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Review Article

Current Trend and Future Perspective of Shrimp Aquaculture in Malaysia: A Review

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ABSTRACT

The requirement for high-quality shellfish aquaculture production, especially shrimp, is increasingly in demand. Currently, shrimp aquaculture has become one of Malaysia's food security measures, which is consistent with the Sustainable Development Goals (SDGs) adopted by the United Nations' 2030 vision for food security and zero hunger. The outbreaks of diseases such as Acute hepatopancreatic necrosis disease (AHPND), Early mortality syndrome (EMS), White spot syndrome virus (WSSV), and infestation of virulence vibriosis bacterial, *V. parahaemolyticus* and *V. harveyi* contributed a significant loss in the shrimp aquaculture production all around the world, as well as shrimp aquaculture production in Malaysia. Due to its major importance, the objectives of this review paper is to introduce the shrimp and prawn cultures in Malaysia emphasized on the current technology and research developed in shrimp aquaculture in Malaysia including the application of biofloc technology, the therapeutics treatment application in shrimp culture, monosex culture of all males using neo-female technology, the current trend of the shrimp production in Malaysia and on the future perspective of shrimp aquaculture in Malaysia. This review paper will generate more information, knowledge, application technology

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and beneficial findings on the shrimp aquaculture, especially for farmers and aquaculturists, in order to generate a high-quality seafood production of shrimp in the future and also to achieve the SDGs goals as well.

Keywords: Aquaculture, current technology, current trends, future perspective, Malaysia, shrimp

INTRODUCTION

Global food production systems have undergone substantial transformation, where aquaculture sectors have emerged as a leading contributor to the supply of proteins from aquaculture products. Its rapid expansion has played a significant role in strengthening the seafood security, supporting economic development, and providing essential nutrition, particularly in developing countries (Food Agricultural Organisation [FAO], 2018; Naylor et al., 2000). Within this growing sector, shrimp aquaculture has become one of the most economically valuable industries, supported by strong export demand, technological progress, and increasingly intensive production practices (FAO, 2018). By the year 2050, aquaculture production is expected to produce up to 129,000 Kt to support the world population's demand (Boyd et al., 2022). As a result, shrimp farming now represents a major source of seafood production and revenue generation, especially across Southeast Asian countries. In Malaysia, shrimp aquaculture is an essential component of the aquaculture industry and contributes directly to the national food security initiatives. The expansion of farming activities involving key commercial species such as Tiger shrimp, *Penaeus monodon* and Whiteleg shrimp, *Litopenaeus vannamei,* has been driven by their high profitability and suitability for intensive aquafarming systems (Liao & Chien, 2011). However, maintaining sustainable shrimp aquaculture production remains a challenging issue due to the increasing environmental pressures, widespread disease, and limitations in biosecurity implementation.

The occurrence of infectious diseases continues to be a major obstacle in shrimp aquaculture worldwide. Diseases and pathogens outbreaks such as White Spot Syndrome Virus (WSSV) and bacteria responsible for Acute Hepatopancreatic Necrosis Disease (AHPND) have caused widespread mass mortality and significant economic damage in leading shrimp-producing regions, including Malaysia (De Schryver et al., 2014; Lightner, 2011; Tran et al., 2013). The rapid spread and recurring nature of these diseases demonstrate the susceptibility of high-density farming systems and highlight the importance of strengthening health management frameworks (Flegel, 2012; Stentiford et al., 2012). In response, the industry has adopted various innovations and technologies aimed at improving production efficiency and environmental sustainability. Biofloc technology, for example, has gained importance as an eco-friendly technology and innovative aquaculture technology system from the application of natural microbial biotechnology that has proven to enhance the good water quality, facilitate nutrient recycling, prevent pathogenic and disease outbreaks, as well as help minimise the reliance on conventional feed inputs (Manan et al, 2017). Furthermore, advancements such as the use of probiotics, refined pond management strategies, and selective breeding techniques have contributed to improving resilience against diseases and better overall aquaculture productivity (De Schryver et al., 2014).

Despite these developments, several issues persist within the Malaysian shrimp aquaculture sector, including disease control, environmental impacts, and consistency in the shrimp aquaculture production performance. Therefore, it is necessary to critically examine current industry practices, recent technological and innovation progress, and future development and trends pathways in the shrimp aquaculture field. This review aims to provide a comprehensive assessment of shrimp aquaculture in Malaysia, focusing on present trends, technological innovations, and future directions to support the development of a sustainable and resilient industry aligned with global food security goals.

SHRIMP AND PRAWN CULTURED IN MALAYSIA

In the 1990s, the main production of marine shrimp in Malaysia was dominated by *Penaeus monodon* (Giant Tiger Shrimp), which is popular among Malaysian farmers. Throughout the years, with the increase in stocking density, farmers have witnessed frequent shrimp diseases in the farm. In 1999, the occurrence of white spot syndrome virus (WSSV) badly hit *P. monodon* in Peninsular Malaysia and caused major loss in the shrimp production during that time. Due to this, farmers shifted their interest into culturing specific pathogen-free (SPF) *Penaeus vannamei* (Whiteleg shrimp). Over 20 years later, rapid production of *P. vannamei* could be seen, which has contributed 72% of the production, followed by 21% of *P. monodon* and 1% of *Penaeus merguiensis* (Chowdhury et al., 2013). The morphological characteristics of shrimp and prawn cultured in Malaysia are as described in Table 1.

Penaeus monodon

Penaeus monodon is one of the largest penaeid shrimp in the world and has dominated the shrimp aquaculture production in Malaysia in the 1990s. It is very popular among Malaysian farmers due to its high market value. In the wild, adult *P. monodon* are found only in tropical marine areas. Meanwhile, larvae, juveniles, adolescents, and sub-adults usually will grow in the estuaries, coastal lagoons and mangrove areas. It is also a nocturnal species, which means they prefer to burrow into the bottom substratum during the day and emerge at night in search of food as a benthic feeders. In nature, *P. monodon* is likely more of a predator rather than an omnivorous scavenger or detritus feeder than other penaeid shrimp (FAO, 2009). The adults of *P. monodon* are often found at 20-50-meter depth in offshore water over muddy sand or sandy bottoms.

Table 1
Morphological characteristics of shrimp and prawn cultured in Malaysia (Fisheries Research Institute Malaysia [FRIM], 2021)

Common Name	Scientific Name	Morphological Characteristic
Black Tiger shrimp	*Penaeus monodon*	Body green-grey or dark greenish blue. Becoming reddish brown in large adults; the carapace is covered with mud-yellow transverse bands. Carapace with grooves and crest distinct; rostrum with 6-8 teeth.
Whiteleg shrimp	*Penaeus vannamei*	Body colour translucent white, but can change depending on feed, substrate and water turbidity. Body laterally compressed, elongated decapods, well-developed abdomen, adapted for swimming, rostrum moderately long,7-10 dorsal teeth.
Banana shrimp	*Penaeus merguiensis*	It has 6-9 dorsal teeth. Rostrum with a high blade and teeth above and below. Hepatic crest absent, and gastro-orbital ridge absent or very feebly defined.
Giant Freshwater prawn	*Macrobrachium rosenbergii*	It has a very long rostrum,11-14 dorsal teeth; the male is larger than the female of the same age. An adult male has very long second chelipeds.

The mating and spawning usually occur at night shortly after moulting, while the cuticle is still soft. Subsequently, sperm kept in a spermatophore (sac) will be inserted inside the closed lycum of the female. The fertilisation occurs externally with the female suddenly extruding sperm from the lycum, and eggs are then laid in offshore waters. The eggs usually will hatch out after 12-15 hours of fertilisation (FAO, 2009). Due to persistent demand from the global market, *P. monodon* has been commercially cultured by the farmers. The increasing density and high production of *P. monodon* have led to disease outbreaks in the commercial farms. The white spot syndrome (WSS) was first observed in Peninsular Malaysia in 1994, affecting more than 80% of the shrimp farms, especially during the rainy season. The shrimp will die within 3 to 7 days after the appearance of white spots on the cuticle (Wang et al., 2000).

Penaeus vannamei

The devastating effect of white spot syndrome virus (WSSV) on the production of *Penaeus monodon* has encouraged Malaysian farmers to shift their shrimp production to the *P. vannamei*. This species has shown a faster growth rate, higher survival rate, high tolerance to ammonia and nitrate, and a wide range of adaptation to different salinities. Due to this, specific pathogen-free (SPF) *P. vannamei* was then introduced in Malaysia in 1999 (Kua et al., 2018).

Till then, production of *P. vannamei* in Malaysia has increased successfully, with the total production in 2010 reaching 69,084 tonnes, which is 50 times higher than *P. monodon* (Kua et al., 2018).

However, *P. vannamei* is non-indigenous to Malaysia, and concerns about disease outbreaks listed by the World Organisation for Animal Health (OIC), for example, Taura syndrome virus (TSV), infectious myonecrosis (IMNV) and infectious hypodermal and haematopoietic necrosis virus (IHHNV) may pose a greater risk to aquaculture in Malaysia. In 2006, Indonesia reported mass mortality of *P. vannamei* caused by IMNV. Three years later, IMNV and TSV were reported to have caused mass mortality in cultivated *P. vannamei* in Indonesia. While in Malaysia, it was reported that there were multiple bacterial infections, which included *V. parahaemolyticus* in the farms (Kua et al., 2018).

As the disease in the cultivation of shrimp farming continues to affect the shrimp production in Malaysia, attempts are required to implement biosecurity strategies in the culture system. The status of SPF *P. vannamei* only refers to its sanitary status and is not hereditary. The SPF *P. vannamei* means that the shrimp is free from certain pathogens, but is not free from all pathogens. Therefore, if the SPF shrimp is exposed to a pathogen, the SPF status is no longer valid. Thus, the implementation of biosecurity in the shrimp cultivation needs to be regularly audited to ensure a low risk of disease outbreaks in the future.

Penaeus merguiensis

The *Penaeus merguiensis* is one of the commercial shrimp species in the region of Indo-Pacific, including Australia, New Guinea, Indonesia, Malaysia, the Philippines, India, and Pakistan (Manan et al., 2012). Unfortunately, this species has been overlooked by farmers due to its slow growth rate compared to *P. monodon*. According to Hoang et al. (2002), the distribution of *P. merguiensis* in the subtropical south-east Queensland implies its ability to withstand cold water temperature. The *P. merguiensis* has been observed to withstand temperatures not lower than 9 °C and temperatures above 18 °C, which is found to consume a wide range of food, for example, crustacean, vegetable matter, phytoplankton, squids and molluscs.

However, the selection of natural food is still necessary to enhance the reproductive performance of *P. merguiensis.* The production of high-quality larvae and post-larvae of *P. merguiensis* is highly dependent on the broodstock condition. Memon et al. (2012) found that *P. merguiensis* fed with fresh squid has a stronger influence on increasing spermatophore quality. It was observed that *P. merguiensis* produces fully matured sperms at the 6th week after being fed with fresh squid. Attempts have been made by Manan et al. (2012) to induce triploidy in *P. merguiensis*. The result showed that a temperature of 15 °C for durations of 10, 15, and 20 minutes is the optimum parameter to induce triploid in *P. merguiensis* by using cold shock treatment.

Macrobrachium rosenbergii

In Malaysia, *Macrobrachium rosenbergii* is locally known as "udang galah". It is popular among Malaysian farmers and is now being cultured on a large scale. The *M. rosenbergii* is a native species in Southeast Asia and is the most important aquaculture species. It is also known as the largest freshwater prawn species. The adult male of this freshwater prawn, *M. rosenbergii,* has been reported with a total body length of 35cm, and the adult female can reach about 29cm (FAO, 2002). The larvae of *M. rosenbergii* need brackish water to survive during early development. Therefore, during spawning season, fully mature females of *M. rosenbergii* will migrate from freshwater to the estuarine. The free-swimming larvae hatched from the eggs will stay attached to the female abdomen. After three to six weeks, the larvae will metamorphose into post larvae and migrate upstream towards freshwater (FAO, 2002). However, without exception, *M. rosenbergii* is also susceptible to disease caused by the parasites, bacteria and also viruses (Table 2).

TECHNOLOGY AND RESEARCH DEVELOPED FOR SHRIMP AQUACULTURE IN MALAYSIA

Biofloc Technology for Shrimp Cultures

Shrimp aquaculture is an essential sector of the Malaysian agriculture industry, contributing significantly to socio-economic development. Among cultured species, the Whiteleg shrimp (*Penaeus vannamei*) is increasingly dominant, representing a key brackish water species and the main contributor to national shrimp production (Ghee-Thean et al., 2016). Due to its growing importance, bio-secured farm designs combined with biofloc technology are well-suited for shrimp aquaculture (Taw et al., 2011). Biosecurity measures include 250-micron mesh screening for water, crab fencing, bird deterrents, water ageing, and controlled movement of farm workers, equipment, and visitors (Taw et al., 2011).

Table 2
List of common diseases in M. rosenbergii (FAO, 2022)

Type of Infection	Common disease
Parasites	Protozoan infestation E.g.: *Zoothamnium* sp., *Vorticella* sp., and *Epistylis* sp.
Bacteria	E.g.: *Vibriosis*
Virus	E.g.: Macrobrachium hepatopancreatic parvo-like virus (MHPV), Macrobrachium muscle virus (MMV), infection hypodermal & hematopoietic necrosis virus (IHHNV), white spot syndrome virus (WSSV), *Macrobrachium rosenbergii* nodavirus (MrNV), extra small virus-like particle (XSV).

Taw et al. (2011) reported significant production improvements compared to previous years, with shrimp reaching 18.8 g in 90 days at a stocking density of 130 PL/m² using biofloc technology. Taw (2017) further noted the successful implementation of a bio-secured modular recirculating aquaculture system (RAS) combined with biofloc technology at Blue Archipelago Farm since October 2011, with no reported cases of EMS or AHPND. This system was designed to treat incoming and wastewater, enhancing biosecurity and disease prevention.

Meanwhile, the Fisheries Research Institute in Gelang Patah, Johor, Malaysia, is developing a new breeding technology to enhance prawn production. This three-year pilot project, involving three prawn breeders, will be tested in Johor and Pahang to support income generation for local fishermen and farmers. Biofloc technology, comprising diverse microbial communities, is recognised as a green technology that reduces environmental impact and enhances aquaculture productivity (Kasan et al., 2017). Biofloc aggregates also contain phytoplankton, zooplankton, protozoa, nematodes, and algae, serving as an additional protein-rich feed source for shrimp (Manan et al., 2017).

Biofloc-associated bacteria such as *Halomonas venusta*, *Halomonas aquamarina*, *Bacillus infantis*, *Bacillus cereus*, *Nitratireductor aquimarinus*, and *Pseudoalteromonas* spp. are known bioflocculant producers that support early biofloc formation and improve water quality for sustainable aquaculture (Kasan et al., 2017). Another study by Manan et al. (2022) identified 43 bacterial species in *P. vannamei* biofloc culture ponds, including *Exiguobacterium* spp., *Bacillus* spp., *Vibrio* spp., *Acinetobacter junii*, *Cobetia marina*, *Rheinheimera aquimaris*, and *Pseudoalteromonas* spp., primarily isolated using HPC agar. The bacteria *Exiguobacterium aestuarii* and *Exiguobacterium profundum* were observed to be dominant in the shrimp biofloc pond sample, where these organisms are capable of producing the extracellular enzyme activity to break down the chemical structures, thus benefiting in eliminating the organic compounds from the aquaculture waste.

According to Taw (2013), the application of biofloc technology for biosecurity could enhance the sustainable aquaculture production by reducing the outbreak of disease outbreak problems and the cost of energy in the shrimp farm operation in Arca Biru Kedah shrimp Farm, Blue Archipelago, Malaysia. The application of biofloc technology also really contributed to natural bioremediation in the zero or minimal water exchange system, improving the shrimp growth performance (Manan et al., 2020) and maintaining the water quality at the optimum level until the end of the culture period (Manan et al., 2017).

Therapeutic Treatment in Shrimp Aquaculture

On the other hand, a research study on a small scale was conducted in the laboratory by Ikhwanuddin et al. (2014) on the therapeutic activity effect of Indian almond, *Terminalia catappa* leaves extraction on the survival rate and growth performance of Tiger shrimp, *Penaeus monodon* postlarvae. It was identified that a 3.0 mg/L concentration of *T. catappa* leaves extraction showed a positive effect on the survival rate and growth performance of *P. monodon* postlarvae. Meanwhile, Kawamura et al. (2019) identified that peppermint, *Metha piperita,* enhanced the feeding activity on giant freshwater prawn, *Macrobrachium rosenbergii,* in all stages except during larvae stage, and the garlic application also enhanced the feeding for the freshwater prawn during juveniles and postlarvae stages. Syahidah et al. (2015) found that garlic was identified as a strong food calling effect as an appetite stimulator for fish, and the bioactive compound in garlic, known as alicin, was identified to help in food ingestion and increase the feed intake in fish. On top of that, the red chilli, *Capsicum annuum,* was identified as the beed feeding attractant for Whiteleg shrimp, *L. vannamei* and ginger, *Zingiber officinale* and papermint as moderate attractants for adults and juvenile shrimp of *L. vannamei* (Kawamura et al., 2019). The therapeutic effect from natural plants was reported to promote positive effects such as stress reduction, promoting growth, appetite stimulator and promoting immunostimulants in aquatic animals (Citarasu, 2010). Several herbal supplements inclusion in the food conducted in 90 days trial also identified help enhance the food intake in crustacean like ginger (*Zingiber officinale*), turmeric (*Curcuma longa*) and garlic (*Allium sativum*) help enhanced the food intake in giant freshwater prawn, *M. rosenbergii* (Rebecca & Bhavan, 2014). The turmeric, *Curcuma longa,* also proven contains a good source of antioxidants and helps increase the survival rate of giant freshwater prawn, *M. rosenbergii* (Rebecca & Bhavan, 2014).

The Use of Probiotics in Shrimp Aquaculture

A study conducted by Mohamad et al. (2020) on the effects of potential probiotics of Lactic Acid Bacteria (LAB) of *Lactobacillus plantarum* and *Entercoccus faecalis* isolated from *M. rosenbergii* prawn found that these probiotics help in improving the aquaculture species growth performance, survival rate, and also help improve the immunity response towards disease infection in the aquaculture operation. Andani et al. (2012) identified that most of the probiotics are supplied as live supplements in the feed to benefit the culture organisms by inhibiting the pathogenic microbes, improving the immunity, survival and growth rate, enhancing the digestion and feed utilisation of the culture organisms, as well as helping improve the water quality in the culture system.

The application of probiotics in aquaculture helps degrade the organic matter in the pond water, stabilises the microbial community for the health ecosystem and also helps maintain the natural environments in the safety and optimum level for the shrimp culture. Currently, many shrimp farmers are applying the new technology of probiotics in their shrimp farms to improve the farm production yield with good aquaculture practices for the sustainability of seafood safety and quality. For example, the probiotics from the *Bacillus subtilis* strain can help inhibit the effect against vibriosis infection in Tiger shrimp, *Penaeus monodon* (Vaseeharan & Ramasamy, 2003).

Monosex Culture Technology

The production using monosex culture also comes into focus as the technique helps increase the aquaculture production (Manan & Ikhwanuddin, 2021). The application of triploidy to the penaeid shrimp in the laboratory scales seems to help increase the shrimp size, faster the shrimp growth rate and also successfully induce monosex culture as well as other techniques of polyploidy, gynogenesis and hormone treatments (Manan & Ikhwanuddin, 2021). Another study conducted by Ikhwanuddin et al. (2019) identified 100% feminisation of *Penaeus merguiensis* postlarvae using 17β-estradiol, an estrogen hormone, with a concentration of 1600 mg/kg.

The monosex culture of all females is economically beneficial and helps increase yield production due to its faster growth rate compared to male culture or mixed cultures (Ikhwanuddin et al., 2019). Another technique using gynogenesis manipulation also could be applied to generate a monosex culture of all-female type offspring with diploid gynogens of fish and crustacean produces (Manan et al., 2020). The monosex culture of all female type offspring from the gynogenesis technique, it could produce female gynogens with better size than males and subsequently can help increase the market size, yield and profitability (Manan et al., 2020).

Micro Bubble Aeration Technology

The application of a micro bubble aeration system was applied in the nursery and pond of shrimp culture in Malaysia in order to help reduce the cost and environmental impact of the shrimp farming. The application of this newly efficient technology is to reduce the amount of water required for shrimp aquaculture by improving the water cleanliness and reducing the effluent and costing for effluent treatment. *M. rosenbergii*, or locally known as the Giant freshwater prawn, is one of the essential commercial aquaculture species that is being given a top priority by the Department of Fisheries Malaysia (DOF) as a seafood product for consumer consumption and also for exportation (Banu, 2014).

Giant freshwater prawn was commonly found in the river and estuaries of tropical and subtropical countries where this species was identified as a significantly important culture species in many countries such as China, India, Bangladesh, Thailand, Vietnam, Malaysia and Brazil (Tan et al., 2020). Asaduzzaman et al. (2006) identified that the culture of all male prawn, *M. rosenbergii,* resulted in higher production than the mixed culture. Banu (2014) conducted research on male Giant freshwater prawn, identifying that male juveniles of *M. rosenbergii* were homogenous after the cold shock treatments and, on the other hand, were heterogeneous after being treated with 17a methyl testosterone hormone.

Neo-female Technology Application for the Production of all Male *M. rosenbergii* Prawn

Males of *M. rosenbergii* grew faster and reached a larger size during harvest compared to the females of the same species. A culture of all-male prawns can increase both production and profit because male prawns can exhibit a faster growth rate compared to female prawn from similar age (Tan et al., 2020). Therefore, a monosex culture of all male prawns would be advantageous to the economic increments. Sagi and Cohen (1990) found out that in crayfish, lobster, spiny lobsters, shrimp and prawn have a WZ-ZZ scheme, where male identified as the homogametic sex. It was identified that the androgenic gland (AG) in crustacean endocrine produced insulin-like androgenic gland (IAGO) hormone for sex differentiation, where without this AG or a deficiency of IAG will result in feminisation (Levy & Sagi, 2020).

Removal of the AG through the AG ablation or microsurgical intervention from the immature male will result in sex reversal into neo-females, which are capable of mating with normal males to produce all-male offspring (Sagi & Aflalo, 2005). Due to its importance, GK Aqua Sdn. Bhd. located in Peninsular Malaysia, was established in 2016 and currently applies the neo-female technology to produce all male *M. rosenbergii*. GK Aqua imported the neo females post larvae from the hatchery of China and Vietnam, where this PL was produced through the gene silencing technology and a complete sex reversal from male into functional neo-females. This neo female broodstock could produce up to 100% male offspring due to the chromosome pairing during mating with the normal male prawn.

On the other hand, GK Aqua also try to produce the neo-female by injecting RNAi silencing chemical, also known as insulin-like androgenic gland hormone, into the normal male prawn, that prevented it from being male and then sex reversal into a neo-female. The use of the RNAi injected into the prawn seems to be safe due to its temporary nature, where the exogenous dsRNA was fully cleared from prawn tissue within 7 days (Lezer et al., 2015). This technique is not a genetically modified product, as there are no hormones or chemicals used. About 1.2 metric tons of all male prawns can be produced every six months with the good survival rate between 60% to 70% of survival (Habib, 2017).

PRODUCTION OF SHRIMP AQUACULTURE IN MALAYSIA

Global aquaculture production continues to rise, with shrimp farming being a major contributor (Hidayati et al., 2020). Since its emergence in the 1920s, aquaculture has grown rapidly and is now a key sector for economic development and food security in Malaysia. Surrounded by rich water bodies, Malaysia hosts diverse shrimp species and ranks as the ninth-largest shrimp exporter globally. The demand for Malaysian shrimp has increased steadily since the 19th century, coinciding with the growing popularity of aquaculture.

Shrimp aquaculture plays a crucial role in Malaysia's agricultural sector by contributing to food supply, GDP growth, employment, and economic development (Ghee-Thean et al., 2016; Lee et al., 2020). There were several main commercial shrimp or prawn species that contribute as a vital economic pillar in the industry of many countries, including Malaysia, which are *Penaeus monodon*, *Penaeus vannamei* and *Macrobrachium rosenbergii* (Soo et al., 2019). Among these, *P. vannamei* is the dominant species in brackish water culture, accounting for 89% of total farmed shrimp production, followed by *P. monodon* (10%) and *M. rosenbergii* (1%) (Ghee-Thean et al., 2016; Muthukrishnan et al., 2019).

Shrimp farming in Malaysia covers an estimated 5,100 hectares (Chowdhury et al., 2013). In 2020, brackish water and freshwater aquaculture productions were 302,807 tonnes and 97,210 tonnes, respectively (Department of Fisheries Malaysia [DOF], 2020). Aquaculture in Malaysia is categorised into brackish water, freshwater, and marine culture, with brackish water aquaculture being the dominant practice (FAO, 2022; Lee et al., 2020). The main cultured species include Tiger shrimp (*Penaeus monodon*), White shrimp (*Penaeus vannamei*), and Giant freshwater prawn (*Macrobrachium rosenbergii*), primarily farmed in pond systems (DOF, 2020; Ismail & Abdullah, 2013).

Brackish water shrimp, including *P. monodon* and *P. vannamei*, contribute 49.80% to the wholesale value of aquaculture production in Malaysia (DOF, 2020). In 2017, shrimp and prawn exports, including live, fresh, or frozen forms, totalled RM1.2 billion from 51,481 tonnes of production (DOF, 2017). These exports mainly went to Singapore, Vietnam, Australia, China, Japan, Taiwan, Korea, Hong Kong, and the European Union. While Tiger shrimp production has gradually increased over the past decade, it remains lower than that of White shrimp.

The production of White shrimp and Giant freshwater prawn significantly increased between 2013 and 2014 but declined substantially in 2020 (DOF, 2011-2020) (Figure 1). This decrease was due to the global COVID-19 pandemic, which disrupted economic activities, including Malaysia's aquaculture sector, as countries imposed strict quarantine measures (Pazir et al., 2022; Waiho et al., 2020). According to a FAO (2020) report, high-value commodities like shrimp were particularly vulnerable to COVID-19, facing export limitations from flight closures and a major decline in sales to hotels and restaurants.

As shrimp is the most traded fishery commodity in Malaysia, that contribute to the 53400 tonnes with a total wholesale value production of RM1.2 million (49.77% of total aquaculture production) in 2019 (DOF, 2019), this pandemic has adversely impacted the national economy of Malaysia as shown in Figure 1. Past research analysis across 26 countries also showed that this global pandemic severely disrupted and significantly decreased business sales during the lockdown or during the Malaysian movement control order (MCO) periods (De Vito & Gomez, 2020). Among the documented affected countries of shrimp production are Bangladesh shrimp (Rahman et al., 2021) and Iran shrimp (Pazir et al., 2022), as the demand for seafood has reduced and led to the collapse of the supply chain drastically.

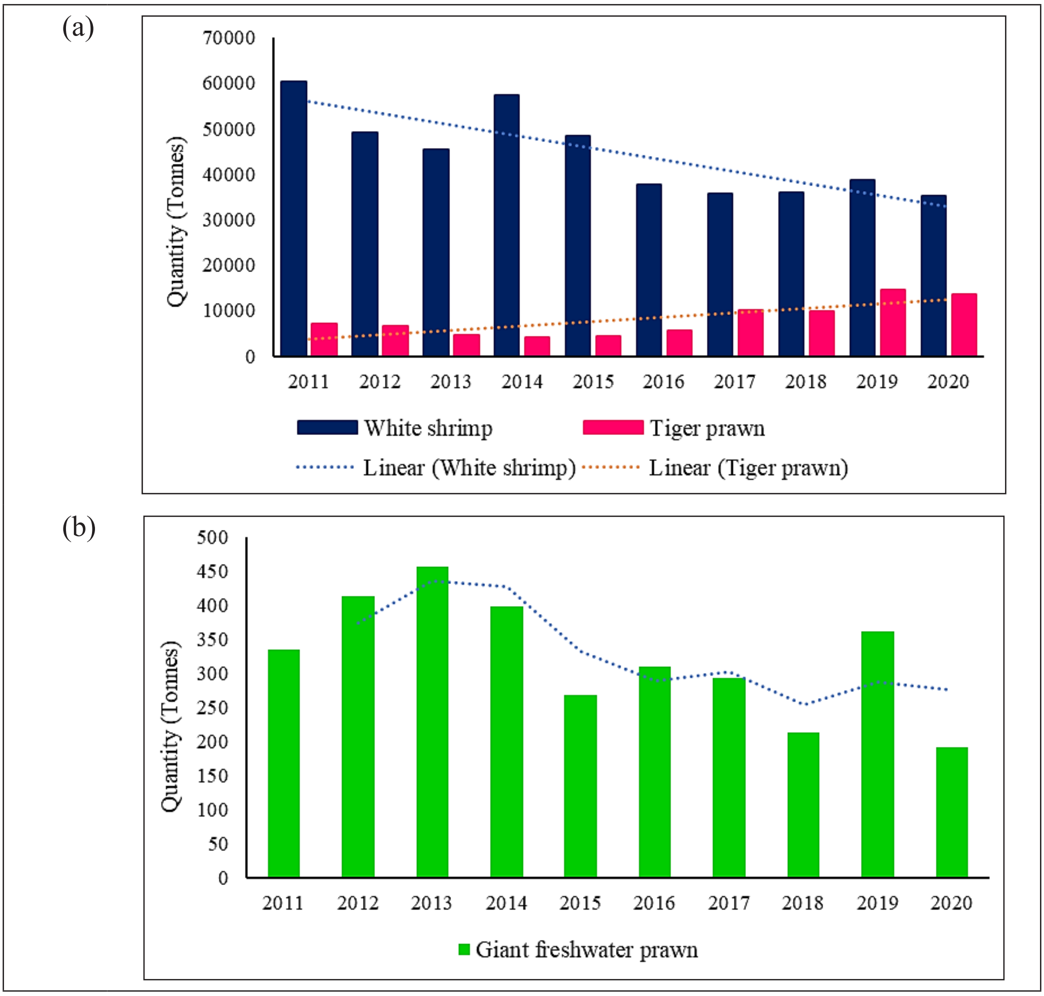

Figure 1. Aquaculture production of (a) White shrimp and Tiger prawn from brackish water culture system and (b) giant freshwater prawn from freshwater culture system from 2010 to 2020. (Department of Fisheries Malaysia, 2019)

However, during the COVID-19 pandemic lockdown, the aquaculture sector was given permission by the government to re-establish the new normal operation to ensure food security in Malaysia (Waiho et al., 2020). Although the total of white shrimp production decreased during COVID-19, some states of Malaysia showed improved culture production, such as Perlis, Perak, Selangor, Johor, Terengganu, Kelantan and Sarawak. Meanwhile, for tiger shrimp, Perlis, Kedah, Negeri Sembilan, Melaka, Johor, Pahang and Terengganu exhibited an increase in culture production. The aquaculture production of giant freshwater prawn indicated a decline for most of the states, except Kedah, which showed an increase in production (DOF, 2019; 2020) (Figure 2).

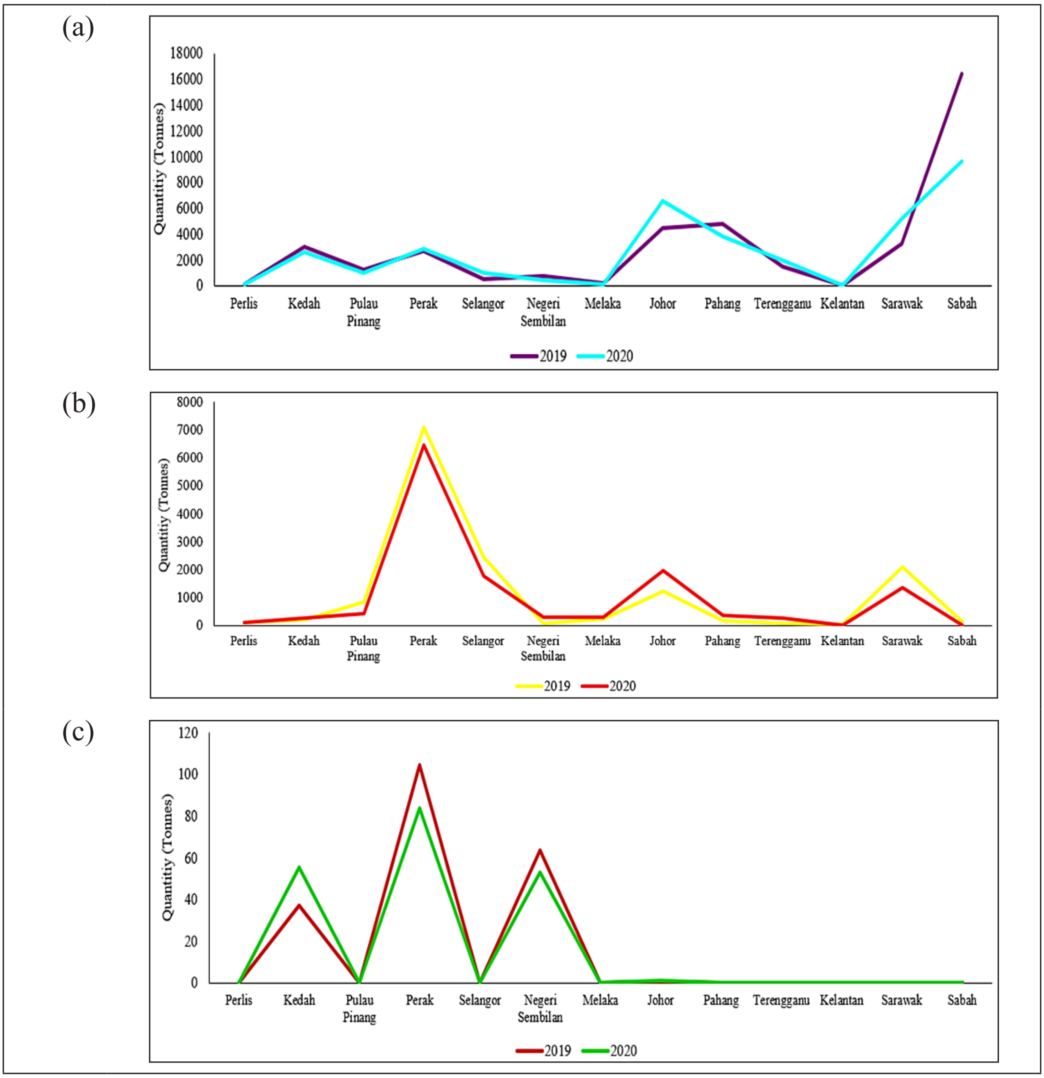

Figure 2. Aquaculture production of shrimp by state and species (a) white shrimp, (b) tiger prawn and (c) giant freshwater prawn in 2019 to 2020 (Department of Fisheries, 2019; 2020)

Five components in the marketing channel have been practised for the production of aquaculture white shrimp, which are the shrimp farmer, distributor, wholesaler, retailer and consumer (Lee et al., 2020) (Figure 3). The shrimp farmer sells the shrimp to the distributor for RM16 per kilogram, and the distributor then sells the shrimp to the wholesaler for RM18 per kilogram. While white shrimp sell for RM20 per kilogram at wholesale, they cost RM23 per kilogram at retail price. The total cost of marketing is RM7 per kilogram. Due to the fact that there is little gap between the channels, the marketing channel is highly effective (Lee et al., 2020).

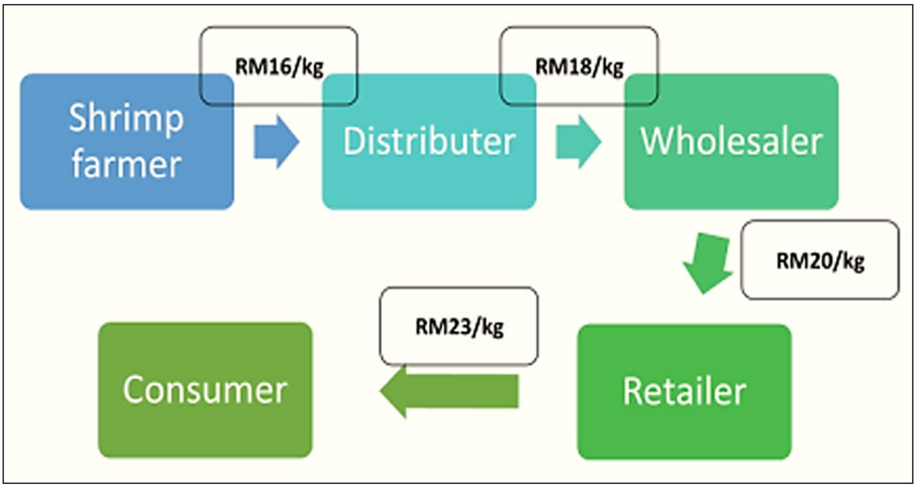

Figure 3. Five components involved in the marketing channel for the production of white shrimp in Kedah started from the shrimp farmer, until reaching the consumer (Lee et al., 2020)

Therefore, with the new strategies and implementation by the Malaysian government and other agencies in supporting the economic initiatives from production to marketing strategies, it is expected to decrease the distractions and losses caused by COVID-19 (Waiho et al., 2020).

CURRENT TREND IN SHRIMP PRODUCTION IN MALAYSIA

Status of Shrimp Production in Malaysia

Shrimp production in Malaysia has steadily increased since the 19th century, contributing to its status as the 9th largest shrimp exporter globally. Currently, 45% of Malaysia's shrimp production comes from capture fisheries, and 55% from aquaculture (Mohd-Haikal & Mohammad-Mustafizur, 2019). With a coastline of 4,809 km and a land area of 329,750 km², Malaysia has developed 5,100 hectares for shrimp farming, including both brackish water and freshwater culture (Chowdhury et al., 2014). The first marine shrimp farm was established in Johor in the 1930s and upgraded to semi-intensive culture in the 1970s (FAO, 2022).

The establishment of privately-owned shrimp hatcheries, farms, and food factories in the 1980s helped commercialise aquaculture in Malaysia. Currently, shrimp culture has experienced a 10% annual growth rate over the past five years, evolving into a profitable and sustainable industry, particularly with high-value species. In 2020, Malaysia's largest shrimp production was from White shrimp, with 35, 063.90 tonnes from ponds and 84.75 tonnes from tank systems. Following disease outbreaks in 2001, production shifted from Tiger shrimp to White shrimp, which now constitutes about 67% of aquaculture shrimp production (Chowdhury et al., 2014). In 2002, aquaculture exports, including shrimp, to Japan totalled 198,892 tonnes, valued at RM1.5 billion.

Then, there were 94 shrimp hatcheries listed in 2003, with an estimated total production of 12 billion fries per year (Mazuki & Subramanian, 2005). In 2010, the total production of marine shrimp from Malaysia reached 87,202 tonnes with a total value of 0.35 billion USD, and simultaneously with that, Malaysia successfully listed as one of the top countries in the world's shrimp production (Chowdhury et al., 2014). The main culture system practices for shrimp culture in Malaysia are ponds, concrete tanks and cages, while the largest harvest is mainly obtained from brackish water. According to the Department of Fisheries Malaysia statistics 2020, the large share of giant freshwater prawn and crayfish harvest in 2020 came from the freshwater pond culture system, which is 191.32 tonnes and 57.43 tonnes respectively, compared to freshwater tank culture, which only produced 1.37 tonnes of Giant freshwater prawn and 6.95 tonnes of crayfish.

Meanwhile, the biggest production of the brackish water species also mostly comes from the pond culture system, which is tiger shrimp, and white shrimp produced 13,524.76 tonnes and 35,063.90 tonnes, respectively, as compared to the tank culture system, which only produces white shrimp with the production of 84.75 tonnes. On the other hand, the lobster culture in brackish water mostly comes from the cage culture system, with total production in 2020 being 0.22 tonnes. The selection of ponds (earthen pond or semi-earthen pond) as an aquaculture system for shrimp culture is more popular in Malaysia, probably due to the simple design and easy to build, low construction costs, long-lasting system, larger stocking density per pond, can generate live feed which can support nutrition supply to the livestock and low maintenance costs. Furthermore, the clay soil can stabilise the bottom of the earthen pond and absorb numerous nutrients and organic matter, thus increasing the productivity of the pond (Khai et al., 2011).

Based on Annual Fisheries Statistics (DOF, 2016; 2017; 2018; 2019; 2020) (Table 3), the overall total production of shrimp was the highest in 2019, with the production of 53,619.28 tonnes valued at RM1,169,099.61 and at the lowest in 2016 with the production of 43,563.04 tonnes valued at 9,355,982.34. The production of freshwater shrimp is highest in 2016 with a total production of 309.34 tonnes valued at RM7,350.34, and at the lowest is in 2019 with a total production of 205.58 tonnes valued at RM12,757.12. Then, the production in 2020 increased by 25.05%, which is 257.07 tonnes valued at 16,265.23. Meanwhile, the production of marine shrimp started low in 2016 with a total production of 43,253.61 tonnes valued at RM43,252.61 and gradually increased in the following year and reached the highest production in 2019, which is 53,413.7 tonnes valued at RM1,257,745.91.

The marine shrimp production dropped by 8.87%, which is 48673.63 tonnes valued at RM1,169,099.61. In conclusion, the trend of freshwater shrimp production seems to drop gradually starting in 2016 until 2019 and then increases in 2020, while in contrast with marine shrimp, which gradually increases from 2016 until 2019 and drops in 2020. A good aquaculture production strategy is determined by the proper operational management, stocking density, production targets and economic achievements planned by the breeder/pond operator. According to Chowdhury et al. (2014), the shrimp farming industry in Asian countries, including Malaysia, China, Thailand, and Indonesia, has experienced and fought the situation of "up and down" in their production due to massive viral disease attacks as well as fluctuation in the global market price. Table 3 shows the total Malaysian aquaculture shrimp production from 2016 to 2020.

The production of shrimp fries and hatchlings from government and private hatcheries from 2016 to 2019 for aquaculture purposes is shown in Table 3. It was shown that private hatchery production is greater than that of the government hatchery. The government hatchery produced 27,302,920 fries in 2017, which is the highest production compared to other years, but drastically declined to the following year of 2018 and 2019, which are 11,915,760 and 11,935,847 fries, respectively. In the meantime, the production of private hatchery was the highest in 2016 (9,111,575,183 fries), and the lowest was in 2017 (4719, 259,449 fries). Overall, the total production of fries and hatchlings from both sectors is at the highest in 2016 (9,111,575,183 fries) and at the lowest in 2017 (4719,259,229 fries). However, the number of fries produced does not seem to be well-linked to the total production of shrimp all year (Table 4), which means that the highest fry production does not guarantee large production as a result. The final result depends on the proper management skills and the quality of the shrimp (high durability).

Table 3
Total Malaysia's aquaculture production of shrimp and value from 2016 to 2020 (Adaptation from Department of Fisheries Malaysia 2016-2020)

Year	Species of Shrimp	Freshwater	Marine	Total
2016	Quantity (tonnes)	309.43	43,253.61	43,563.04
	Value (RM'000)	17,350.34	918,632	935,982.34
2017	Quantity (tonnes)	293.74	45,783.09	46,076.83
	Value (RM'000)	16,655.34	1,067,337.05	1,083,992.39
2018	Quantity (tonnes)	213.42	45,923.23	46,136.65
	Value (RM'000)	12,088.51	1,114,951.96	1,127,040
2019	Quantity (tonnes)	205.58	53413.7	53,619.28
	Value (RM'000)	12,757.12	1,257,745.91	1,270,503
2020	Quantity (tonnes)	257.07	48673.63	48,673.63
	Value (RM'000)	16,265.23	1,169,099.61	1,169,099.61

Table 4
Production of shrimp fries and hatchlings from government and private hatcheries from 2016 to 2019

Hatchery	Year			
	2016	2017	2018	2019
Government	17,835,183	27,302,920	11,915,760	11,935,847
Private	9,093,740,000	4,691,956,529	6,474,892,952	5,200,107,156
Total production	9,111,575,183	4,719,259,449	6,486,808,712	5,212,043,003

Note. Quantity in pieces

Production risk analysis indicates that the lack of farmers' knowledge and experience related to shrimp aquaculture management, operational skill, marketing, and accounting has a negative impact on technical inefficiency and cost inefficiency (Thean, 2014). Therefore, the Malaysian government needs to take the initiative by holding workshops and training related to aquaculture operation and marketing strategies, as well as motivational seminars to increase farmers' knowledge related to proper and efficient shrimp culture and to give mental encouragement in increasing their efficiency in managing their farming projects while obtaining higher production. Another common problem encountered by the shrimp aquaculture industry is disease outbreaks, world market price, quality of broodstock, feed availability and quality, banned drugs and antibiotics used, environmental impact and control, world trade obstacles, as well as market cooperation and public associations management, which need to be faced and resolved precisely (Vergel, 2017).

Human Resources and Economic Development Through Aquaculture and Shrimp Farming

Aquaculture generated employment for 20,976 people in 2004, and via six different culture system practices, with the highest total employment in the freshwater pond and concrete culture system, with a percentage of 70% (Figure 4). The number of aquaculturists increased from 21,100 individuals in 2005 to 21,790 individuals in 2015 but slightly decreased to 20,262 individuals in 2020 (DOF, 2020; Mazuki & Subramanian, 2005). In some areas, especially in small-scale cultural practices, the aquaculture farms are worked by family members and close relatives. The total number of aquaculture workers is mostly contributed by men, which is 90% and only 10% by women (FAO, 2022).

Lack of knowledge in aquaculture practices at the beginning of the intensive culture period in the 19th century has led to huge damage due to poor management and disease outbreaks (Shariff & Subasinghe, 1993). In view of such encounters, the availability of qualified human resources in relevant subjects and disciplines is required for sustainable development and management in the aquaculture industry.

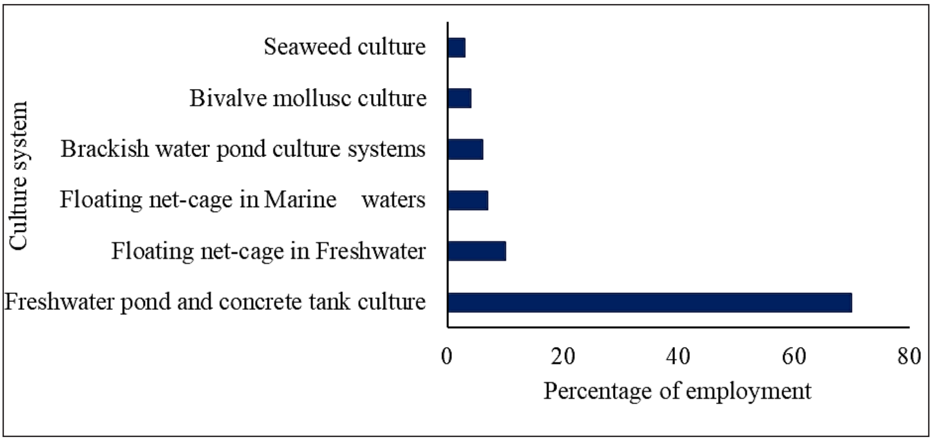

Figure 4. Percentage of employment in the Malaysian aquaculture industry in 2004 based on culture system practices (modified from FAO, 2022)

Due to this fact, in the last few years, the participation of skilled and qualified fish farmers as well as the participation of professionals from local and foreign higher institutions has brought the aquaculture industry, including shrimp farming, towards success with huge profit and sustainable outcome.

In the last two years (2019-2020), the employment in aquaculture farms and labour for shrimp marketing access in seafood industries was also disrupted by the lockdown during the pandemic, COVID-19 and served badly to the small-scale aquaculture entrepreneurs in the most developing countries, hence cutting off their incomes and also causing unemployment (Reardon et al., 2020). Nowadays, after the pandemic, the shrimp farming entrepreneurs are struggling to rebuild this industry and return to the situation it was before the pandemic.

Demand and Market Trend of Shrimp

Market Research Report (2022) states that the market size of global shrimp was estimated to expand from $33.81 billion in 2021 to $53.63 billion in 2028 at a Compound annual growth rate (CAGR) of 6.81% in the prediction period of 2021 to 2028. The CAGR in terms of shrimp production refers to the average yearly growth rate of a shrimp investment in a period of more than one year, and it symbolises the most precise methods to analyse and define profits for a specific property, investment matters and other matters that can develop a pattern in the revenue. The COVID-19 pandemic has caused a disturbance in the international aquaculture industry, including shrimp farming. The pandemic harshly interrupted the farming and marketing activities of seafood production.

A series of lockdowns due to the COVID-19 pandemic in most countries worldwide has contributed to the health and economic crisis that has also shaken food and nutrition safety (Sumner et al., 2020). The shrimp industry also negatively impacts its market demand and supply chain during the pandemic. The growth rate of the shrimp global market declined to 14.46% if compared to the average growth from 2017 to 2019 before the pandemic outbreak. The low market demand during the lockdown was resulting dumping of seafood supply because it could not be marketed during the lockdown, resulting in a decrease in the market trend. Nowadays, the shrimp industry is returning to the track step by step as the market demand and trend have gradually increased after the struggle against the after-effects of the pandemic.

FUTURE PERSPECTIVE IN SHRIMP AQUACULTURE IN MALAYSIA

The aquaculture of shrimp is one of Malaysia's food security measures and is consistent with the Sustainable Development Goals (SDGs) adopted by the United Nations' 2030 vision for food security and zero hunger. Strategic planning for aquaculture management to generate a large amount of shrimp with excellent quality, low mortality, and high market demand. Aquaculture products are among the essential sources of protein in the world. Implementing technology to establish a high-tech system in aquaculture management is an excellent starting point for achieving more profitability. SD-AQEP, a system dynamics model of the eco-aquaculture system developed by the local iSHARP aquaculture sector, increased the system's productivity by improving feedstock, water utilisation, and wastewater management (Isa et al., 2021).

Good aquaculture practice (GAP) is required to manage broodstock, ponds, and water quality (Samah, 2020). Even though insufficient compliance with requirements for outstanding biosecurity and effective aquaculture operations in shrimp farms and hatcheries has been identified as a significant factor in the spread of disease from one farm to another, there is still a substantial amount of work to be done. Farmers have essential responsibilities as biosecurity monitors in shrimp farms (Padilah, 2022), such as producing healthy shrimp seedlings, checking the water quality of ponds and water resources regularly, and sterilising spent nets and trawlers before reusing them in other ponds.

Acute hepatopancreatic necrosis disease (AHPND), also known as early mortality syndrome, is an emerging shrimp illness that has reduced worldwide shrimp (*Litopenaeus vannamei*) output by more than 60%, with annual global economic losses of up to $1 billion predicted (Yan et al., 2019). This AHPND was caused by a virulent strain of bacteria, including *V. parahaemolyticus*, *V. punensis, V. harveyi, V. owensii, V. campbelli,* and *Shewanella* sp., carrying the pVA1 plasmid (63-70 kb) expressing the binary PirAVP and PirBVP toxins. Chemicals and antibiotics were widely employed in the battle against AHPND and must be regulated to prevent the creation of antibiotic-resistant bacteria, which may pose global health risks. (Kumar, 2021). Earlier research identified tetracyclines, sulfamides, and quinolones as Malaysian aquaculture's three most prevalent antibiotics. It was also determined that the relative abundance of resistance genes declined from *sul2> tet(M)>sul1>sul3* and that there is no association between antibiotic residue and resistance genes (Thiang, 2021).

Future research endeavours in increased monitoring, detection, and prevention are necessary to maintain shrimp aquaculture development in Malaysia as a step toward increasing biosecurity in the country's aquaculture industry (Chiew, 2019). Marketing and sales are vital for preserving the shrimp supply to consumers and maximising profit margins. The regulation of white leg shrimp production involves two main expenditures: feed and fingerling costs, which account for about 48% of total operating costs, and 17% of overall operating costs. The nutrient-rich diet is also expensive, including shrimp's nutritional needs. It contains fish, rice bran, soy, vitamins, and minerals. However, giving a low-cost food deficient in vital nutrients causes the shrimp production cycle to expand slowly.

CONCLUSION

In conclusion, shrimp aquaculture in Malaysia plays a vital role in supporting food security and aligning with global sustainability goals, but it continues to face significant challenges from disease outbreaks that reduce productivity and profitability. Advances such as biofloc technology, improved therapeutics, and monosex culture systems demonstrate promising progress toward enhancing production efficiency. However, sustaining long-term growth requires more resilient and health-focused farming strategies. Greater emphasis should be placed on natural and sustainable approaches to disease prevention and growth enhancement.

Hypothetically, as a recommendation, future research should be conducted on the inclusion of herbal additives in shrimp feed diets, as these may improve shrimp health, strengthen immune responses, and enhance growth performance while reducing dependence on chemical treatments.

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REFERENCES

Andani, H. R. R., Tukmechi, A., Meshkini, S., & Sheikhzadeh, N. (2012). Antagonistic activity of two potential probiotic bacteria from fish intestines and investigation of their effects on growth performance and immune response in rainbow trout (*Oncorhynchus mykiss*). *Journal of Applied Ichthyology*, *28*(5), 728-734. https://doi.org/10.1111/j.1439-0426.2012.01974.x

Asaduzzaman, M., Wahab, M. A., Yi, Y., Diana, J. S., & Lin, C. K. (2006). Bangladesh prawn-farming survey reports industry evaluation. *Global Aquaculture Advocate*, *9*(6), 40-42. https://aquafishcrsp.oregonstate.edu/sites/aquafishcrsp.oregonstate.edu/files/nop06-a14.pdf

Banu, R. (2014). *Influence of heterogeneous individual growth on male freshwater prawn Macrobrachium rosenbergii De Man for sustainable monosex culture* [Doctoral dissertation, Universiti Putra Malaysia]. Institutional Repository. http://psasir.upm.edu.my/id/eprint/70339/1/FP%202014%2071%20-%20IR.pdf

Boyd, C. E., McNevin, A. A., & Davis, R. P. (2022). The contribution of fisheries and aquaculture to the global protein supply. *Food Security*, *14*, 805-827. https://doi.org/10.1007/s12571-021-01246-9

Chiew, I., Salter, A. M., & Lim, Y. S. (2019). The significance of major viral and bacterial diseases in Malaysian aquaculture industry. *Pertanika Journal of Tropical Agricultural Science*, *42*(3), 1023-1047.

Chowdhury, M. A., Talib, A., & Yahya, K. (2013). *A review on marine shrimp aquaculture production trend and sustainability in Malaysia and the world perspective* [Conference presentation].

Chowdhury, M. A., Talib, A., & Yahya, K. (2014). A review on marine shrimp aquaculture production trend and sustainability in Malaysia and the world perspective. *Proceedings of the Conference: International Fisheries Symposium*, Can Tho University, Can Tho, Vietnam.

Citarasu, T. (2010). Herbal biomedicines: A new opportunity for aquaculture industry. *Aquaculture International*, *18*, 403-414. https://doi.org/10.1007/s10499-009-9253-7

Department of Fisheries Malaysia. (2011). *Annual Fisheries Statistics 2011*. Ministry of Agriculture and Agro-Based Industry Malaysia.

Department of Fisheries Malaysia. (2012). *Annual Fisheries Statistics 2012*. Ministry of Agriculture and Agro-Based Industry Malaysia.

Department of Fisheries Malaysia. (2013). *Annual Fisheries Statistics 2013*. Ministry of Agriculture and Agro-Based Industry Malaysia.

Department of Fisheries Malaysia. (2014). *Annual Fisheries Statistics 2014*. Ministry of Agriculture and Agro-Based Industry Malaysia.

Department of Fisheries Malaysia. (2015). *Annual Fisheries Statistics 2015*. Ministry of Agriculture and Agro-Based Industry Malaysia.

Department of Fisheries Malaysia. (2016). *Annual Fisheries Statistics 2016*. Ministry of Agriculture and Agro-Based Industry Malaysia.

Department of Fisheries Malaysia. (2017). *Annual Fisheries Statistics 2017*. Ministry of Agriculture and Agro-Based Industry Malaysia.

Department of Fisheries Malaysia. (2018). *Annual Fisheries Statistics 2018*. Ministry of Agriculture and Agro-Based Industry Malaysia.

Department of Fisheries Malaysia. (2019). *Annual Fisheries Statistics 2018*. Ministry of Agriculture and Agro-Based Industry Malaysia.

Department of Fisheries Malaysia. (2020). *Annual Fisheries Statistics 2018*. Ministry of Agriculture and Agro-Based Industry Malaysia.

Department of Fisheries Malaysia. (2020). *Annual fisheries statistics: Number of aquaculturists* [Perangkaan perikanan tahunan: Bilangan penternak akuakultur]. (Vol. 1, pp. 1-84). Ministry of Agriculture and Agro-Based Industry Malaysia.

De Schryver, P., Defoirdt, T., & Sorgeloos, P. (2014). Early mortality syndrome outbreaks: A microbial management issue in shrimp farming? *PLoS Pathogens*, *10*(4), Article e1003919. https://doi.org/10.1371/journal.ppat.1003919

De Vito, A., & Gómez, J. P. (2020). Estimating the COVID-19 cash crunch: Global evidence and policy. *Journal of Accounting and Public Policy*, *39*(2), Article 106741. https://doi.org/10.1016/j.jaccpubpol.2020.106741

Food and Agriculture Organisation. (2002). *Farming freshwater prawns: A manual for the culture of the giant river prawn (Macrobrachium rosenbergii)*. Food and Agriculture Organisation of the United Nations. https://www.fao.org/3/y4100e/y4100e00.htm#TOC

Food and Agriculture Organisation. (2009). *Penaeus monodon*. In *Cultured aquatic species fact sheets*. Food and Agriculture Organisation of the United Nations. http://www.fao.org/fishery/docs/CDrom/aquaculture/I1129m/file/en/en_gianttigerprawn.htm

Food and Agriculture Organisation. (2018). *The state of world fisheries and aquaculture 2018*. Food and Agriculture Organisation of the United Nations. https://www.fao.org/3/i9540en/I9540EN.pdf

Food and Agriculture Organisation. (2020). *The impact of COVID-19 on fisheries and aquaculture: A global assessment from the perspective of regional fishery bodies*. Food and Agriculture Organisation of the United Nations. http://www.fao.org/3/ca9279en/CA9279EN.pdf

Food and Agriculture Organisation. (2022). *Macrobrachium rosenbergii*. In *Cultured Aquatic Species Information Programme* (Text by New, M. B.). Fisheries and Aquaculture Division. Food and Agriculture Organisation of the United Nations. https://www.fao.org/fishery/en/culturedspecies/macrobrachium_rosenbergii/en

Fisheries Research Institute Malaysia. (2021). *FRI database system*. https://fri.dof.gov.my/fri.php/database_stores/store_view_page/85/1

Flegel, T. W. (2012). Historic emergence, impact and current status of shrimp pathogens in Asia. *Journal of Invertebrate Pathology*, *110*(2), 166-173. https://doi.org/10.1016/j.jip.2012.03.004

Ghee-Thean, L., Islam, G. M. N., & Ismail, M. M. (2016). Malaysian white shrimp (*P. vannamei*) aquaculture: An application of stochastic frontier analysis on technical efficiency. *International Food Research Journal*, *23*(2), 638-645.

Hidayati, N. V., Prudent, P., Asia, L., Vassalo, L., Torre, F., Widowati, I., Sabdono, A., Syakti, A. D., & Doumenq, P. (2020). Assessment of the ecological and human health risks from metals in shrimp aquaculture environments in Central Java, Indonesia. *Environmental Science and Pollution Research*, *27*(33), 41668-41687. https://doi.org/10.1007/s11356-020-09967-8

Hoang, T., Lee, S. Y., Keenan, C. P., & Marsden, G. E. (2002). Effect of temperature on spawning of *Penaeus merguiensis*. *Journal of Thermal Biology*, *27*(6), 433-437. https://doi.org/10.1016/S0306-4565(02)00013-X

Ikhwanuddin, M., Moh, J. H. Z., Manan, H., Noor-Hidayati, A. B., Aina-Lyana, M. A., & Nor Juneta, A. S. (2014). Effect of Indian almond, *Terminalia catappa* leaves water extract on the survival rate and growth performance of black tiger shrimp, *Penaeus monodon* post larvae. *AACL Bioflux*, *7*(2), 85-93. https://bioflux.com.ro/docs/2014.85-93.pdf

Ikhwanuddin, M., Bahar, H., Ma, H., & Manan, H. (2019). Effect of estrogen hormone, 17β-estradiol on feminisation of banana shrimp, *Penaeus merguiensis* (de Man, 1888) postlarvae and the identification of the age of external sex differentiation. *Aquaculture Reports*, *13*, Article 100177. https://doi.org/10.1016/j.aqrep.2018.100177

Isa, S. H., Ramlee, M. N. A., Lola, M. S., Ikhwanuddin, M., Azra, M. N., Abdullah, M. T., Zakaria, S., & Ibrahim, Y. (2021). A system dynamics model for analysing the eco-aquaculture system of integrated aquaculture park in Malaysia with policy recommendations. *Environment, Development and Sustainability*, *23*(1), 511-533. https://doi.org/10.1007/s10668-020-00594-4

Ismail, M. M., & Abdullah, A. M. (2013). Shrimp trade competitiveness of Malaysia and selected ASEAN countries. *Journal of International Food & Agribusiness Marketing*, *25*(1), 98-115. https://doi.org/10.1080/08974438.2013.800009

Kasan, N. A., Ghazali, N. A., Ikhwanuddin, M., & Ibrahim, Z. (2017). Isolation of potential bacteria as inoculum for biofloc formation in Pacific whiteleg shrimp, *Litopenaeus vannamei* culture ponds. *Pakistan Journal of Biological Sciences*, *20*(6), 306-313. https://doi.org/10.3923/pjbs.2017.306.313

Kawamura, G., Yong, A. S. K., Loong, A. H., Doison, A., Ooi, S. Y., & Lim, L. S. (2019). Malaysian herbs as feeding attractants and enhancers for the giant freshwater prawn (*Macrobrachium rosenbergii*) and the whiteleg shrimp (*Litopenaeus vannamei*). *Borneo Journal of Marine Science and Aquaculture*, *3*(2), 57-67. https://doi.org/10.51200/bjomsa.v3i2.1793

Khai, N. X., Noh, K. M., Islam, G. N., & Ismail, M. M. (2011). *Mangrove conservation and shrimp farming in market* (IKDPM Occasional Paper 2011/16). Institute for Agricultural and Food Policy Studies, Universiti Putra Malaysia.

Kua, B. C., Fariduddin, M. O., Marzukhi, O., & Iftikhar, A. M. A. (2018). Mortality outbreaks in whiteleg shrimp (*Penaeus vannamei* Bonne 1931) cultured in Peninsular Malaysia. *Asian Fisheries Science*, *31*, 242-256. https://doi.org/10.33997/j.afs.2018.31.S1.017

Kumar, V., Roy, S., Behera, B. K., Bossier, P., & Das, B. K. (2021). Acute hepatopancreatic necrosis disease (AHPND): Virulence, pathogenesis and mitigation strategies in shrimp aquaculture. *Toxins*, *13*(8), Article 524. https://doi.org/10.3390/toxins13080524

Lee, W. C. (2020). Marketing margins of aquaculture shrimp production in Kedah. *Borneo Journal of Marine Science and Aquaculture*, *4*(1), 20-23. https://doi.org/10.51200/bjomsa.v4i1.1992

Levy, T., & Sagi, A. (2020). The "IAG-switch"—A key controlling element in decapod crustacean sex differentiation. *Frontiers in Endocrinology*, *11*, Article 651. https://doi.org/10.3389/fendo.2020.00651

Lezer, Y., Aflalo, E. D., Manor, R., Sharabi, O., Abilevich, L. K., & Sagi, A. (2015). On the safety of RNAi usage in aquaculture: The case of all-male prawn stocks generated through manipulation of the insulin-like androgenic gland hormone. *Aquaculture*, *435*, 157-166. https://doi.org/10.1016/j.aquaculture.2014.09.040

Liao, I. C., & Chien, Y. H. (2011). The Pacific white shrimp, *Litopenaeus vannamei*, in Asia: The world's most widely cultured alien crustacean. In B. Galil, P. Clark, & J. Carlton (Eds.), *In the wrong place - alien marine crustaceans: Distribution, biology and impacts* (Vol. 6, pp. 489-519). Springer. https://doi.org/10.1007/978-94-007-0591-3_17

Lightner, D. V. (2011). Virus diseases of farmed shrimp in the Western Hemisphere. *Journal of Invertebrate Pathology*, *106*(1), 110-130. https://doi.org/10.1016/j.jip.2010.09.012

Manan, H., Ikhwanuddin, M., Shahreza, M. S., Abol-Munafi, A. B., & Fariduddin, M. O. (2012). Triploidy induction using cold shock treatment in banana shrimp, *Penaeus merguiensis* (de Man, 1888). *Borneo Science*, *30*, 64-69. https://www.researchgate.net/publication/321487615_Triploidy_induction_using_cold_shock_treatment_in_banana_shrimp_Penaeus_merguiensis_De_Man_1888

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. *Applied Water Science*, *7*, 2437-2446. https://doi.org/10.1007/s13201-016-0421-4

Manan, H., Amin-Safwan, A., Kasan, N. A., & Ikhwanuddin, M. (2020). Effects of biofloc application on survival rate, growth performance and specific growth rate of Pacific whiteleg shrimp, *Penaeus vannamei* culture in closed hatchery system. *Pakistan Journal of Biological Sciences*, *23*(12), 1563-1571. https://doi.org/10.3923/pjbs.2020.1563.1571

Manan, H., & Ikhwanuddin, M. (2021). Triploid induction in penaeid shrimps aquaculture: A review. *Reviews in Aquaculture*, *13*(1), 619-631. https://doi.org/10.1111/raq.12489

Manan, H., Rosland, N. A., Mat Deris, Z., Che Hashim, N. F., 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*. *Aquaculture Research*, *53*(5), 2029-2041. https://doi.org/10.1111/are.15731

Market Research Report. (2022). *Shrimp market size*. Fortune Business Insights Publishers.

Mazuki, H., & Subramanian, K. (2005). *Shrimp farming in Malaysia*. Agricultural Science and Technology Information (AGRIS), Food and Agriculture Organisation of the United Nations.

Memon, A. J., Ikhwanuddin, M., Talpur, A. D., Khan, M. I., Fariduddin, M. O., Safiah, J., & Abol-Munafi, A. B. (2012). To determine the efficiency of different fresh diets in improving the spermatophore quality of banana shrimp *Penaeus merguiensis* (De Man, 1888). *Journal of Animal and Veterinary Advances*, *11*(9), 1478-1485. https://doi.org/10.3923/javaa.2012.1478.1485

Mohamad, N., Manan, H., Sallehhuddin, M., Musa, N., & Ikhwanuddin, M. (2020). Screening of lactic acid bacteria isolated from giant freshwater prawn (*Macrobrachium rosenbergii*) as potential probiotics. *Aquaculture Reports*, *18*, Article 100523. https://doi.org/10.1016/j.aqrep.2020.100523

Mohd-Haikal, I., & Mohammad-Mustafizur, R. (2019). *Status of shrimp production in Malaysia with an emphasis on overexploited species*. Paper presented at the International Conference on Oceanography and Sustainable Marine Production (ICOSMAP), Kuantan, Pahang. http://irep.iium.edu.my/78587/

Muthukrishnan, S., Defoirdt, T., Ina-Salwany, M. Y., Yusoff, F. M., Shariff, M., Ismail, S. I., & Natrah, I. (2019). *Vibrio parahaemolyticus* and *Vibrio harveyi* causing acute hepatopancreatic necrosis disease (AHPND) in *Penaeus vannamei* (Boone, 1931) isolated from Malaysian shrimp ponds. *Aquaculture*, *511*, Article 734227. https://doi.org/10.1016/j.aquaculture.2019.734227

Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M. C. M., Clay, J., Folke, C., Lubchenco, J., Mooney, H., & Troell, M. (2000). Effect of aquaculture on world fish supplies. *Nature*, *405*, 1017-1024. https://doi.org/10.1038/35016500

Padilah, B., Rohaiza-Asmini, Y., Gan, H. M., Rozana, W. A. W., Sajiri, W. M. H. W., & Kua, B. C. (2022). Detection of PirA/B toxin genes for acute hepatopancreatic necrosis disease (AHPND) and *Vibrio parahaemolyticus* in *Penaeus vannamei* culture from major white shrimp producing farms in Malaysia. *Pertanika Journal of Tropical Agricultural Science*, *45*(1), 171-186. https://doi.org/10.47836/pjtas.45.1.10

Pazir, M. K., Ahmadi, A., & Khezri, P. H. (2022). The effect of COVID-19 pandemic on the shrimp industry of Iran. *Marine Policy*, *136*, Article 104900. https://doi.org/10.1016/j.marpol.2021.104900

Rahman, M. S., Majumder, M. K., Sujan, M. H. K., & Manjira, S. (2021). Livelihood status of coastal shrimp farmers in Bangladesh: Comparison before and during COVID-19. *Aquaculture Reports*, *21*, Article 100895. https://doi.org/10.1016/j.aqrep.2021.100895

Reardon, T., Mishra, A., Nuthalapati, C. S., Bellemare, M. F., & Zilberman, D. (2020). COVID-19's disruption of India's transformed food supply chains. *Economic and Political Weekly*, *55*(18), 18-22. https://www.gmfc.ac.in/wp-content/uploads/2020/08/MAY-2-2020-Vol-LV-No-18.pdf#page=18

Rebecca, A. A., & Bhavan, P. S. (2014). Growth promotion and survival enhancement of freshwater prawn *Macrobrachium rosenbergii* postlarvae fed with *Allium sativum*, *Zingiber officinale* and *Curcuma longa*. *International Journal of Pure and Applied Zoology*, *2*(2), 138-149.

Sagi, A., & Aflalo, E. D. (2005). The androgenic gland and monosex culture of freshwater prawn *Macrobrachium rosenbergii* (De Man): A biotechnological perspective. *Aquaculture Research*, *36*(3), 231-237. https://doi.org/10.1111/j.1365-2109.2005.01238.x

Sagi, A., & Cohen, D. (1990). Growth, maturation and progeny of sex reversed *Macrobrachium rosenbergii* males. *World Aquaculture*, *21*, 87-90.

Samah, R. (2020). Increasing the fish production with good aquaculture practices. *International Journal of Business and Technology Management*, *2*(1), 27-33.

Shariff, M., & Subasinghe, R. P. (1993). Diseases in Malaysian aquaculture. In R. P. Subasinghe & M. Shariff (Eds.), *Diseases in aquaculture: The current issues* (pp. 49-59). Malaysian Fisheries Society.

Soo, T. C. C., Devadas, S., Mohamed Din, M. S., & Bhassu, S. (2019). Differential transcriptome analysis of the disease tolerant Madagascar-Malaysia crossbred black tiger shrimp, *Penaeus monodon* hepatopancreas in response to acute hepatopancreatic necrosis disease (AHPND) infection: Inference on immune gene response and interaction. *Gut Pathogens*, *11*, Article 13. https://doi.org/10.1186/s13099-019-0319-4

Stentiford, G. D., Neil, D. M., Peeler, E. J., Shields, J. D., Small, H. J., Flegel, T. W., Vlak, J. M., Jones, B., Morado, F., Moss, S., Lotz, J., Bartholomay, L., Behringer, D., Hauton, C., & Lightner, D. V. (2012). Disease will limit future food supply from the global crustacean fishery and aquaculture sectors. *Journal of Invertebrate Pathology*, *110*(2), 141-157. https://doi.org/10.1016/j.jip.2012.03.013

Sumner, A., Hoy, C., & Ortiz-Juarez, E. (2020). *Estimates of the impact of COVID-19 on global poverty*. United Nations University. https://doi.org/10.35188/UNU-WIDER/2020/800-9

Syahidah, A., Saad, C. R., Daud, H. M., & Abdelhadi, Y. M. (2015). Status and potential of herbal applications in aquaculture: A review. *Iranian Journal of Fisheries Sciences*, *14*(1), 27-44.

Tan, K., Jiang, H., Jiang, D., & Wang, W. (2020). Sex reversal and the androgenic gland (AG) in *Macrobrachium rosenbergii*: A review. *Aquaculture and Fisheries*, *5*(6), 283-288. https://doi.org/10.1016/j.aaf.2019.11.004

Taw, N., Thong, P. Y., Ming, L. T., Thanabatra, C., & Salleh, K. Z. (2011). Malaysia shrimp farm redesign successfully combines biosecurity, biofloc technology. *Global Aquaculture Advocate*, 1-6.

Taw, N. (2013). *Recent developments of biosecurity and biofloc technology*. Paper presented at the Aquaculture America Conference, Nashville, Tennessee.

Taw, N. (2017). Sustainable shrimp farming in bio secure RAS and biofloc technology: Commercial experience and approaches to disease control. *Journal of Fisheries and Livestock Production*, *5*(2), Article 1000231.

Thean, L. G. (2014). *Efficiency performance of Malaysian brackish water white shrimp* [Master's thesis, Universiti Putra Malaysia]. Institutional Repository.

Thiang, E. L., Lee, C. W., Takada, H., Seki, K., Takei, A., Suzuki, S., Wang, A., & Bong, C. W. (2021). Antibiotic residues from aquaculture farms and their ecological risks in Southeast Asia: A case study from Malaysia. *Ecosystem Health and Sustainability*, *7*(1), Article 1926337. https://doi.org/10.1080/20964129.2021.1926337

Tran, L., Nunan, L., Redman, R. M., Mohney, L. L., Pantoja, C. R., Fitzsimmons, K., & Lightner, D. V. (2013). Determination of the infectious nature of acute hepatopancreatic necrosis syndrome affecting penaeid shrimp. *Diseases of Aquatic Organisms*, *105*(1), 45-55. https://doi.org/10.3354/dao02621

Vaseeharan, B., & Ramasamy, P. (2003). Control of pathogenic *Vibrio* spp. by *Bacillus subtilis* BT23, a possible probiotic treatment for black tiger shrimp *Penaeus monodon*. *Letters in Applied Microbiology*, *36*(2), 83-87. https://doi.org/10.1046/j.1472-765X.2003.01255.x

Vergel, J. C. V. (2017). Current trends in the Philippines' shrimp aquaculture industry: A booming blue economy in the Pacific. *Oceanography & Fisheries Open Access Journal*, *5*(4), 85-89. https://doi.org/10.19080/OFOAJ.2017.05.555668

Waiho, K., Fazhan, H., Ishak, S. D., Kasan, N. A., Liew, H. J., Norainy, M. H., & Ikhwanuddin, M. (2020). Potential impacts of COVID-19 on the aquaculture sector of Malaysia and its coping strategies. *Aquaculture Reports*, *18*, Article 100450. https://doi.org/10.1016/j.aqrep.2020.100450

Wang, Y. G., Lee, K. L., Najiah, M., Shariff, M., & Hassan, M. D. (2000). A new bacterial white spot syndrome (BWSS) in cultured tiger shrimp *Penaeus monodon* and its comparison with white spot syndrome (WSS) caused by virus. *Diseases of Aquatic Organisms*, *41*(1), 9-18. https://doi.org/10.3354/dao041009

Yan, C. Z. Y., Austin, C. M., Ayub, Q., Rahman, S., & Gan, H. M. (2019). Genomic characterisation of *Vibrio parahaemolyticus* from Pacific white shrimp and rearing water in Malaysia reveals novel sequence types and structural variation in genomic regions containing the Photorhabdus insect-related (Pir) toxin-like genes. *FEMS Microbiology Letters*, *366*(17), Article fnz211. https://doi.org/10.1093/femsle/fnz211