterotrophic bacteria were identified as the most dominant bacteria compared to the nitrifying bacteria as they have a higher growth rate and also higher microbial biomass yield (Manan et al., 2017; Hargreaves, 2006). In the biofloc system the uneaten feed and feces substances were converted into microbial protein by heterotrophic bacteria with the addition of carbon sources and strong aeration system where the C/N ratio should be maintained between 10:1 and 20:1 (Yuvarajan, 2020).

There are various carbon sources that can be applied in the biofloc system such as wheat flour, corn flour, tapioca flour, rice bran, sweet potato, jaggery and molasses where the selection of the carbon sources should be cheaper and cost effective, besides also easily available in the market (Avnimelech, 2007; Yuvarajan, 2020). It was also discovered that biofloc shows a beneficial effect as it has beneficial nutritional properties, contributes to the exogenous digestive enzyme, has a potential to control the pathogens and is also beneficial in immunostimulant effects (El-Sayed, 2021). Biofloc also been suggested as a new alternative for the sustainable aquaculture production which could contribute to FAO sustainable development goal (SDGs), SDG 2 to end hunger related to food security (El-Sayed, 2021).

Table 1. The application of biofloc technology in the most recent study and its application in aquaculture operation

No.	Culture organisms	C:N ratio	Remarks, growth performance, survival, productivity, water quality effect	Reference
1	2	3	4	5
1.	Artemia culture	C:N ratio 10:1, using glucose as carbon sources	Glucose improved artemia biomass, increased biofloc volume, reduced the total ammonia nitrogen (TAN), nitrite, nitrate in water also suppressed the pathogenic bacteria growth.	Liang et al. (2022)
2.	Pacific Whiteleg shrimp, *Litopenaeus vannamei*	–	Cyanobacterium *A. platensis* removed 90% of phosphate in effluent, reduced nitrogen load and produced 0.50 g/L *A. platensis* biomass. Possible to integrate *A. platensis* to reduced effluents of *L. vannamei* raised in biofloc system.	Holanda et al. (2021)
3.	Pacific Whiteleg shrimp, *Litopenaeus vannamei*	C:N ratio 16: 1	Biofloc using wheat flour as carbon sources could reduce the dietary protein, maintaining high zootechnical performance, high growth performance, increase the total heterotrophic bacteria count.	Mansour et al. (2022)
4.	-	C:N ratio (5, 10, 15, 20), carbon sources (molasses, rice bran, glucose, sucrose)	C:N ratio at 20:1 using sucrose showed the best ammonia declining trend at flow rate 5.0 to 7.5 L/min with addition of bioflocculant bacteria of *B. infantis*.	Ramli et al. (2022)
5.	Pacific Whiteleg shrimp, *Litopenaeus vannamei*	C:N ratio 10–15:1	Biofloc system increased the *Bacillus* population and decreased the luminous *Vibrio* population which helped in controlling disease cause by *Vibrio* spp. population, reduced the feed cost, enhanced the shrimp survival and growth.	Das and Mandal (2021)
6.	Mud crab, *Scylla olivacea*	-	Highest survival of mud crab when fed both commercial pellet and biofloc up to 30% survival rate for the crablets, maintained the water quality and nutrients level.	Kasan et al. (2022)
7.	Mud crab, *Scylla paramamosain*		Reduced the pathogenic bacteria, *Vibrio* spp., increased the heterotrophic bacteria, reduced the nutrients level from early until end of culture periods, maintained water quality, sedimentable solids of 2ml/L biofloc identified suitable to be applied in crab culture.	Kasan et al. (2021 a)
8.	Pacific Whiteleg shrimp, *Litopenaeus vannamei*	C:N ratio 15:1	Biofloc increased the BW, increased the ADG and SGR, inhibited the pathogenic bacteria, *Vibrio* spp., improved the water quality and shrimp growth performance.	Kasan et al. (2021 b)
9.	Narrow-clawed crayfish, *Astacus leptodactylus*	C:N ratio, 15:1, using molasses	Survival rate 100% of crayfish culture in biofloc system compared to control (77%).	Genc et al. (2019)

Table 1 – contd.

1	2	3	4	5
10.	Co-culture of Nile tilapia (*Oreochromis niloticus*) and red claw crayfish (*Cherac quadricarinatus*)	C:N ratio 10–15:1, using molasses	Total ammonia nitrogen (TAN), nitrite and nitrate were identified lower in biofloc treatment, increase of C:N ratio gave positive effects on feed utilization efficiency and also helped sustain the good water quality in the co-culture of these two organisms in biofloc system.	Azhar et al. (2020)
11.	Pacific Whiteleg shrimp, *Litopenaeus vannamei*	C:N ratio, 10:1	Biofloc contains varieties of bacteria known as *Exiguobacterium aestuarii*, *E. profundum*, *E. aurantiacum*, *Vibrio diabolicus*, *Bacillus pumilus*, *B. cereus*, *B. safensis B. subtilis*, *A. junii*, *C. marina*, *R. aquimaris* and *Pseudoalteromonas* sp. *Exiguobacterium* spp. were the dominant bacteria in the biofloc pond culture which identified as potential probiotic that have high tolerance to fluctuation in water quality and help remediate and recycle organic compound in shrimp pond.	Manan et al. (2022)
12.	Pacific Whiteleg shrimp, *Litopenaeus vannamei*	C:N ratio, 10:1 using molasses	Abundance of microorganisms identified in biofloc included phytoplankton, zooplankton, protozoa, nematode, microalgae from group Chlorophyceae (green algae), Bacillariophyceae (diatoms), Cyanophyceae (BGA) dominated the biofloc, heterotrophic bacteria (*Pseudomonas aeroginosa*, *Vibrio fluvialis*, and *Aeromonas hydrophilia*, *A. salmonicida*), biofloc contributed as natural bioremediation and biodegradation agent, helped in maintaining the water quality until end of culture period.	Manan et al. (2017)
13.	Freshwater prawn, *Macrobrachium rosenbergii*		The addition of probiotics *Bacillus subtilis* and *Bacillus licheniformis* as low as 1.08×10^5 CFU/g contributed to higher survival of prawn in the biofloc system, *B. licheniformis* had better colonization in BFT water, while *B. subtilis* best colonization in hepatopancreas of the prawn.	Frozza et al. (2021)
14.	-	-	Specific biofloc bacteria such as *Rhodococcus* sp., *Bacillus* sp. found to be microplastic degrader including polyethylene (PE), polystyrene (PS), and polypropylene (PP), biofloc producing bacteria degrade microplastic and convert it into less toxic compound (CO_2, CH_4).	Hossain et al. (2022)
15.	Freshwater prawn, *Macrobrachium rosenbergii*	C:N ratio 6.25, using molasses	Increased the prawn growth performance when biofloc culture with addition of *Chlorella* sp. Addition of *Chlorella* sp. improved biofloc physical and biochemical characteristics and also increased growth performance of juvenile's prawn and lowered the FCR in biofloc treatments.	Ekasari et al. (2021)
16.	Red swamp crayfish, *Procambarus clarkii*	C:N ratio >15 using wheat bran and glucose	Increased the BW, SGR of the crayfish in biofloc treatment, the total hepatopancreatic lipid and ash contents higher in biofloc treatment. Biofloc promoted health to the crayfish in terms of immune system and antioxidant enzyme activities. Culture in biofloc was also identified more effective than in traditional commercial diet in the farmed juvenile crayfish.	Li et al. (2019)

The inoculation of biofloc producing bacteria of *Bacillus infantis* helped in accelerating the production of beneficial heterotrophic bacteria and increased the biofloc volume that helps in maintaining the good water quality in culture system (Che Hashim et al., 2021). Meanwhile, Kasan et al. (2021 a) identified the effect of different sedimentable solids effects in improving the water quality and survival rate of *Scylla paramamosain* crab larvae culture and found out that the number of pathogenic bacteria was reduced when the heterotrophic bacteria of biofloc are dominant in the culture tank and also identified that the nutrients level were depleted in the early culture of the larvae until the end of culture stage. The sedimentable solid of 2 ml/L is suggested to be applied in crab culture of *S. paramamosain* in the biofloc system which helped in maintaining the water quality and increased the survival rate and performance of the crab larvae culture. Manan et al. (2022) conducted a study on the bacteria community in biofloc shrimp culture pond of *P. vannamei* through 16S rRNA gene sequencing and identified that the varieties of bacteria identified in the biofloc included *Exiguobacterium aestuarii*, *E. profundum*, *E. aurantiacum*, *Bacillus pumilus*, *B. velezensis*, *B. cereus*, *B. safensis*, *B. subtilis*, *Vibrio diazotrophicus*, *V. diabolicus*, *V. natriegens*, *Rheinheimera aquimaris*, *Acinetobacter junii*, *Cobetia marina* and also

V. harveyi where Restrepo et al. (2021) identified that the *Vibrio diabolicus* is a probiotic bacteria that control pathogenic bacteria in shrimp gastrointestinal tract and help improve survival rate of shrimp. The combination of commercial pellet with rapid biofloc aggregation as a diet help increase the survival rate of the mud crab crablet *S. olivacea* culture and also help maintaining the good water quality and nutrients level in the crab culture system (Kasan et al., 2022). Table 1 shows the most recent study on the application of biofloc technology in the aquaculture system and operation.

Integrated multi trophic aquaculture (IMTA)

Globally, aquaculture is the fastest growing food production sector in agriculture with an average annual growth rate of 5.3% during 2001 to 2018 (FAO, 2020). Additionally, aquaculture also gained worldwide recognition for being one of the most sustainable options for minimizing poverty and enhancing food security (Barange et al., 2018). The demand for seafood is escalating in parallel with the rising of global growth populations (Goh et al., 2022). The rapid rise in the development of aquaculture that depends on the formulated feed (i.e., fed species), coincided with numerous negative impacts on the environments (Bergqvist and Gunnarsson, 2011). Due to characteristic of aquaculture effluents that are commonly rich in organic and inorganic nutrients, it is challenging to release them to natural water bodies as it can cause deterioration of environment (Herath and Satoh, 2015).

Previous studies have shown the effect of nutrients release into the aquatic ecosystem have caused to eutrophication on various biota such as the release of the nitrogen (N = 52–95%), the aquafeed (60%), carbon (C = 80–88%) and phosphorus (P = 85%) into the aquaculture systems will remain in the systems in particulate, dissolved or gaseous forms which later the nutrients required for the growth of phytoplankton and bacteria (Perdikaris et al., 2016; Tom et al., 2021). Despite that, heavy metals and drug residues that are detrimental to aquatic creatures can also be found in dissolved and particulate forms (Sharifinia et al., 2022). Therefore, efforts to establish an environmentally friendly aquaculture system and specific treatment facility have been made to discard the excessive nutrients and pollutants that contribute to eutrophication especially in marine environments (Perdikaris et al., 2016; Thomas et al., 2021).

Among the well established systems is an integrated multi trophic aquaculture (IMTA) system (Khanjani et al., 2022 b). IMTA is a new generation aquaculture that was developed to increase profitability, minimizing environmental effects, the expanding of commercial production and enhancing the intensive sustainability in aquaculture system by the implementation of ecosystem-oriented approach (Troell et al., 2009; Sanz-Lazaro and Sanchez-Jerez, 2020). The IMTA benefits from the simultaneous cultivation of numerous species by generating income from marine products such as crustaceans (shrimps, crabs, and lobsters), gastropods (abalones, snails), bivalves (oysters, scallops, mussels, clams) and some species of sea cucumbers, sea urchins, jellyfish, finfish including algae (Barrington et al., 2009; Zamora et al., 2018). IMTA system allows for the recapture and conversion of nutrients and by-products, uneaten feed and wastes into fertilizer, feed and energy for the other crops as well as utilize the synergistic interactions between species (Neori et al., 2004; Chopin et al., 2008).

There were three groups of extractive species in which each of the groups consumed a different proportion of the waste released by the fed fish (e.g. shrimp and finfish) which are: (1) an autotrophic species known as species that takes up inorganic nutrients and reoxygenating the water, (2) a filter feeder plays a role in removing excess particulate organic matter (POM) suspended in the water column, and (3) a deposit feeder is a scavenger on POM that settles on the bottom) (Soto, 2009; Ferreira et al., 2012) (Table 2). In IMTA systems, both organic and inorganic extractive species are vital because they can use suspended organic materials to retain and reduce the amount of waste that feeding species produce (Alexander and Hughes, 2017; Rosa et al., 2020).

The system of IMTA claimed that employing more feed from high-trophic animal cultures able to improve the production of low-trophic species and discard the organic matter from wastewater can minimize the harmful effects in the culture systems (Soto, 2009; Khanjani et al., 2022 b). IMTA also can both add and remove inorganic nutrients because seaweeds absorb nitrogen produced by animal IMTA species (DFO, 2013). The IMTA benefits from the simultaneous cultivation of numerous species by generating income from marine products such as crustaceans (e.g. shrimps, crabs, lobsters), gastropods (abalones, snails), bivalves (oysters, scallops, mussels, clams) and some species of sea cucumbers, sea urchins, jellyfish, finfish including algae (Barrington et al., 2009; Zamora et al., 2018).

Table 2. Types of extractive groups in integrated multi trophic aquaculture (IMTA) system

Type of extractive groups	Organism	References
Autotrophic species (inorganic extractive)	Seaweed or other aquatic vegetation	Shpigel et al., 2018
Filter feeder	Shellfish Bivalves (oyster, scallop, mussel, clams	Chopin et al., 2008; Cubillo et al., 2016; Granada et al., 2016
Deposit feeder (organic extractive)	Sea cucumber Sea urchins Polychaetes	Chopin et al., 2008; Zamora et al., 2018; Grosso et al., 2021

There were few crucial steps in developing the IMTA system. For example, selection of correct combination species and population sizes as it can maintain the ecosystem sustainability and improving total yield produced, deployed appropriate technologies that is compatible with the conditions of chosen environments, enacting the proper laws and regulations, discovering new markets, promoting awareness and education, setting up the production chain, and continuous research (Barrington et al., 2009; Rosa et al., 2020). All the aforementioned steps must be consolidated for the successfully developed of IMTA system. There also should be cooperation among aquaculture engineers, biologists, economists, natural and social scientists and business investors as having an interdisciplinary mentality is crucial for the IMTA to be formed successfully (Chopin, 2008).

Microalgae application in aquaculture

Microalgae are extensively used as a nutritional supplements diet for the aquatic animals and are widely used in the aquaculture industry (Ma et al., 2020). Microalgae were utilized widely in aquaculture as the nutritional feed diet where larvae of molluscs, echinoderms, crustaceans and fish larvae feed on microalgae (Muller-Feuga, 2000). In aquaculture, the most species being given for feed such as *Chlorella* sp., *Tetraselmis* sp., *Scenedesmus* sp., *Pavlova* sp., *Phaeodactylum* sp., *Chaetoceros* sp., *Nanochloropsis* sp., *Skeletonema* sp. and *Thalassiosira* sp. where these types of microalgae have a rapid growth rate and are stable to be cultured in various temperature, light and nutrients in the hatchery system (Sirakov et al., 2015). Meanwhile, some microalgae such as *Dunaliella salina, Haematococcus pluvialis* and *Spirulina* sp. are widely used for natural pigmentation from the carotenoid astaxanthin that produced pink color to the culture prawn, salmon fish and also for ornamental fish (Sirakov et al., 2015).

Nowadays, microalgae have been successfully used worldwide as an alternative protein sources to replace fishmeal (Roy and Pal, 2015). Many types of microalgae were found useful in increasing the growth of culture organism, use as feed utilization, increase physiological activity, deal with stress response, disease resistance and starvation tolerance of aquaculture animals (Roy and Pal, 2015). A study conducted by Zhang et al. (2022 b) recognized that Whiteleg shrimp, *L. vannamei* culture under two species of microalgae *Nannochloropsis oculata* and *Thalassiosira pseudonana* helped to increase the shrimp survival rate, inhibited the growth of pathogenic *Vibrio* sp. and also helped to increase the shrimp yield where these two species of microalgae contain beneficial minerals and vitamins that help enhance immunity and resist environmental stress (Zhang et al. 2022 b). The culture using these two species of microalgae also improved the muscle shrimp quality as well as being an effective strategy for an ecologically friendly and healthy shrimp culture environment (Zhang et al., 2022 b).

In the nature, there are some species of wild microalgae that can be utilized for enhancing immunostimulants and also help increase growth performance of culture animals which come from species *Haematococcus pluvialis, Arthrospira platensis* (spirulina), and also *Chlorella* spp. (Ma et al., 2020). Currently there are also successfully used microalgae to be developed for oral vaccine in the aquaculture industry coming from species *Chlamydomonas reinhardtii, Dunaliela salina* and from cyanobacteria group as well (Ma et al., 2020). Usually microalgae biomass used as a feed source as the cell metabolites of microalgae identified contain essential amino acids, healthy triglyceride as fat supply, vitamins, pigments and contain bioactive compounds that can increase the survival rate of culture animals, improve coloration and quality of fillet of product (Nagappan et al., 2021). Microalgae that also can recover nutrients, release oxygen as well as increase the yield of production were also identified as a potential biotechnology in aquaculture wastewater treatment and also as supplement for fish diet (Li et al., 2020).

By integrating microalgae into the recirculated aquaculture system (RAS), it can help to maximize the recycling process of nutrients where identified can remove $NH_4^+{}_-$ N up to 95.49% to 100% and also is efficient in removing phosphate, PO_4^3 higher than 80% (Duan et al., 2022). Microalgae such as *Chlorella marina*, *Tetraselmis suecica* and *Picochlorum maculatum* can help remediate the nutrients from aquaculture wastewater where these types of microalgae can remove maximum amount of NH_3-N, NO_2-N, total nitrogen (TN) and total phosphorus (TP) (Meril et al., 2022). The uptake of the nutrients from the wastewater of aquaculture system can be developed into microalgae biomass which can then be used as biofertilizer (Meril et al., 2022).

A recent study conducted by Soto-Rodriguez et al. (2021) identified that marine microalgae from species *Chaetoceros calcitrans* possess an antibiotic activity from the hydrophilic compound of its cells towards the highly virulent bacteria Vp M0904 of *Vibrio parahaemolyticus* strains which are responsible for AHPND or acute hepatopancreatic necrosis disease. Microalgae combination with bacteria such as *Isochrysis galbana* with *Alteromonas* sp. and *Labrezia* sp. with *Marinobacter* sp. can give better result of total length, survival and also metamorphosis of *P. vannamei* larvae (Sandhya et al., 2020).

Monosex culture and application of neo-female technology

Monosex culture is aquaculture biotechnology that produces all-male or all-female populations of a culture species. However, not all species are suitable for monosex culture because it depends on their sexual dimorphism characteristics. Sexual dimorphism refers to the circumstances where the sexes of a species display different appearances of several features such as secondary sex characteristics, color, size (length and weight), shape, or behavior (including cognitive traits). Due to the sexual dimorphism, some species' size differences were exaggerated and became subjects for sexual selection.

For example, if the female of a fish species is generally more prominent than the male, so that in aquaculture perfecting the production of all-female populations on a big scale would be great and more beneficial than mixed sex culture (Ventura, 2018). The reason for the sizes difference may be triggered by the environmental influence including ecological habitat (Laporte et al., 2018), geographical distribution (Jiménez et al., 1998), sex-specific development and growth rates (Kelly et al., 1999; Hüssy et al., 2012), migration arrangements (Eltink, 1987) and variances of spawning behavior (Jakobsen and Ajiad, 1999).

Even though monosex culture is only practical to select the number of commercially valuable species due to sexual dimorphism characteristics, this technique of either all-male or all-female culture is very effective to boost the yield of production and meet the market demand. A case study on freshwater crayfish, yabbies (*Cherax albidus*) showed that the males and females in monosex culture grew faster at 17% and 31% respectively compared to the mixed-sex population, while the all-male population in monosex culture showed a greater gross value of production at 70% than normal mixed-sex population (Lawrence et al., 2000). While the preliminary study by Nair et al. (2006) reported that the production of all-male giant freshwater prawn that grows faster and larger than females (Sagi et al., 1986) through hand segregation method has shown positive production income by 60% (Nair et al., 2006). The production rate of a cultured species was increased when focusing on only growing one sex population due to focusing on faster growing gender with high-quality growth performance and without worrying about wasting energy due to unwanted reproduction since no breeding activities can be done by only one sex (Roderick, 2004). Presently, the common species that are used for monosex culture were all-male Nile tilapia, *Oreochromis niloticus* (Felix et al., 2019), all-male giant freshwater prawn, *Macrobrachium rosenbergii* (Sagi and Afalo, 2005), all-male whiteleg shrimp, *Litopenaeus vannamei* (Sagi, 2013) and all-male red-claw crayfish, *Cherax quadricarinatus* (Rosen et al., 2010).

Generating monosex technique

Monosex culture can be done by manual segregation or by sex reversal, which focuses straight on the preferred sex. The manual segregation method involves minimal technology, so it is quite ineffective, slow to obtain results, tedious and uneconomical. While the sex reversal method implicates an extensive quantity of hormones to alter the sex ratio in the population to produce the preferred gender. For instance, sex reversal in fish can be done by steroid manipulations (Smith et al., 2009). According to Lawrence (2004) and Siddiqui et al. (1997), for the last 30 years, countless research trials have been done to find better techniques of monosex culture production in specific crustacean species until the best method was successfully designed such as androgenic gland (AG) transplantation, androgenic gland ablation, as well as dsRNA and siRNA knockdown of insulin-like androgenic gland hormone (IAG) (Nagamine et al., 1980; Sagi et al., 1990; Manor et al., 2004; Ventura et al., 2009, 2012; Tan et al., 2020 a).

Manual segregation method

Through this method, the sexes were separated manually and cultured in different ponds or tanks by sexes. This simple method is always used on fish especially tilapia to produce their monosex culture. This manual sex sorting is simple and easy to be done but consumes more time, needs skilled workers to identify the sexes and also resulting in 3–10% inaccuracies (Felix et al., 2019). The process involves visual inspection to distinguish and separate males from females by looking at the external sex characteristic such as genital papillae, body size and body colour. The process of segregation is not practical for large production considering the large numbers of fish need to be sorted, so that more times are required and the process is slow to be done thus becoming stressful to the fish. Prabu et al. (2019) state that the manual segregation methods are tiresome and not truly effective on small-size tilapia because it is hard to distinguish their sex differentiation between males and females (Prabu et al., 2019). So, due to this reason, the method of manual segregation is rarely used for commercial purposes and only fits the small-scale production (Penmann and McAndrew, 2000).

Androgenic gene silencing in producing neo-female

The androgenic gene silencing method is practical for crustacean species especially shrimp and the most common target species is giant freshwater prawn, *Macrobrachium rosenbergii*, whiteleg shrimp, *Litopenaeus vannamei* and red claw crayfish, *Cherax quadricarinatus* which is targets on all-male culture. Through this method, all-male population production was done by gene silencing in the androgenic gland (AG) using the method of RNA interference (Ventura and Sagi, 2012). The AG is an endocrine gland that controls sexual differentiation in crustaceans, specifically in producing male sex hormones. As shown in Figure 3, the process of AG removal involves a microsurgical procedure on a male juvenile (early PL) which is bearing two homologous sex chromosomes of ZZ (Ventura and Sagi, 2012; Sagi, 2013) and then producing neo-female's offspring that own complete and functional sex reversal of male bearing neo-ZZ chromosomes (Aflalo et al., 2006). When neo-female (neo-ZZ) was bred with normal male (ZZ), the 100% male progeny will be successfully produced (Sagi et al., 1990). The method using RNA interference (RNAi) was identified as the most efficient and cost effective for silencing of gene expression in crustaceans (Tan et al., 2020 b).

dsRNA and siRNA intervention of insulin-like androgenic gland hormone (IAG)

RNA intervention (RNAi), either using double-strand RNA (dsRNA) or small intervention RNA (siRNA), is a standard reverse genetic manipulation method for the research gene function especially on RNAi of the insulin-like androgenic gene (IAG) in inhibiting the production of spermatid in crustacean (Ge at al., 2020). Generally, the IAG gene indeed promotes masculinization that generates sexual differentiation and enhances exuviation (Ventura and Sagi, 2012) as well as contributes to the growth performance in crustacean (Taketomi et al., 1990). So basically, IAG is a key component in the sexual manipulation of crustacean species and also an important element for the sex reversal to promote monosex hereditary (Ventura et al., 2012).

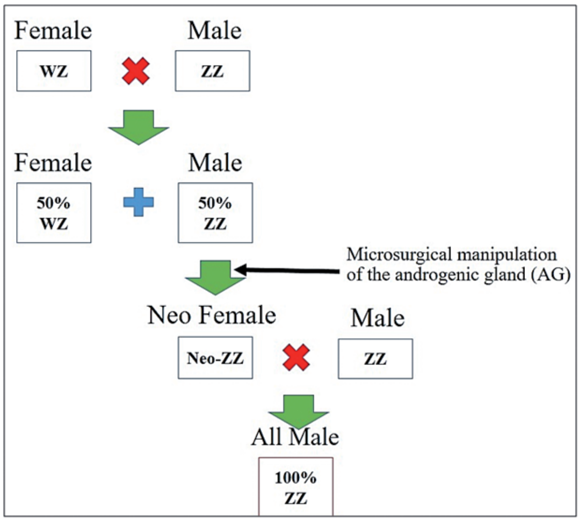

Figure 3. Androgenic gene silencing for sex reversal and monosex culture of crustaceans through microsurgical manipulation of the androgenic gland (AG). Labels; WZ: female gene, ZZ: male gene, Neo-ZZ: Neo female gene (modified from Sagi, 2013)

The cDNA sequence of IAG in red-claw crayfish, *Cherax quadricarinatus* named Cq-IAG was first obtained by using suppression subtractive hybridization (SSH) (Manor et al., 2007) and later research reported that IAG not only induces sex differentiation and spermatogenesis of this species but also acts as a significant role in male gametes survival (Rosen et al., 2010; Ventura et al., 2011). Cq-IAG silencing stimulates intense sex-related changes, comprising male characteristics feminization, decline in sperm mass production, massive testicular deterioration, activated the vitellogenin gene and generated yolk proteins in the developing oocytes. Upon gene silencing, AG cells become hypertrophied probably caused by low levels of hormone redirected in the reduction of manufacture of the insulin-like hormone (Rosen et al., 2010). Later, the feminization of the crustacean species became clear and the sex reversal is successful in converting the male population to the female population. This developed method is being practiced in the research study and still not being practiced on a commercial scale. With further study conducted, we might see the application of this RNAi technique in the aquaculture sector for the upcoming year from now.

Triploidy and polyploidy

Manipulation of chromosome set and hybridization are two effective methods for improving the genetics of aquaculture species (Guo et al., 2009). Past researches on hybrid vigour in fish and shellfish imply that desirable hybrid traits may involve the potential mixing of favourable genes from biparental parents (Gorshkov et al., 2002; Hedgecock and David, 2007). Organisms with one or more additional chromosome sets are referred as polyploidy (Xiao et al., 2011). It has long been acknowledged on the prevalence of polyploidy in flowering plants with 30% to 70% polyploidy rate was documented in the evolutionary history (Ramsey and Schemske, 1998; Landis et al., 2018). In the polyploidization process of animal genetic breeding, hybridization plays a vital role in developing heterogenous genome and micro chromosomes that has greatly benefited economy of many countries (Zhang et al., 2022 a).

Table 3. Different organisms using hybridization of polyploidy in aquaculture

Hybridization	Findings	Reference
Triploid Pacific oyster (F) × Portuguese oyster (M)	Triploid hybrids have high growth, survival and yield rate of offsprings	Jiang et al., 2022
Diploid (F) × Tetraploid (M) Portuguese oysters	Fast growth rate was shown in triploid offspring oysters.	Zhang et al., 2022 a
Allotriploids of Hongkong oysters (F) × Suminoe oyster (M)	Hybrid offspring showed fast growth rate and wide adaptability to salinity.	Qin et al., 2020
Allotetraploid common carp (F) × Homodiploid Blunt snout bream (M)	A new autotetraploid fish showed high survival rate, which can ensure its population expansion and application.	Wang et al., 2020
Atlantic salmon (F) × Triploid Rainbow trout (M)	Gametes of *Salmo salar* bearing improved genetic traits can be produced in shorter time.	Hattori et al., 2019
Diploid Grass carp (F) × Triploid Topmouth culter (M)	Hybrid offspring showed higher level of total amino acid contents than the parental species.	Wu et al., 2019
Triploid Mozambique tilapia (F) × Nile tilapia (M)	Larger size of erythrocyte biometrics in triploid hybrid tilapia compared to diploid groups.	Hassan et al., 2018
Allotriploid Hong Kong oysters (F) × Pacific oyster (M)	Faster growth and higher survival rates than the parental species.	Zhang et al., 2014

Hybridization process is essential for biological adaptability, sustaining gene communion in the populations, and for biological evolution process (Xiao et al., 2011; Xu et al., 2019). There are few steps to know before initiating hybridization such as need to have a thorough understanding of the broodstock management, genetic constitution of the brood stock, and monitor the viability and fertility of the progeny of culture organisms (Rahman et al., 2018). Typically, interspecific hybrids showed faster growth rate compared to parent species (Qin et al., 2020) (Table 3). Based on the origin of the chromosome sets, triploids can be divided into autotriploids and allotriploids (triploid hybrids) (Jiang et al., 2022). Instead of two sets of chromosomes, hybrid triploids contain three sets (Yoo et al., 2018).

Survival rate of hybrids are usually low. However, it can be improved by induction of triploid genotypes in hybrid cross (Bartley et al., 2000; Yoo et al., 2018). Interestingly, due to the combination of hybridization and polyploidization, triploid hybrids are expected to enhance heterosis, survival, growth and disease resistance relative to autopolyploids (Zhang et al., 2014). In addition, due to characteristic triploids that are typically sterile will benefit aquaculture because it can improve growth rate, increase tolerance towards environment and resilience in culture conditions (Piferrer et al., 2009; Qin et al., 2019). Triploids will improve growth as the energy is converted into growth and development and not for gamete production, and reproduction due to its sterile condition (Manan and Ikhwanuddin, 2021). Although ploidy effects do exist, triploids are physiologically and behaviourally similar to diploids (Fraser et al., 2012). Triploids are thus appealing to the aquaculture sector as a way to reduce the costs associated with early maturation and eliminate genetic interactions between wild and cultured populations and to prevent the possible environmental risk resulting from the escape and release of hybrids into natural waters (Taranger et al., 2010; Wang et al., 2020).

Probiotic and prebiotic application in aquaculture

Aquaculture industries comprised of variety of finfish, mollusks, crustaceans, and algal plants are one of the fastest-growing food-producing sectors with increasing demand by years. However, disease outbreaks have become one of the main constraints on aquaculture production and trade, which hugely affects the economic development of the sector in most countries. For instance, in the shrimp and crabs culture subsector, disease problems have become the limiting factors of their growth and development. So far, the use of disinfectants and antimicrobial drugs (conventional methods) showed limited success in the prevention or cure of aquatic disease. Moreover, there is a growing concern about the use, and particularly the abuse of antimicrobial drugs not only in human medicine and agriculture, but also in aquaculture sectors (Verschuere et al., 2000). The massive use of antimicrobials for growth promotion and disease prevention in aquatic animals has led to increase the selective pressure exerted on the microbial world, and encourage the bacterial resistance through natural emergence. The resistant bacteria managed to proliferate even after an antibiotic was introduced, and they also can transfer their resistance genes to other bacteria that have never been exposed to the antibiotic. Therefore, further researches and new strategies are needed to reduce antimicrobial overuse and inappropriate practices.

In disease management, the emphasis should be on prevention, which is likely to be more cost-effective than cure approach. This may result in less reliance on chemicals (antimicrobials, disinfectants, and pesticides), which primarily treat the symptoms of a problem rather than the cause. Several strategies for the alternative use of antimicrobials in disease control have been proposed, with positive results in aquaculture already well reported. The decrease in antimicrobial agents' consumption was reported; mainly due to emerging of effective vaccines, enhancing the non-specific defence mechanisms of the host by immunostimulants (alone or in combination with vaccines), bioaugmentation, and the application of both probiotics and prebiotics. Based on the positive reports, these alternative approaches were identified as critical points for improving aquatic environmental quality, and as major areas for future research in disease control in aquaculture.

Both probiotics and prebiotics are widely used as feed additives in aquaculture sector. It is believed that they provide beneficial effects to the host by combating diseases, therefore directly improve growth by increasing the size and weight of the host, and in some cases, act as alternative antimicrobial compounds, as well as stimulating immunity response. Generally, probiotics live in microbial feed additives that modulate gastrointestinal microbial communities, whereas prebiotics refer to the non-digestible forage additives which stimulate the abundance or activity of beneficial gastrointestinal bacteria or probiotics (Akhter et al., 2015). According to Dimitroglou et al. (2011), probiotics and prebiotics have received widespread attention in aquaculture sector due to their effectiveness on the production improvement, health and disease resistance of aquatic animals.

Initially, the probiotics have been defined as organisms or substances that contribute to the balance of intestinal microbials (Parker, 1974). According to Gismondo et al. (1999), the terminology of probiotic emerged from the Greek words "pro" and "bios" meaning "for life" and is often referred to as a life supporter, which naturally helps to improve the overall health of the host organism. According to the World Health Organization (WHO) and the Food and Agriculture Organization (FAO), probiotics can be referred to as live microorganisms which, when administered or introduced in an appropriate amount to the host, will provide health benefits (FAO, 2001). Nonetheless, FAO and WHO has expanded aquaculture to include a diverse spectrum of Gram-positive and Gram-negative bacteria, bacteriophages, microalgae, and yeast (Table 4) with the application via the aqueous or water channel, as well as providing through the feed (pellet). The basis of the FAO and WHO definition is that probiotics are live organisms that are taken orally and have some demonstrable health advantages. They have been widely employed for disease management in aquaculture, particularly in developing nations (FAO, 2001; Irianto and Austin, 2003; Kazun and Kazun, 2014; Nayak, 2010).

Probiotic microorganisms are known to possess immune stimulant effect, and are widely served for many purposes, mainly in increasing economic growth, promoting digestion, absorption and suppression of infectious diseases (Nayak, 2010). Besides immunomodulation, they are believed to have diverse modes of action in living organisms, such as competing with potential pathogens by placing repressive molecules or through direct competition for space, oxygen and nutrients in the digestive tract of an organism (Fuller, 1987). In some cases, mostly in aquatic animals, they also tend to stick with the mucosal epithelium of gastrointestinal tract and directly help to resist pathogens (Korkea-Aho et al., 2012; Lazado et al., 2011; Luis-Villasenor et al., 2011; Mahdhi et al., 2012). Moreover, probiotics have also been reported to enhance the digestibility of food in the form of enzymes, such as amylases, alginate lyases and proteases (Zokaeifar et al., 2012; ten Doeschate and Coyne, 2008). Some studies also reported that they boosted the production of nutrients (fatty acids, vitamin B_{12}, biotin, etc.) which has a positive effect on the animal's health (Sugita et al., 1991; Zhou et al., 2010). The nutrients produced are used as a supplementary food for improving intestinal microbial balance which indirectly offers beneficial effects to the host. Live bacteria as probiotics also act as alternative for chemicals and antibiotics, and functions as signalling molecules to activate the immune system (Akhter et al., 2015). So far, much attention has been on the immunomodulatory effects of probiotics in aquaculture. The researches on efficiency and validation of immunity on fish and shellfish such as shrimp were also reported widely.

On the other hand, prebiotics refer to the indigestible food ingredients that beneficially and selectively affect the host by promoting or stimulating the growth or activity of one or a limited number of bacteria in the colon of an organism. They can alter the colonic microflora, thus increase the number of good bacteria compositions. According to Akhter et al. (2015), prebiotics function as a growth factor to specific commensal bacteria that inhibit the adhesion and invasion of pathogenic microorganisms in the colon epithelium. They tend to compete for the same glycoconjugates found on the surface of epithelial cells of the host, decrease the pH of the colon, prefer the function of barrier, improve the production of the mucus, produce the short chain of fatty acids and also induce the production of cytokine. Most of the prebiotics are carbohydrates, which are derived from various plants or cell wall components of yeast. They can be classified according to their molecular size or degree of polymerization, such as monosaccharides, polysaccharides or oligosaccharides. Examples of prebiotics included inulin, fructooligosaccharides, mannan-oligosaccharides, galacto-oligosaccharides, arabinogalactans, etc.

Table 4. Aquaculture probiotics that work on particular diseases (Akhter et al., 2015)

Organism category	Genus/group
Bacterial candidates	
Gram-positive bacteria	*Arthrobacter* (*V. harveyi*, *V. parahaemolyticus*), *Bacillus* (A. *hydrophila*, *Edw. ictaluri*, *V. harveyi*, *Y. ruckeri*), *Brevibacillus* (*Vibrio* spp.), *Brochothrix* (*A. bestiarum*), *Clostridium* (*A. hydrophila*, *V. anguillarum*), *Carnobacterium* (*V. anguillarum*, *V. ordalii*, *Y. ruckeri*), *Enterococcus* (*Edw. tarda*, *V. harveyi*, *V. parahaemolyticus*), *Kocuria* (*V. anguillarum*, *V. ordalii*), *Lactobacillus* (*A. salmonicida*, *Lc. garvieae*, *Ps. fluorescens*, *Streptococcus* sp./*St. iniae*), *Lactococcus* (*V. anguillarum*), *Leuconostoc* (*Lc. garvieae*), *Microbacterium* (*V. anguillarum*), *Micrococcus* (*A. hydrophila*, *A. salmonicida*), *Pediococcus* (*Photobacteriumdamselae subsp. damselae*, *V. anguillarum*), *Rhodococcus* (*V. anguillarum*), *Streptococcus* (*V. harveyi*), *Streptomyces* (*V. harveyi*, *V. proteolyticus*), *Vagococcus* (*V. anguillarum*) and *Weissella*
Gram-negative bacteria	*Aeromonas* (*A. bestiarum*, *A. salmonicida*, *Lc. garvieae*, *Streptococcus* sp./*St. iniae*, *V. tubiashii*), *Agarivorans*, *Alteromonas* (*V. coralliilyticus*, *V. pectenicida*, *V. splendidus*), *Bdellovibrio* (*A. hydrophila*), *Burkholderia*, *Citrobacter* (*A. hydrophila*), *Enterobacter* (*F. psychrophilum*), *Neptunomonas* (*V. coralliilyticus*, *V. pectenicida*, *V. splendidus*), *Phaeobacter* (*V. anguillarum, V. parahaemolyticus), Pseudoalteromonas* (*V. anguillarum*, *V. pectenicida*, *V. splendidus*), *Pseudomonas* (*A. salmonicida*, *Photobacteriumdamselae subsp. damselae*, *V. anguillarum*, *V. harveyi*), *Rhodobacter* (*V. anguillarum*), *Rhodopseudomonas*, *Roseobacter* (*V. anguillarum*), *Shewanella* (*Ph. damselae subsp. piscicida*), *Synechococcus* (*V. harveyi*), *Thalassobacte*r, *Vibrio* (*A. salmonicida*, *V. anguillarum*, *V. harveyi*, *Y. ruckeri*) and *Zooshikella* (*Streptococcus* sp./*St. iniae*)
Non-bacterial candidates	
Bacteriophages	*Myoviridae* (*Pseudomonas plecoglossicida*) and *Podoviridae* (*Pseudomonas plecoglossicida*)
Microalgae	*Dunaliella salina*, *D. tertiolecta*, *Isochrysis galbana*, *Navicula*, *Phaedactylum tricornutum*, *Tetraselmis suecica*
Yeast	*Debaryomyces hansenii*, *Phaffia rhodozyma*, *Saccharomyces exiguous*, *S. cerevisiae* (*A. hydrophila*, *Streptococcus* sp.), *Yarrowia lipolytica*

*The pathogens controlled by the probiotics are given in the ().

Generally, prebiotics have a beneficial effect on the gut-associated lymphoid tissue (GALT). Prebiotics such as inulin and fructo-oligosaccharides are among the nutritionary therapeutic preparations (Akhter et al., 2015). They are often used to prepare the expansion of normal bacterial flora and inhibit pathogen ontogenesis for healthy bowel function. Aside from that, they were utilized to prevent pathogen genesis and proliferation. These immunosaccharides act to relieve the function and dependable of the phagocytic cells and increased bacterial activities, stimulate natural killer cells, complement, lysozyme and host's antibody response (Akhter et al., 2015). Despite the potential advantages of prebiotics for health, growth performance, and quality in numerous terrestrial species, their application in the growing of fish and shellfish in the aquaculture industry still received little attention.

Black soldier fly (BSF) as aquatic animal feed

The animal-protein feed is more preferred in the poultry and aquaculture industry compared to plant protein because it contains balanced essential amino acids and high value of vitamins compared to plant sources (Saima et al., 2008; Swinscoe et al., 2018). The uses of insects as natural food sources nowadays are popular in aquaculture and one of them is black soldier fly larvae, *Hermetia illucens* (BSFL). The amino acid content in BSFL is similar to fishmeal and highly suitable to become a substitute protein in fish diets without nutritional deficits (Barroso et al., 2014; Lock et al., 2016). The abundance of this insect and ease of culture in mass production make this species the best choice as animal feed for the aquaculture industry

Barragan-Fonseca et al. (2017) and Khairuzzaman et al. (2021) state that BSFL is not a pest insect. This insect does not approach humans to bite, sting, or spread diseases because they depend only on water and food waste to live and grow (Wang and Shelomi, 2017). In fact, this insect is testified to decrease the population of pathogenic bacteria such as *Salmonella enteritidis* and *Escherichia coli* considering the natural bacteria in BSFL's gut acts as prebiotics and can kill the harmful bacteria (Zheng et al., 2013; Lalander et al., 2015). In addition, Park et al. (2014) state that these BSF larvae also can develop antimicrobials element that can act against both positive and negative gram-bacteria.

The excellent ability of BSFL in converting organic waste matter to rich protein and fat biomass as well as being full of other good nutritional components make them suitable for replacement of fish meal or other protein sources as the main ingredient in the production of aquaculture feed (Gao et al., 2019; Zozo et al., 2022). The crude protein content in BSFL meal is 40 to 60% (Al-Qazzaz et al., 2016), while crude lipids content is around 15 to 49% depending on the method of processing as well as the types of substrates used to produce the meal (Makkar et al., 2014). The use of BSF larvae in the aquaculture industry is known as environmentally friendly due to their ability in converting waste into a useful product and low-cost investment (Kim et al., 2021).

In a case study of using BSFL-based pellet as feed to the African catfish fingerling, *Clarias gariepenus* it was reported that the final weight gains of the fish given BSFL-based pellet was 6.45 g while in fish given a commercial diet (fish meal-based pellet) it was only 1.9 g in the duration of 28 days of study and can be claimed as excellent with lower budget cost (Hamid et al., 2021). On the other hand, Belghi et al. (2019) reported that the usage of BSFL meal as substitute fish meal in the Atlantic salmon diet is also successful without disturbing the fish digestion and growth performance. The use of BSFL meal was also studied as a fish meal substitute (48% replacement) for the yellow catfish diet (Dietz and Liebert, 2018) and as a soybean meals replacement (50% replacement) in the diet of Nile tilapia. Through some research, it was shown that the acceptance of culture fish on an insect-based diet is positive due to the strong natural attractant of aromatic compound existing in the insect that triggers them to consume it (Rawski et al., 2020; Kierończyk et al., 2018). In conclusion, it was clear that BSFL meal can become an alternative source of protein in commercial aquaculture food production which shows excellent quality and is easily produced in large quantity as the usage of fish meal or soybean meal, and most importantly the production cost will be reduced due to the lower price of the main ingredient and easy mass production.

Vaccines application in aquaculture

In the past decade, aquaculture has undergone tremendous development. Nowadays, a sustainable aquaculture industry is of great importance for worldwide food supply and economy as this sector provides and contributes a large part of high-quality protein sources for human consumption. However, along with the fast expansion of aquaculture, the high densities of targeted species farming have increased the risks of various aquatic diseases outbreak. Not just economic losses, such diseases also lead to ecological hazards in terms of pathogen spread to marine ecosystems, thus infecting the wild fish and polluting the environment. Therefore, the fish health is essential for the aquaculture industry to be environmentally sustainable and a prerequisite for the intensive production globally. A recent study by Adams (2019) reported that intensive and large-scale fish farming has created conditions with rapid spread and vast outbreaks of all kinds of infectious fish diseases. In order to overcome the problems, continuous use of antibiotics and drug residues was widely practiced in aquaculture sector. However, the usage of both antibiotics and drug residues has caused backlash impact such as intensive pollution along with risks for food safety and indirectly increased the antimicrobial resistance (Su et al., 2021). Therefore, the application of vaccination is believed to be the most effective and environmentally friendly approach to battle infectious diseases, with minimal impact on ecology and applicability to most species of farmed fish.

A vaccine can be defined as a development of biologically based preparation to improve the immunity towards a specific disease or a group of diseases (Mondal and Thomas, 2022). Vaccines can also be referred to as biological agents that elicit an immune response to a particular antigen obtained from an infectious pathogen causing the disease. To date, vaccination is an important aspect in aquaculture and has become a widely common practice worldwide as an efficient treatment for the prevention of a wide variety of viral diseases and bacterial infections (Ma et al., 2019). However, there are only 34 fish vaccines commercially available globally to date (Su et al., 2021), thus showing the urgent need for further development of vaccines to manage the food safety presently. Snieszko et al. (1938) used vaccines to prevent disease in carp by immunizing them with the bacterium *Aeromonas punctate* reported as the first protective immunity in aquaculture. A study by Duff (1942) was the first report in English indicating the protection in rainbow trout, *Oncorhynchus mykiss* against *Aeromonas salmonicida* by oral administration and parenteral inoculation.

Since the 1940s when the first fish vaccine was introduced to prevent diseases (Snieszko and Friddle, 1949), many vaccines which have a huge impact on reducing the bacterial and viral pathogenic diseases have been developed (Gudding and Goodrich, 2014). Large numbers of vaccines have been reported for tilapia (*Oreochromis niloticus*/*mossambicus*), Atlantic salmon (*Salmo salar*), rainbow trout (*Oncorhynchus mykiss*), sea bass (*Dicentrarchus labrax*), sea bream (*Sparus aurata*), amberjack (*Seriola dumerili*), yellowtail (*Seriola quinqueradiata*), catfish (*Ictalurus punctatus*), and Vietnamese catfish (*Pangasianodon hypophthalmus*) (Clarke et al., 2013; Assefa and Abunna, 2018; Su et al., 2021). According to Shefat (2018), there are currently over 30 commercially available vaccines against major infectious bacterial and viral diseases of fish, including; *Arthrobacter* vaccine, *Vibrio anguillarum-ordalii*, *A. salmonicida* bacterin, *Yersinia ruckeri* bacterin, and other vaccines against bacteria in salmonids, *Flavobacterium columnare* vaccine, and *E. ictaluri* bacterin against bacteria in grouper, infectious pancreatic necrosis virus (IPNV) vaccine, infectious salmon anemia vaccine, nodavirus vaccine, and other vaccines against viruses in salmonids and seabass, *Streptococcus agalactiae* vaccine, and *Streptococcus iniae* vaccine against tilapia streptococcosis, as well as spring viremia of carp vaccine, koi herpes virus (KHV) vaccine, grass carp haemorrhage disease vaccine, and other vaccines against viruses in carps.

Generally, the vaccines can be classified into three types, normally based on their preparation methods; live vaccine, inactivated vaccine, and genetically engineered vaccine (Ma et al., 2019; Su et al., 2021). Live vaccines are prepared with pathogens managed by attenuation or mutated attenuation. Inactivated vaccines refer to inactivated pathogenic microorganisms that remain immunogenic and possess ability to induce specific resistance in aquatic animals after inoculation. The third type which is genetically engineered vaccines, involved different types including recombinant subunit vaccines, DNA vaccines, gene deletion or mutant vaccines, and also live-vector vaccines. Presently, the most widely applied vaccines are live attenuated and inactivated vaccines (Ma et al., 2019). A new type and option, the plant-produced vaccines (plant biotechnological techniques) are also being considered and still in developing stage (Su et al., 2021). The delivery methods for vaccines can be either injection, immersion (water bathing), and also oral administration. Each kind of vaccine has its own advantages and disadvantages, and normally the choice of vaccine and their delivery method is largely depending on characteristics of the farmed fish species, such as size, feeding habits, economic value, water quality, etc. Economic cost, pathogens and protection required are another essential factor that need to be seriously considered before applying and choosing the suitable vaccines. According to Su et al. (2021), future fish vaccines against infectious pathogens should be cost-effective and environmentally friendly, and should be allowed for large-scale production to be available and suitable not only for intensive farming, but also for small fish farmers. To prevent the infection of the disease in shrimp, vaccine has become a promising tool (Shreedharan et al., 2022). The application of polyvalent vaccine enhances the protective efficiency of the vaccine used in shrimp as the vaccine is completed with adjuvant, nutritional additive and immunostimulants (Shreedharan et al., 2022).

Internet of Things (IoT)

Water quality monitoring is the crucial part that should be taken into consideration in the aquaculture operation. Through the application and expansion of IoT, the water quality could be monitored continuously with the help of sensors developed to ensure the successes of the animal growth and survival (Raju and Varma, 2017). It was identified that the application of IoT in the aquaculture has been developed vastly in the last of few years which focused on the water quality monitoring (Dupont et al., 2018). The application of IoT has transformed the aquaculture sector with the application of real time monitoring solution towards less human handling and monitoring (Gupta et al., 2022). With the application of IoT, the data pickup by the sensor will be transferred to the farmers mobile via cloud and through this initiative, the initial prevention and precaution can be taken into action to minimize the impact losses (Raju and Varma, 2017) if anything occurs in the farm such as power outage during the culture process. The application of IoT in aquaculture should be smart, easy to use, reliable, highly efficient and affordable to be procured by the aquafarmers (Dupont et al., 2018). Meanwhile Lim and Majid (2021), who developed a wireless system of IoT for remote monitoring of aquaculture farm, identified that the system could be improved with integrating an autonomous farming system. The rate of mortality can be reduced and profitability can be increased as the farmer can monitor the water through the smartphone using this IoT monitoring system (Lim and Majid, 2021).

According to Prapti et al. (2021), in terms of water quality, temperature, dissolved oxygen and pH are the top-most priority water quality parameters in the IoT based aquaculture system and also sometimes equipped with alarm system for actuation. There are several approaches provided by the IoT based aquaculture such as real time monitoring, remote monitoring, automated, early warning monitoring, online monitoring and also autonomous (Prapti et al., 2021). In the smart aquaculture operation, IoT was applied as a high technology approach to produce food in a sustainable way and become one of the most recent advanced ICT technologies being applied in the Industrial Revolution 4.0 (IR4.0) for aquaculture industry production (Prapti et al., 2021). On top of that, with the development in the computers like Arduino, Raspberry Pi innovation can be achieved in the field of IoT which can be applied in the aquafarming and in aquaculture operation as well (Saha et al., 2018). Huan et al. (2020) developed a water quality monitoring system for aquaculture based on narrow band Internet of Things (NB-IoT) technology where this technology comprehends remote collection and data storage of multi-sensor processor for information such as temperature, DO, pH and also centralized management for breeding ponds. The development of the IoT in the aquaculture operation will help promote the development of aquaculture informatization as well as help farmers to monitor aquaculture ponds in more accurate and convenient ways (Huan et al., 2020). Other things that should come into consideration are the cost of implementing the IoT, the initial setup costs, cost to enable the water quality sensor, mobile data for real time monitoring, cloud storage, and also remote centers for analysis (Karimanzira and Rauschenbach, 2019). The cost for maintenance of the IoT system is also expensive especially on maintenance of the water sensors as the water sensors are very sensitive and need good maintenance to be working efficiently.

Conclusion

Aquaculture facing many challenges lately from the disease outbreaks, broodstock improvements, water deterioration issue, limited land occupied and thus a most recent development in aquaculture technology is a must and obligatory. In order to increase the aquaculture production and also support the SDGs goals towards zero hunger and no poverty, aquaculture sector needs an efficient and productive technology to reach this target. Nowadays, new technologies are being actively developed by the researchers and scientists in aquaculture field to help aquaculture societies to reach a higher production, green environment of aquaculture operation towards a sustainable aquaculture production in the near future.

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Author contributions

Hidayah Manan: conceptualization, writing original manuscripts and conducting the revision of manuscript, Siti Jalilah Mohammad: writing original manuscripts, Fazlan Fauzan: conceptualization, idea contributions on first draft manuscript and commenting on critical part of manuscript, Nor Azman Kasan: English proofreading and commenting on critical part of manuscript, Mhd Ikhwanuddin: commenting and reviewing critical part of manuscript, Adnan Amin-Safwan: writing original manuscripts, Nur Syazwani Abdullah: writing original manuscripts, Mamat Nur-Syahirah: writing original manuscripts.

Conflict of interest

The authors declare no conflict of interest.

Ethical approval

All the applicable international, national and institutional guidelines for the care and use of animals were followed by the authors.

Data availability statement

Data not available.

References

Abbaszadeh A., Mozanzadeh M.T., Qasemi A., Oujifard, A., Nafisi B.M. (2022). Effects of the addition of *Calanopia elliptica, Artemia franciscana*, and *Brachionus rotundiformis* in a nursery biofloc system on water quality, growth, gut morphology, health indices, and transcriptional response of immune and antioxidant related genes in *Penaeus vannamei*. Aquac. Int., 30: 653–676.

Adams A. (2019). Progress, challenges and opportunities in fish vaccine development. Fish & Shellfish Immunol., 90: 210–214.

Aflalo E.D., Hoang T.T.T., Nguyen V.H., Lam Q., Nguyen D.M., Trinh Q.S., Raviv S., Sagi A. (2006). A novel two-step procedure for mass production of all-male populations of the giant freshwater prawn *Macrobrachium rosenbergii*. Aquaculture, 256: 468–78.

Akhter N., Wu B., Memon A.M., Mohsin M. (2015). Probiotics and prebiotics associated with aquaculture: a review. Fish Shellfish Immunol., 45: 733–741.

Alexander K.A., Hughes A.D. (2017). A problem shared: technology transfer and development in European integrated multitrophic aquaculture (IMTA). Aquaculture, 473: 13–19.

Al-Qazzaz M.F., Ismail D., Akit H., Idris L.H. (2016). Effect of using insect larvae meal as a complete protein source on quality. Rev. Bras. de Zootec., 45: 518–523.

Assefa A., Abunna F. (2018). Maintenance of fish health in aquaculture: review of epidemiological approaches for prevention and control of infectious disease of fish. Vet. Med. Int., 5432497.

Avnimelech Y. (2007). Feeding with microbial flocs by tilapia in minimal discharge bio-flocs technology ponds. Aquaculture, 264: 140–147.

Azhar M.H., Suciyono S., Budi D.S., Ulkhaq M.F., Anugrahwati M., Ekasari J. (2020). Biofloc-based co-culture systems of Nile tilapia (*Oreochromis niloticus*) and red claw crayfish (*Cherax quadricarinatus*) with different carbon-nitrogen ratios. Aquacult. Int., 28: 1293–1304.

Barange M., Bahri T., Beveridge M.C.M., Cochrane K.L., Funge-Smith S., Poulain F. (2018). Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options. Rome: FAO. FAO Fisheries and Aquaculture Tech. Paper No. 627: 628.

Barragan-Fonseca K.B., Dicke M., Van Loon J.J. (2017). Nutritional value of the BSF (*Hermetia illucens* L.) and its suitability as animal feed – a review. J. Insects Food Feed, 3: 105–120.

Barrington K., Chopi T., Robinson S. (2009). Integrated multi-trophic aquaculture (IMTA) in marine temperate waters. Integrated mariculture: a global review. FAO Fisheries Aquaculture Tech. Paper., 529: 7–46.

Barroso F., De Haro C., Sanchez-Muros M., Venegas E., Martinez-Sanchez A., Perez-Banon C. (2014). The potential of various insect species for use as food for fish. Aquaculture, 422–423: 193–201.

Bartley D.M., Rana K., Immink A.J. (2000). The use of inter-specific hybrids in aquaculture and fisheries. Rev. Fish Biol Fish., 10: 325–337.

Belghi I., Liland N.S., Gjesdal P., Biancarosa I., Menchetti E., Li Y., Waagbo R., Krogdahl A., Lock E.J. (2019). Black soldier fly larvae meal can replace fish meal in diets of seawater phase Atlantic salmon (*Salmo salar*). Aquaculture, 503: 609–619.

Bergqvist J., Gunnarsson S. (2011). Finfish aquaculture: animal welfare, the environment, and ethical implications. J. Agric. Environ. Ethics., 26: 75–99.

Catalani K.M. (2020). Aquamimicry system: Technological alternative for intensive cultivation of marine shrimp *Litopenaeus vannamei*. A comparison with the Biofloc system (BFT). Thesis for master's degree in aquaculture. Federal University of Rio Grande, Brazil, 58.

Che Hashim N.F.C., Manan H.., Okomoda V.T., Ikhwanuddin M., Khor W., Abdullah S.R.S.A., Kasan N.A. (2021). Inoculation of bioflocculant-producing bacteria for enhanced biofloc formation and pond preparation: Effect on water quality and bacterial community. Aquac. Res., 53: 1602–1607.

Chopin T., Robinson S.M.C., Troell M., Neori A., Buschmann A.H., Fang J. (2008). Multitrophic integration for sustainable marine aquaculture. In: Ecological Engineering, Vol. 3 of Encyclopedia of Ecology, Jørgensen S.E., Fath B.D. (eds). Elsevier, Oxford, pp. 2463–2475.

Clarke J.L., Waheed M.T., Lössl A.G. (2013). How can plant genetic engineering contribute to cost-effective fish vaccine development for promoting sustainable aquaculture? Plant Mol. Biol., 83: 33–40.

Cubillo A.M., Ferreira J.G., Robinson S.M., Pearce C.M., Corner R.A., Johansen J. (2016). Role of deposit feeders in integrated multi-trophic aquaculture – a model analysis. Aquaculture, 453: 54–66.

Das S.K., Mandal A. (2021). Environmental amelioration in biofloc based rearing system of white leg shrimp (*Litopenaeus vannamei*) in West Bengal, India. Aquat. Living Res., 34: 1–12.

Deepak A.P., Vasava R.J., Elchelwar V.R., Tandel D.H., Vadher K.H., Shrivastava V., Prabhakar P. (2020). Aquamimicry: New and innovative approach for sustainable development of aquaculture. J. Entomol. Zool. Stud., 8: 1029–1031.

DFO (2013). Review of the organic extractive component of integrated multi-trophic aquaculture (IMTA) in Southwest New Brunswick with emphasis on the blue mussel. 2013: 56.

Dietz C., Liebert F. (2018). Does graded substitution of soy protein concentrate by an insect meal respond on growth and N-utilization in Nile tilapia (*Oreochromis niloticus*). Aquac. Rep., 12: 43–48.

Dimitroglou A., Merrifield D.L., Carnevali O., Picchietti S., Avella M.A., Daniels C.L., Güroy D., Davies S. (2011). Microbial manipulations to improve fish health and production – a Mediterranean perspective. Fish Shellfish Immunol., 30: 1–16.

Duan J., Cui R., Huang Y., Ai X., Hao Y., Shi H., Huang A., Xie Z. (2022). Identification and characterization of four microalgae strains with potential application in the treatment of tail-water for shrimp cultivation. Algal Res., 66: 102790.

Duff D. (1942). The oral immunization of trout against *Bacterium Salmonicida*. J. Immun., 44: 87–94.

Dupont C., Cousin P., Dupont S. (2018). IoT for aquaculture 4.0 Smart and easy-to-deploy real-time water monitoring with IoT."2018 Global Internet of Things Summit (GIoTS), 1–5.

Ekasari J., Nugroho U.A., Fatimah N., Angela D., Hastuti Y.P., Pande G.S.J.P., Natrah F.M.I. (2021). Improvement of biofloc quality and growth of *Macrobrachium rosenbergii* in biofloc systems by *Chlorella* addition. Aquacult. Int., 29: 2305–2317.

El-Gayar O.F. (2008). The use of information technology in aquaculture management. Aquac. Econ. Manag., 1: 109–128.

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.

Eltink A.T.G.W. (1987). Changes in age- and size distribution and sex ratio during spawning and migration of Western mackerel (*Scomber scombrus* L.). J. Conseil Intern. l'Exploration de la Mer., 44: 10–22.

FAO (2001). Health and Nutritional Properties of Probiotics in Food Including Powder Milk with Live Lactic Acid Bacteria.

FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. Food and Agriculture Organization of The United Nations.

FAO/WHO (2001). Expert Consultation Report on Evaluation of Health and Nutritional Properties of Probiotics in Food Including Powder Milk with Live Lactic Acid Bacteria.

Felix E., Avwemoya F.E., Abah A. (2019). Some methods of monosex tilapia production: A review. Int J. Fish Aquat. Res., 4: 42–49.

Ferreira J.G., Saurel C., Ferreira J.M. (2012). Cultivation of gilthead bream in monoculture and integrated multi-trophic aquaculture. Analysis of production and environmental effects by means of the FARM model. Aquaculture, 358: 23–34.

Fraser T.W., Fjelldal P.G., Hansen T., Mayer I. (2012). Welfare considerations of triploid fish. Rev. Fish. Sci., 20: 192–211.

Frozza A., Fiorini A., Vendruscolo C.G., Rosado F.R., Konrad D., Rodrigues M.C.G., Ballester E.L.C. (2021). Probiotic in the rearing of freshwater prawn *Macrobrachium rosenbergii* (de Man, 1879) in a biofloc system. Aquac. Res., 52: 4269–4277.

Fuller R. (1987). A review, probiotics in man and animals. J. Appl. Bacteriol., 66: 365–378.

Gao Z., Wang W., Lu X., Zhu F., Liu W., Wang X., Lei C. (2019). Bioconversion performance and life table of black soldier fly (*Hermetia illucens*) on fermented maize straw. J. Clean. Prod., 230: 974–980.

Ge H.L., Tan K., Shi L.L., Sun R., Wang W.M., Lia Y.H. (2020). Comparison of effects of dsRNA and siRNA RNA interference on insulin-like androgenic gland gene (IAG) in red swamp crayfish *Procambarus clarkia*. Gene, 752: 144783.

Genc E., Kaya D., Dincer S., Genc M.A., Aktas M. (2019). Biofloc application in narrow-clawed crayfish (*Astacus leptodactylus*) culture: preliminary results. Proc. 3rd International Congress on Advances in Bioscience and biotechnology (ICABB), Kiev, Ukraine, 10–14.07.2019. Book of Proceeding, pp. 71–78.

Gismondo M.R., Drago L., Lombardi A. (1999). Review of probiotics available to modify gastrointestinal flora. Int. J. Antimicrob. Agents., 12: 287–292.

Goh J.X.H., Tan L.T.H., Law J.W.F., Ser H.L., Khaw K.Y., Letchumanan V., Lee L.H., Goh B.H. (2022). Harnessing the potentialities of probiotics, prebiotics, synbiotics, paraprobiotics, and postbiotics for shrimp farming. Rev. Aquacult., 14: 1478–1557.

Gorshkov S., Gorshkova G., Hadani A., Gordin H., Knibb W. (2002). Chromosome set manipulations and hybridization experiments in gilthead seabream (*Sparus aurata*). II. Assessment of diploid and triploid hybrids between gilthead seabream and red seabream (*Pagrus major*). J. Appl. Ichthyol., 18: 106–112.

Granada L., Sousa N., Lopes S., Lemos M.F.L. (2016). Is integrated multitrophic aquaculture the solution to the sectors' major challenges? – a review. Rev Aquac., 8: 283–300.

Grosso L., Rakaj A., Fianchini A., Morroni L., Cataudella S., Scardi M. (2021). Integrated multi-trophic aquaculture (IMTA) system combining the sea urchin *Paracentrotus lividus*, as primary species, and the sea cucumber *Holothuria tubulosa* as extractive species. Aquaculture, 534: 1–11.

Gudding R., Goodrich T. (2014). The history of fish vaccination. In: Fish Vaccination, Gudding R., Lillehaug A., Evensen O. (eds). 1st ed. John Wiley & Sons, Inc., New York, pp. 1–11.

Guo X., Wang Y., Xu Z., Yang H. (2009). Chromosome set manipulation in shellfish. In: New Technologies in Aquaculture: Improving Production Efficiency, Quality and Environmental Management, Burnell G., Allan G. (eds). Woodhead Publishing, Cambridge, UK, pp. 165–194.

Gupta S., Gupta A., Hasija Y. (2022). Chapter 30 – Transforming IoT in Aquaculture: A cloud solution. AI, Edge and IoT-based Smart Agriculture. Intelligent Data-Centric Systems, 2022: 517–531.

Hamid N.A.A, Zakaria N.F., Ali N. (2021). Study on utilization of black soldier fly larvae (*Hermetia illucens*) as protein substitute in the pellet diet of *Clarias gariepenus* fingerling. Adv. Agric. Food Res. J., 3: 1–6.

Hargreaves J.A. (2006). Photosynthetic suspended-growth system in aquaculture. Aquac. Eng., 34: 344–363.

Hassan A., Okomoda V.T., Pradeep P.J. (2018). Triploidy induction by electric shock in Red hybrid Tilapia. Aquaculture, 495: 823–830.

Hattori R.S., Yoshinaga T.T., Katayama N., Hattori-Ihara S., Tsukamoto R.Y., Takahashi N. S., Tabata Y.A. (2019). Surrogate production of *Salmo salar* oocytes and sperm in triploid *Oncorhynchus mykiss* by germ cell transplantation technology. Aquaculture, 506: 238–245.

Hedgecock D., Davis J.P. (2007). Heterosis for yield and crossbreeding of the Pacific oyster *Crassostrea gigas*. Aquaculture, 272: 17–29.

Herath S.S., Satoh S. (2015). Environmental impact of phosphorus and nitrogen from aquaculture. Feed and Feeding Practices in Aquaculture. Woodhead Publishing, pp. 369–386.

Holanda M., Besold C., Sempere F.L., Abreu P.C., Poersch L. (2021). Treatments of effluents from marine shrimp culture with biofloc technology: Production of *Arthrospira* (Spirulina) *platensis* (cyanobacteria) and nutrient removal. J. World Aquac. Soc., 53: 669–680.

Hossain S., Manan H., Shukri Z.N.A., Othman R., Kamaruzzan A.S., Rahim A.I.A., Khatoon H., Mihaz T.M.M., Islam Z., Kasan N.A. (2022). Microplastics biodegradation by biofloc-producing bacteria: an inventive biofloc technology approach. Microbiol Res., 2022: 127239.

Huan J., Li H., Wu F., Cao W. (2020). Design of water quality monitoring system for aquaculture ponds based on NB-IoT. Aquac Eng., 90: 1–10.

Hüssy K., Coad J.O., Farrell E.D., Clausen L.W., Clarke M.W. (2012). Sexual dimorphism in size, age maturation, and growth characteristics of boarfish (*Capros aper*) in the Northeast Atlantic. ICES J. Marine Sci., 69: 1729–1735.

Irianto A., Austin B. (2003). Use of dead probiotic cells to control furunculosis in rainbow trout, *Onchorhynchus mykiss* (Walbaum). J. Fish Dis., 26: 59–62.

Jakobsen T., Ajiad A. (1999). Management implications of sexual differences in maturation and spawning mortality of Northeast Arctic cod. J. Northwest Atl. Fish. Sci., 25: 125–132.

Jiang G., Li Q., Xu C. (2022). Growth, survival and gonad development of two new types of reciprocal triploid hybrids between *Crassostrea gigas* and *C. angulata*. Aquaculture, 559: 738451.

Jiménez M.P., Sobrino I., Ramos F. (1998). Distribution pattern, reproductive biology, and fishery of the wedge sole *Dicologlossa cuneata* in the Gulf of Cadiz, south-west Spain. Mar Biol., 131: 173–187.

Karimanzira D., Raushenbach T. (2019). Enhancing aquaponics management with IoT-based Predictive Analytics for efficient information utilization. Inf. Process. Agric., 6: 375–385.

Kasan N.A., Yee C.S., Manan H., Ideris A.RA., Kamruzzan A.S., Waiho K., Lam S.S., Mahari W.A.W., Ikhwanuddin M.., Suratman S., Tamrin M.L.M. (2021 a). Study on the implementation of different biofloc sedimentable solids in improving the water quality and survival rate of mud crab, *Scylla paramamosain* larvae culture. Aquac. Res., 52: 4807–4815.

Kasan N.A., Manan H., Ismail T.I.T., Salam A.I.A., Rahim A.I.A., Kamaruzzan A.S., Ishak A.N., Deraman S., Nasrin Z., Engku Chik C.E.N., Che Hashim N.F., Iber B.T. (2021 b). Effect of biofloc product Rapid BFTTM vs. clear water system in improving the water quality and growth performance of Pacific Whiteleg shrimp, *P. vannamei*, cultured in indoor aquaculture system. Aquac. Res., 52: 6504–6513.

Kasan N.A., Manan H., Lal M.T.M., Rahim A.I.A., Kamaruzzan A.S., Ishak A.N., Ikhwanuddin M. (2022). A novel study on the effect of rapid biofloc as pellet feed on the survival rate and water quality of mud crab, *Scylla olivacea* culture. J. Sustain Sci. Manag., 17: 46–54.

Kazun B., Kazun K. (2014). Probiotics in aquaculture. Med. Weter., 70: 25–29.

Kelly C.J., Connolly P.L., Bracken J.J. (1999). Age estimation, growth, maturity, and distribution of the bluemouth rockfish *Helicolenus d. dactylopterus* (Delaroche 1809) from the Rockall Trough. ICES J. Marine Sci., 56: 61–74.

Khairuzzaman M.W., Jamaluddin M.A., Sani M.S.A. (2021). Black soldier fly larvae as animal feed: implications on the *halal* status of meat products. Halalsphere, 1: 1.

Khanjani M.H., Mozanzadeh M.T., Foes G.K. (2022 a). Aquamimicry system: a suitable strategy for shrimp aquaculture – a review. Ann. Anim. Sci., 22: 1201–1210.

Khanjani M.H., Zahedi S., Mohammadi A. (2022 b). Integrated multitrophic aquaculture (IMTA) as an environmentally friendly system for sustainable aquaculture: functionality, species, and application of biofloc technology (BFT). Environ. Sci. Pollut. Res., 29: 67513–67531.

Khanjani M.H., Mohammadi A., Emerenciano M.G.C. (2022 c). Microorganisms in biofloc aquaculture system. Aquac. Rep., 26: 1–17.

Kierończyk B., Rawski M., Pawełczyk P., Różyńska J., Golusik J., Mikołajczak Z., Józefiak D. (2018). Do insects smell attractive to dogs? A comparison of dog reactions to insects and commercial feed aromas – a preliminary study. Ann. Anim. Sci., 18: 795–800.

Kim C.H., Ryu J., Lee J., Ko K., Lee J., Park K.Y., Chung H. (2021). Use of black soldier fly larvae for food waste treatment and energy production in Asian countries: a review. Processes, 9: 161.

Korkea-Aho T.L., Papadopoulou A., Heikkinen J., Von wright A., Adams A., Austin B., Thompson K.D. (2012). *Pseudomonas* M162 confers protection against rainbow trout fry syndrome. J. Appl. Microbiol., 113: 24–35.

Lakra W.S., Ayyappan S. (2003). Recent advances in biotechnology applications to aquaculture. Asian-Australas. J. Anim. Sci., 16: 455–462.

Lalander C., Fidjeland J., Diener S., Eriksson S., Vinneras B. (2015). High waste-to-biomass conversion and efficient *Salmonella* spp. reduction using black soldier fly for waste recycling. Agron. Sustain Dev., 35: 261–271.

Landis J.B., Soltis D.E., Li Z., Marx H.E., Barker M.S., Tank D.C., Soltis P.S. (2018). Impact of whole-genome duplication events on diversification rates in angiosperms. Am. J Bot., 105: 348–363.

Laporte M., Berrebi P., Claude J., Viyoles D., Pourovira Q., Raymond J.C., Magnan P. (2018). The ecology of sexual dimorphism in size and shape of the freshwater benny *fluviatilis*. Curr. Zool., 64: 183–191.

Lawrence C.S., Cheng Y.W., Morriss N.M., Williams I.H. (2000). A comparison of mixed-sex vs. monosex grow out and different diets on the growth rate of freshwater crayfish *Cherax albidus*. Aquaculture, 185: 281–289.

Lazado C.C., Caipang C.M.A., Brinchmann M.F., Kiron V. (2011). In vitro adherence of two candidate probiotics from Atlantic cod and their interference with the adhesion of two pathogenic bacteria. Vet. Microbiol., 148: 252–259.

Li H., Chen S., Liao K., Ku Q., Zhou W. (2020). Microalgae biotechnology as a promising pathway to eco-friendly aquaculture: a state-of-the-art review. J. Chem. Technol. Biotechnol., 96: 837–852.

Li J., Li J., Sun Y., Liu X., Liu M., Cheng Y. (2019). Juvenile *Procambarus clarkii* farmed using biofloc technology or commercial feed in zero-water exchange indoor tanks: A comparison of growth performance, enzyme activity and proximate composition. Aquac. Res., 50: 1834–1843.

Liang X., Zhang C., Du D., Gao M., Sui L. (2022). Application of biofloc technology in recirculation *Artemia* culture system. J. Oceanol. Limnol., 40: 1669–1677.

Lim J.H., Majid A.H. (2021). IoT Monitoring System for Aquaculture Farming. Progr. Eng. Appl. Technol., 2: 567–577.

Lock E., Arsiwalla T., Waagbo R. (2016). Insect larvae meal as an alternative source of nutrients in the diet of Atlantic salmon (*Salmo salar*) postsmolt. Aquac. Nutr., 22: 1202–1213.

Luis-Villasenor I.E., Macias-Rodriguez M.E., Gomez-Gil B., Ascencio-Valle F., Campa-Cordova A.I. (2011). Beneficial effects of four *Bacillus* strains on the larval cultivation of *Litopenaeus vannamei*. Aquaculture, 321: 136–144.

Ma J., Bruce T.J., Jones E.M., Cain K.D. (2019). A review of fish vaccine development strategies: conventional methods and modern biotechnological approaches. Microorganisms, 7: 18.

Ma K., Ba Q., Wu Y., Chen S., Zhao S., Wu H., Fan J. (2020). Evaluation of microalgae as immunostimulants and recombinant vaccines for diseases prevention and control in aquaculture. Front. Bioeng. Biotechnol., 16.

Mahdhi A., Kamoun F., Messina C., Santulli A., Bakhrouf A. (2012). Probiotic properties of *Brevibacillus brevis* and its influence on sea bass (*Dicentrarchus labrax*) larval rearing. Afr. J. Microbiol. Res., 6: 6487–6495.

Makkar H.P., Tran G., Heuz´e V., Ankers P. (2014). State-of-the-art on use of insects as animal feed. Anim. Feed Sci. Technol., 197: 1–33.

Manan H., Ikhwanuddin M. (2021). Triploid induction in penaeid shrimps aquaculture: a review. Rev. Aquac., 13: 619–631.

Manan H., Moh J.H.Z., Kasan N.A., Suratman S., Ikhwanuddin M. (2017). Identification of biofloc microscopic composition as the natural bioremediation in zero water exchange of Pacific white shrimp, *Penaeus vannamei*, culture in closed hatchery system. Appl. Water. Sci., 7: 2437–2446.

Manan H., Rosland N.A., Deris Z.M., Hashim N.F.C., Kasan N.A., Ikhwanuddin M., Suloma A., Fauzan F. (2022). 16S rRNA sequences of *Exiguobacterium* spp. bacteria dominant in a biofloc pond cultured with Whiteleg shrimp, Penaeus vannamei. Aquac. Res., 53: 2029–2041.

Manor R., Aflalo E.D., Segall C., Weil S., Azulay D., Ventura T., Sagi A. (2004). Androgenic gland implantation promotes growth and inhibits vitellogenesis in *Cherax quadricarinatus* females held in individual compartments. Invertebr. Reprod. Dev., 45: 151–159.

Mansour A.T., Ashry O.A., Ashour M., Alsaqufi A.S., Ramadan K.M.A., Sharawy Z. (2022). The optimization of dietary protein level and carbon sources on biofloc nutritive values, bacteria abundance, and growth performances of Whiteleg shrimp (*Litopenaeus vannamei*) juveniles. Life (Basel), 12: 888.

Meril D., Piliyan R., Perumal S., Sundarraj D.K., Binesh A. (2022). Efficacy of alginate immobilized microalgae in the bioremediation of shrimp aquaculture wastewater. Process Biochem., 122: 196–202.

Mondal H., Thomas J. (2022). A review on the recent advances and application of vaccines against fish pathogens in aquaculture. Aquacult. Int., 30: 1971–2000.

Muller-Feuga A. (2000). The role of microalgae in aquaculture: situation and trends. J. Appl. Phycol., 12: 527–534.

Nagamine C., Knight A.W., Maggenti A., Paxman G. (1980). Masculinization of female *Macrobrachium rosenbergii* (de man) (Decapoda, Palaemonidae) by androgenic gland implantation. Gen. Comp. Endocrinol., 41: 442–457.

Nagappan S., Das P., Quadir M.A., Thaher M., Khan S., Mahata C., Al-Jabri H., Vatland A.K., Kumar G. (2021). Potential of microalgae as sustainable feed ingredient for aquaculture. J. Biotechnol., 341: 1–20.

Nair C.M., Salin K.R., Raju M.S., Sebastian M. (2006). Economic analysis of monosex culture of giant freshwater prawn (*Macrobrachium rosenbergii* De Man): a case study. Aquac. Res., 37: 949–954.

Nayak S.K. (2010). Probiotics and immunity: a fish perspective. Fish Shellfish Immunol., 29: 2–14.

Neori A., Chopin T., Troell M., Buschmann A.H., Kraemer G.P., Halling C., Shpigel M. Yarish C. (2004). Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. Aquaculture, 231: 361–391.

Panigrahi A., Otta S.K., Kumaraguru Vasagam K.P., Shyne Anand P.S., Biju I.F., Aravind R., (2019). Training manual on Biofloc technology for nursery and grow-out aquaculture, CIBA TM Series, 15: 172.

Park S., Chang B., Yoe S. (2014). Detection of antimicrobial substances from larvae of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae). Entomol. Res., 44: 58–64.

Parker R.B. (1974). Probiotics, the other half of the antibiotic story. Anim. Nutr. Health, 29: 4–8.

Penman D.J., McAndrew B.J. (2000). Genetics for the management and improvement of cultured tilapias. In: Tilapias: Biology and exploitation. Springer, Dordrecht, pp. 227–266.

Perdikaris C., Chrysafi A., Ganias K. (2016). Environmentally friendly practices and perceptions in aquaculture: a sectoral case-study from a Mediterranean-based industry. Rev. Fish. Sci., 24: 113–125.

Piferrer F., Beaumont A., Falguière J.C., Flajšhans M., Haffray P., Colombo L. (2009). Polyploid fish and shellfish: production, biology and applications to aquaculture for performance improvement and genetic containment. Aquaculture, 293: 125–156.

Prabu E., Rajagopalsamy C.B.T., Ahilan B., Jeevagan I.J.M.A., Renuhadevi M. (2019). Tilapia – an excellent candidate species for world aquaculture: a review. Annu. Res. Rev. Biol., 31: 1–14.

Prapti D.R., Shariff A.R.M., Che Man H., Ramli N.M.., Perumal T., Shariff M. (2021). Internet of Things (IoT)-based aquaculture: An overview of IoT application on water quality monitoring. Rev. Aquac., 14: 979–992.

Qin Y., Zhang Y., Mo R., Zhang Y., Li J., Zhou Y., Ma H., Xiao S., Yu Z. (2019). Influence of ploidy and environment on grow-out traits of diploid and triploid Hong Kong oysters *Crassostrea hongkongensis* in southern China. Aquaculture, 507: 108–118.

Qin Y., Li X., Noor Z., Li J., Zhou Z., Ma H., Xiao S., Mo R., Zhang Y., Yu Z. (2020). A comparative analysis of the growth, survival and reproduction of *Crassostrea hongkongensis, Crassostrea ariakensis*, and their diploid and triploid hybrids. Aquaculture, 520: 1–11.

Rahman M.A., Lee S.G., Yusoff F.M., Rafiquzzaman S.M. (2018). Hybridization and its application in aquaculture. In: Sex control in aquaculture, Wang H.P., Piferrer F., Chen S.L., Shen Z.G. (eds). John Wiley & Sons, pp. 163–178.

Raju K.R.S.R., Varma G.H.K. (2017). Knowledge Based Real Time monitoring system for aquaculture using IoT. Proc. IEEE 7th International Advance computing conference (IACC), pp. 318–321.

Ramli S.S., Jauhari I., Manan H., Ikhwanuddin M., Kasan N.A. (2022). Effect of different C/N ratio, carbon sources, and aeration flow rates on ammonia fluctuations during start-up period of biofloc-based system. Aquacult. Int., 31: 367–380.

Ramsey J., Schemske D.W. (1998). Pathways, mechanisms, and rates of polyploid formation in flowering plants. Annu. Rev. Ecol. Evol. Syst., 29: 467–501.

Rawski M., Mazurkiewicz J., Kierończyk B., Józefiak D. (2020). Black soldier fly full-fat larvae meal as an alternative to fish meal and fish oil in Siberian sturgeon nutrition: The effects on physical properties of the feed, animal growth performance, and feed acceptance and utilization. Animals, 10: 11.

Restrepo L., Donínguez-Borbor C., Bajaña L., Betancourt I., Rodríguez J., Bayot B., Reyes A. (2021). Microbial community characterization of shrimp survivors to AHPND challenge test treated with an effective shrimp probiotic (*Vibrio diabolicus*). Microbiome, 9: 88.

Roderick E. (2004). Monosex tilapia production. Global aquaculture advocate. Available online at: https://www.globalseafood.org/advocate/monosex-tilapia-production/.

Romano N. (2017). Aquamimicry: a revolutionary concept for shrimp farming. The Global Aquaculture Advocate, 1–6. https://www.globalseafood.org/advocate/aquamimicry-a-revolutionary-concept-for-shrimp-farming/ (Access: 27/9/2022).

Rosa J., Lemo M.F.L., Crespo D., Nunes M., Freitas A., Ramos F., Miguel Â.P., Leston S. (2020). Integrated multitrophic aquaculture systems – potential risks for food safety. Trends Food Sci. Technol., 96: 79–90.

Rosen O., Manor R., Weil S., Gafni O., Linial A., Aflalo E.D., Ventura T., Sagi A. (2010). A sexual shift induced by silencing of a single insulin-like gene in crayfish: ovarian upregulation and testicular degeneration. PLoS ONE., 5: 12.

Roy S.S., Pal R. (2015). Microalgae in aquaculture: a review with special references to nutritional value and fish dietetics. Proc. Zool. Soc., 68: 1–8.

Sagi A. (2013). Monosex culture of prawns through androgenic gene silencing. Infofish International. Available at: globalseafood.org/advocate/monosex-culture-of-prawns-through-temporal-androgenic-gene-silencing/.

Sagi A., Afalo E.D. (2005). The androgenic gland and monosex culture of freshwater prawn *Macrobrachium rosenbergii* (De Man): a biotechnological perspective. Aquac. Res., 36: 231–237.

Sagi A., Ra'anan Z., Cohen D., Wax Y. (1986). Production of *Macrobrachium rosenbergii* in monosex population: yield characteristics under intensive monoculture conditions in cages. Aquaculture, 51: 265–275.

Sagi A., Cohen D., Milner Y. (1990). Effect of androgenic gland ablation on morphotypic differentiation and sexual characteristics of male freshwater prawns, *Macrobrachium rosenbergii*. Gen. Comp. Endocrinol., 77: 15–22.

Saha S., Hasan Rajib R., Kabir S. (2018). IoT based automated fish farm aquaculture monitoring system. Proc. International Conference on Innovations in Science, Engineering and Technology (ICISET), pp. 201–206.

Saima M.A., Khan M.Z., Anjum M.I., Ahmed S., Rizwan M., Ijaz M. (2008). Investigation on the availability of amino acids from different animal protein sources in golden cockerels. J. Anim. Plant. Sci., 18: 3–56.

Sandhya S.V., Sandeep K.P., Vijayan K.K. (2020). *In vivo* evaluation of microbial cocktail of microalgae-associated bacteria in larval rearing from zoea I to mysis I of the Indian white shrimp, *Penaeus indicus*. J. Appl. Phycol., 32: 3949–3954.

Sanz-Lazaro C., Sanchez-Jerez P. (2020). Regional integrated multitrophic aquaculture (RIMTA): spatially separated, ecologically linked. J. Environ. Manage., 271: 1–6.

Satoh N., Takaya Y., Takeuchi T. (2009). The effect of docosahexaenoic and eicosapentaenoic acids in live food on the development of abnormal morphology in hatchery-reared brown sole *Pseudopleuronectes herzensteini*. Fish. Sci., 75: 1001–1006.

Sharifinia M., Keshavarzifard M., Hosseinkhezri P., Khanjani M.H., Yap C.K., Smith W.O., Daliri M., Haghshenas A. (2022). The impact assessment of desalination plant discharges on heavy metal pollution in the coastal sediments of the Persian Gulf. Mar. Pollut. Bull., 178: 1–8.

Shefat S. (2018). Vaccines for use in finfish aquaculture. Acta. Scient. Pharmaceut. Sci., 2: 15–19.

Shpigel M., Shauli L., Odintsov V., Ashkenazi N., Ben-Ezra D. (2018). *Ulva lactuca* biofilter from a land-based integrated multi trophic aquaculture (IMTA) system as a sole food source for the tropical sea urchin *Tripneustes gratilla elatensis*. Aquaculture, 496: 221–231.

Shreedharan K., Kulkarni A., Rajendran K.V. (2022). Prospects of vaccination in crustaceans with special reference to shrimp. In: Fish immune system and vaccines, Makesh M., Rajendran K.V. (eds). Springer, Singapore, pp. 181–216.

Sirakov I., Velichkova K., Stoyanova S., Staykov Y. (2015). The importance of microalgae for aquaculture industry. Rev. Int. J. Fish. Aquat., 2: 31–37.

Smith C.A., Roeszler K.N., Ohnesorg T., Cummins D.M., Farlie P.G., Doran T.J., Sinclair A.H. (2009). The avian Z-linked gene DMRT1 is required for male sex determination in the chicken. Nature, 461: 267–271.

Snieszko S.F., Friddle S.B. (1949). Prophylaxis of furunculosis in brook trout (*Salvelinus fontinalis*) by oral immunization and sulfamerazine. Prog. Fish C., 11: 161–168.

Snieszko S., Piotrowska W., Kocylowski B., Marek K. (1938). Badania bakteriologiczne i serologiczne nad bakteriami posocznicy karpi. Memoires de l'Institut d'Ichtyobiologie et Pisciculture de la Station de Pisciculture Experimentale a Mydlniki de l'Universite Jagiellonienne a Cracovie, Nr 38.

Soto D. (2009). Integrated mariculture: a global review. FAO fisheries and aquaculture technical paper no. 529. Food and Agriculture Organization of the United Nations (FAO).

Soto-Rodriguez S.A., Magollon-Servin P., Lopez-Vela M., Sot M.N. (2021). Inhibitory effect of marine microalgae used in shrimp hatcheries on *Vibrio parahaemolyticus* responsible for acute hepatopancreatic necrosis disease. Aquac. Res., 53: 1337–1347.

Su H., Yakovlev I.A., van Eerde A., Su J., Clarke J.C. (2021). Plant-produced vaccines: future applications in aquaculture. Front. Plant Sci., 12: 718775.

Sugita H., Miyajima C., Deguchi H. (1991). The vitamin B_{12}-producing ability of the intestinal microflora of freshwater fish. Aquaculture, 92: 267–276.

Swinscoe I., Oliver D.M., Gilburn A.S., Lunestad B.T., Lock E.J., Ornsrud R., Quilliam R.S. (2018). Seaweed-fed black soldier fly (*Hermetia illucens*) larvae as feed for salmon aquaculture: assessing the risks of pathogen transfer. J. Insects Food Feed, 5: 1–14.

Taher S., Romano N., Arshad A., Ebrahimi M., Teh J.C., Ng W.K., Kumar V. (2017). Assessing the feasibility of dietary soybean meal replacement to the swimming crab, *Portunus pelagicus*, juveniles. Aquaculture, 469: 88–94.

Taketomi Y., Murata M., Miyawaki M. (1990). Androgenic gland and secondary sexual characters in the crayfish *Procambarus clarkii*. J. Crustac. Biol., 10: 492–497.

Tan K., Zhou M., Jiang H., Jiang D., Li Y., Wang W. (2020 a). siRNA-mediated *MrIAG* silencing induces sex reversal in *Macrobrachium rosenbergii*. Mar. Biotechnol., 22: 456–466.

Tan K., Jiang H., Jiang D., Wang W. (2020 b). Sex reversal and the androgenic gland (AG) in *Macrobrachium rosenbergii:* A review. Aquac. Fish., 5: 283–288.

Taranger GL, Carillo M, Schulz R.W., Fontaine P., Zanuy S., Felip A., Weltzien F.A., Dufour Karlsen O., Norberg B., Andersson E., Hausen T. (2010). Control of puberty in farmed fish. Gen. Comp. Endocrinol., 165: 483–515.

Ten Doeschate K.I., Coyne V.E. (2008). Improved growth rate in farmed *Haliotis midae* through probiotic treatment. Aquaculture, 284: 174–179.

Thomas M., Pasquet A., Aubin J., Nahon S., Lecocq T. (2021). When more is more: taking advantage of species diversity to move towards sustainable aquaculture. Biol Rev., 96: 767–784.

Tom A.P., Jayakumar J.S., Biju M., Somaraja J., Ibrahim M.A. (2021). Aquaculture wastewater treatment technologies and their sustainability: a review. Energy Nexus., 4: 1–9.

Troell M., Joyce A., Chopin T., Neori A., Buschmann A.H., Fang J.G. (2009). Ecological engineering in aquaculture – potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. Aquaculture, 297: 1–9.

Ventura T. (2018). Monosex in Aquaculture. In: Marine organisms as model systems in biology and medicine. Results and problems in cell differentiation, Kloc M., Kubiak J. (eds). Springer, Cham, 65.

Ventura T., Sagi A. (2012). The insulin-like androgenic gland hormone in crustaceans: From a single gene silencing to a wide array of sexual manipulation-based biotechnologies. Biotechnol. Adv., 30: 1543–1550.

Ventura T., Manor R., Aflalo E.D., Weil S., Raviv S., Glazer L., Sagi A. (2009). Temporal silencing of an androgenic gland-specific insulin-like gene affecting phenotypical gender differences and spermatogenesis. Endocrinology, 150: 1278–1286.

Ventura T., Rosen O., Sagi A. (2011). From the discovery of the crustacean androgenic gland to the insulin-like hormone in six decades. Gen. Comp. Endocrinol., 173: 381–388.

Ventura T., Manor R., Aflalo E.D., Weil S., Rosen O., Sagi A. (2012). Timing sexual differentiation: full functional sex reversal achieved through silencing of a single insulin like gene in the prawn, *Macrobrachium rosenbergii*. Reprod. Biol., 86: 90.

Verschuere L., Rombaut G., Sorgeloos P., Verstraete W. (2000). Probiotic bacteria as biological control agents in aquaculture. Microbiol. Mol. Biol. Rev., 64: 651–671.

Wang S., Zhou P., Huang X., Liu Q., Lin B., Fu Y., Liu S. (2020). The establishment of an autotetraploid fish lineage produced by female allotetraploid hybrids × male homodiploid hybrids derived from *Cyprinus carpio* (♀) × *Megalobrama amblycephala* (♂). Aquaculture, 515: 1–14.

Wang Y.S., Shelomi M. (2017). Review of BSF (*Hermetia illucens*) as animal feed and human food. Foods, 91.

Wu C., Huang X., Hu F., Ouyang Y., Zhao L., Wang S., Li W., Fan J., Zhang C., Ren L. (2019). Production of diploid gynogenetic grass carp and triploid hybrids derived from the distant hybridization of female grass carp and male topmouth culter. Aquaculture, 504: 462–470.

Xiao J., Zou T., Chen Y., Chen L., Liu S., Tao M., Zhan C., Zhao R., Zhou Y., Long Y., You C. (2011). Coexistence of diploid, triploid and tetraploid crucian carp (*Carassius auratus*) in natural waters. BMC Genet., 12: 1–15.

Xu H., Li Q., Han Z., Li S., Yu H., Kong L. (2019). Fertilization, survival and growth of reciprocal crosses between two oysters, *Crassostrea gigas* and *Crassostrea nippona.* Aquaculture, 507: 91–96.

Yoo G.Y., Lee T.H., Gil H.W., Lim S.G., Park I.S. (2018). Cytogenetic analysis of hybrids and hybrid triploids between the river puffer, *Takifugu obscurus*, and the tiger puffer, *Takifugu rubripes*. Aquac. Res., 49: 637–650.

Yue K., Shen Y. (2022). An overview of disruptive technologies for aquaculture. Aquacult. Fish., 7: 111–120.

Yuvarajan P. (2020). Study on floc characteristics and bacterial count from biofloc-based genetically improved farmed tilapia culture system. Aquac. Res., 52: 1743–1756.

Zamora L. N., Yuan X., Carton A.G., Slater M.J. (2018). Role of deposit-feeding sea cucumbers in integrated multitrophic aquaculture: progress, problems, potential and future challenges. Rev. Aquac., 10: 57–74.

Zeng S., Khoruamkid S., Kongpakdee W., Wei D., Yu L., Wang H., Deng Z., Weng S., Huang Z., He J., Satapornvanit K. (2020). Dissimilarity of microbial diversity of pond water, shrimp intestine and sediment in Aquamimicry system. AMB Express, 10: 1–1.

Zhang Y., Zhang Y., Wang Z., Yan X., Yu Z. (2014). Phenotypic trait analysis of diploid and triploid hybrids from female *Crassostrea hongkongensis* × male *C. gigas*. Aquaculture, 434: 307–314.

Zhang Y., Qin Y., Yu Z. (2022 a). Comparative study of tetraploid-based reciprocal triploid Portuguese oysters, *Crassostrea angulata*, from seed to market size. Aquaculture, 547: 1–8.

Zhang P., Peng R., Jiang X., Jiang M., Zeng G. (2022 b). Effects of *Nannochloropsis oculata* and *Thalassiosira pseudonana* monocultures on growth performance and nutrient composition of *Litopenaeus vannamei*. Algal. Res., 66.

Zheng L., Crippen T.L., Singh B., Tarone A.M., Dowd S., Yu Z., Wood T.K., Tomberlin J.K. (2013). A survey of bacterial diversity from successive life stages of black soldier fly (Diptera: Stratiomyidae) by using 16S rDNA pyrosequencing. J. Med. Entomol., 50: 647–658.

Zhou Q.C., Buentello J.A., Gatlin III D.M. (2010). Effects of dietary prebiotics on growth performance, immune response and intestinal morphology of red drum (*Sciaenops ocellatus*). Aquaculture, 309: 253–257.

Zokaeifar H., Balcazar J.L., Saad C.R., Kamarudin M.S., Sijam K., Arshad A., Nejat N. (2012). Effects of *Bacillus subtilis* on the growth performance, digestive enzymes, immune gene expression and disease resistance of white shrimp, *Litopenaeus vannamei*. Fish Shellfish Immunol., 33: 683–689.

Zozo B., Wicht M.M., Mshayisa V.V., Wyk J.V. (2022). The nutritional quality and structural analysis of black soldier fly larvae flour before and after defatting. Insects, 13: 168.

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