ISSN: 2456-2912
VET 2024; SP-9(2): 352-356

www.veterinarypaper.com
Received: 19-01-2024
Accepted: 24-02-2024

Shailendra Kumar
ICAR- Central Inland Fisheries Research Institute, Barrackpore, Kolkata, West Bengal, India

Lavkush
Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, India

Puneet Kumar Patel
Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, India

Mitrasen Maurya
Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, India

Parul
Choudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India

Amit Singh Kshatri
Choudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India

Corresponding Author:
Lavkush
Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, India

A most lethal pathogen of shrimp in aquaculture: Systematic review

Shailendra Kumar, Lavkush, Puneet Kumar Patel, Mitrasen Maurya, Parul and Amit Singh Kshatri

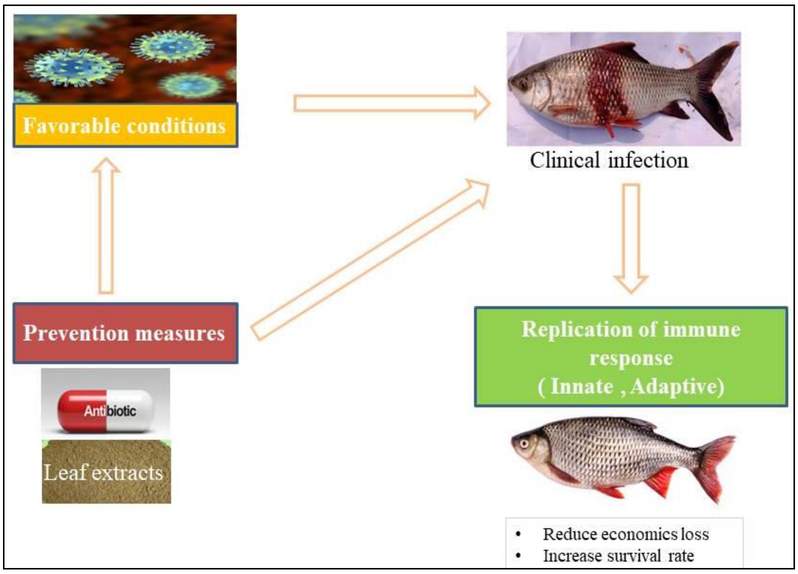
Abstract
Disease outbreaks are more prominent in aquaculture throughout the world due to favourable condition which subsequently reduce industry's productivity, profitability, and long-term viability in global aquaculture production. One of the most common diseases in Asia, WSSV causes most dangerous to shrimp aquaculture. Vaccinations and other techniques have shown to be an effective pathogen-prevention strategy against the pathogens. For example, immunizations and other preventive measures that are developed to shield shrimp aquaculture against various viral diseases. But developing such preventive methods as quickly as needed would be difficult because diseases and germs infrequently. This review aims to collect information on the host ranges, immunity to the WSSV virus, genome size, morphology of the virus, pathological changes, and prevention and management procedures that have been used to develop a successful aquaculture.

Keywords: Pathways, probiotics, mortality, RNAi, monovalent

Introduction
With worldwide aquaculture production growth rate were 2015 2022 was 8.1%, which make aquaculture industry fastest animals food producing sectors and becoming a significant source cheaper proteins diet. In 2020, fish production was recorded at 179 million tons worldwide, with an anticipated US$ 401 billion as the overall first sale value. Over the past 30 years, Asia has produced 89% of the world's total in volume terms, making it a major producer globally. China is the world's largest producer of fish, producing 1.8 million tons annually. Aquaculture is one of the food animal production industries with the fastest rate of growth, thanks to its use of advanced farming techniques.
Aquaculture methods that are successful rely on biological, chemical, and physical elements such water as well as the health of the fish raised there (Prabu *et al*., 2019) [28]. High fish farming productivity results from intensifying and diversifying aquaculture; but, uncontrolled transboundary migrations of aquatic animals and animal products throughout the world can cause serious disease outbreaks. Fish under the intensive culture method were cultivated in conditions of high stocking density, which put them under stress. Stress is brought on by bacteria, viruses, parasites, and fungus, among other abiotic and biotic variables such as low water quality parameters and ambient temperature. Nevertheless the advancements, the aquaculture sector has suffered significant financial losses due to the advent of infectious diseases such as the white spot syndrome virus (WSSV). The virus is extremely infectious and can kill 100% of shrimp within three to ten days of an epidemic outbreak in the farming system. The projected global economic loss resulting from WSSV since its inception in 1991 is between 8 and 15 billion USD (Dey *et al*., 2020) [6].

Structure, shape, morphology and genome characteristic of WSSV
The virus known as white spot syndrome is bacilliform, non-occluded, enveloped, and its enveloped virions have a maximum width of 70 nm and a length of 210–380 nm (Chou *et al*., 1995; Flegel and Alday-Sanz, 1998; Li *et al*., 2005; Rajendran *et al*., 2003) [42, 8, 23, 29]. According to research on the WSSV, different viral particles have different genome sizes. On average, the genome spans approximately 300 Kilobases.

ATG initiation codons are found in between 531 and 684 open reading frames (ORFs) in the WSSV genome, according to studies on sequence analysis (Wang *et al*., 1995; Yang *et al*., 2001) [42, 45]. Occasionally, a tail-like appendage at one end of the WSSV virion can be seen on electron micrographs stained negatively. As described by Durand *et al*. (1997) [7] and Nadala and Loh (1998) [26], the nucleocapsid is a stacked ring structure inside the envelope that resembles a crosshatch. It is composed of globular protein subunits with a diameter of 10 nm grouped in 14–15 vertical striations spaced every 22 nm along the long axis. About 21–29% of these ORFs have been shown to encode WSSV proteins or to share their identity with other known proteins.



Clinical manifestation, host range and pathological changes induce by WSSV

White spot disease (WSD), which affects several economically significant decapod species, is caused by WSSV. In Asian shrimp farms, WSSV was initially discovered in 1921 (Inouye *et al*., 1994) [16]. It was then reported in several other nations throughout the world (Karunasagar *et al*., 1997; Stentiford and Lightner, 2011) [17, 38]. Clinical symptoms of the condition might include reddish-brown body discoloration, lethargy, decreased eating, and increased mortality in addition to white patches on the exoskeleton. WSSV has a broad spectrum of hosts or carriers, including over 93 species of arthropods and even polychaetes, where WSSV accumulation has been seen in their digestive tracts, in addition to shrimp (Flegel, 1997; Sánchez-Paz, 2010) [9, 32]. Durand *et al.* (1997) [7] and Wang *et al*. (2000) [43] have reported that hypertrophied nuclei displaying marginated chromatin and amphophilic intranuclear inclusions are suggestive of WSSV infection. These intranuclear inclusions are notably larger and different from Cowdry A-type inclusions found in infectious hypodermal and hemopoietic necrosis viruses. Over time, infected nuclei expand and become more basophilic.

Immunity against the WSSV infection in shrimp

Generally, invertebrates are having cellular as well as humoral immunity to fight against the pathogenic microorganism and give protection from these pathogens. Plants, arthropods, and mammals have all evolved to use RNA interference (RNAi) as a post-transcriptional gene regulatory mechanism. It is the regulation of target gene expression by means of chromatin remodeling, translation suppression, and mRNA instability (Geley and Muller, 2004) [11]. There are number of proteins (Drosha, Pasha, Dicer1 and Ago1) with miRNA biogenesis in shrimps. Till now, more than 40 viral miRNAs encoded by WSSV reported viral infected cells. A growing volume of research indicates that the main players in the shrimp canonical miRNA synthesis pathway are involved in a number of viral infections, including occasionally WSSV. PmAgo, a P. monodon Ago1 protein with over 80% sequence homology with insect Ago1 homologs, was specifically stimulated to rise two- to three-fold (YHV) during the early stages of yellow head virus infection (Unajak *et al*., 2006) [40]. Furthermore, in order to promote viral infection, WSSV miRNAs target virus genes. He and colleagues demonstrated that WSSV-miR-66 targeted the wsv094 and wsv177 genes during the early stages of WSSV infection, whereas WSSV-miR-68 targeted the wsv248 and wsv309 genes (He *et al*., 2014) [13]. Infected cells containing virus-derived siRNAs (vsiRNAs) suggest that RNA interference (RNAi) is a natural antiviral immunity mechanism in plants and insects. vsiRNAs serve as defense mechanism specificity determinants as well as a molecular marker for the induction of natural antiviral RNAi.

Numerous PPRs are recognized in vertebrates; these include nucleic acid-based components like TLR9, AIM2, and cGAS, which identify RNA in the form of dsDNA, other TLRs, RIG1, and so forth (Barrat *et al*., 2016; Hornung *et al*., 2014) [3, 14]. According to a report (Robalino *et al*. 2004) [31], researchers found that different unrelated dsRNAs could provide shrimp with sequence-independent antiviral protection against WSSV and TSV. The suggested that innate immunity is being activated as a component of the system. According to a study by Li *et al*., (2015) [21], the promoter of the secreted interferon-like cytokine Vago4 interacts directly with the IRF-like transcription factor in shrimps, activating the JAK/STAT signaling pathway.

Drosophila Dicer2 and shrimp Dicer2 are nucleic acid receptors just like RIG-I in mammals and which is up regulated against the challenge WSSV infection in shrimp (Chen *et al*. 2011) [5]. Apoptosis is a fundamental kind of innate host defense that is thought to have been evolutionarily conserved across animal species. It plays a significant role throughout development and homeostasis which is activation of enzyme caspase cascades in the organism. According to MacKenzie and Clark (2012) [25], the members of a family of highly conserved cysteine-dependent aspartate-specific proteases, caspases are essential for regulating and performing apoptosis and have done so throughout evolution. With the help of other adaptor molecules, cytochrome c can cause the cleavage and activation of initiator caspase-9. Through the cleavage of internal mitochondrial route and the extrinsic death receptor pathway can be connected (Luo *et al.,* 1998) [24].

Shrimp's humoral immunity to WSSV infection has also been thoroughly studied. It includes the ProPO system's ability to fight infection, the Toll pathway, the IMD pathway, and interference with the JAK/STAT pathway. Shrimps' exceptional expression against Vibrio parahaemolyticus, Vibrio alginolyticus, and Staphylococcus aureus bacterial infections suggests that both Gram-positive and Gram-negative bacteria are likely to be the cause of the Toll and IMD pathway activation in shrimps (Li and Xiang, 2013) [22]. According to research, shrimp Tolls function as pattern recognition receptors through mutual interaction, similar to human TLRs. They can identify microbially generated products like LPS, PGN, and CpG ODN (Sun *et al.,* 2017) [39]. It is still not entirely clear how the shrimp IMD pathway is activated and regulated. After bacterial infection, Relish is generally the target of signaling directed by the IMD pathway. To activate Relish, phosphorylation and cleavage are needed to eliminate the C-terminal IκB-like domain. A key component of the nucleic acid-induced nonspecific antiviral signaling system in shrimps is the JAK/STAT pathway. The knockdown of LvJAK from L. vannamei increases the viral burden and death rate subsequent to WSSV infection (Song *et al*., 2015) [36]. WSSV has created several strategies to disrupt the host's JAK/STAT pathway and encourage the expression of its genes. The prophenoloxidase activating system (proPO system) controls melanization in a range of invertebrates, which is thought to be an essential component of host defense in response to pathogenic infection. Thus far, the melanization/proPO system in shrimps has been found to be composed of prophenoloxidase 1 (proPO1), proPO2, proPO-activating enzyme 1 (proPPAE1), and proPPAE2 from L. vannamei and P. monodon (Sritunyalucksana *et al*., 1999; Lai *et al*., 2005; Charoensapsri *et al*., 2011) [37, 19, 4].

Control measure and prevention methods of WSSV in aquaculture

There are various methods to control the viral infection in shrimp culture which include probiotics, vaccines, peptides, immmunostimulant, prebiotics, RNAi, leaf extracts etc. However, due to the complex ecosystem of pond, it is difficult to control infection fully and to protect the aquatic animals. Plasmid-loaded nanoparticles have the potential to be an effective gene delivery mechanism because of their rapid transition from the cytoplasmic compartment to the degradative endo-lysosomal compartment (Panyam and Labhasetwar, 2003) [27]. As per the investigation done by Rajeshkumar *et al*. (2009) [30] found that the protective ecicacy of encapsulating the VP28 gene of WSSV in chitosan nanoparticles by oral administration in *P. monodon* revealed 50% survival even after 30 days, whereas the control group experienced 100% mortality. There is study claimed that the vaccine can be injected via nanoparticles as carrier and no abnormality caused by this particle in shrimp. Five main WSSV structural genes—VP28, VP26, VP24, VP19, and VP15—were targeted in the study conduceed by Sarathi *et al*. (2008) [2, 18] in order to synthesize equivalent dsRNA since the proteins that these genes express is widely distributed inside the WSSV and are essential to the infection process. Sivakumar *et al*. (2016) [35] tested 388 marine bioactive compounds against the envelope protein VP28 using MD simulations and flexible molecular docking. The lead candidates were chosen according to the binding free energy (DGb) of MM/PBSA. Their results showed that the compounds with the highest binding free energies were Lindgomycin and Astropectenol B, at about 31.031 KJ/mol and 40.453 KJ/mol, respectively. Several studies suggest that adding seaweed and its extracts to food may be a potential treatment for WSSV infection in shrimp. Schleder *et al.* (2020) [33] recently investigated the effect of combining the brown seaweeds Sargassum filipendula and Undaria pinnatifida on resistance to WSSV-infected L. vannamei.

Table 1: Overview of WSSV infection in shrimp aquaculture

Shrimp species	Mortality (control)	Survival rate	Immunological parameters	Prevention	Country	Ref.
P. monodon	100%	50 -86%	prophenoloxidase, superoxide dismutase and superoxide anionincrreased signifcatly	DNA construct with chitosan nanoparticles	India	Rajeshkumar *et al.*, 2009 [30]
L. vannamei	78.1%	68- 70%	Increased lipid metabolism, and modulation in AMPs	Sea weed extract	Brazil	Schleder *et al.*, 2020 [33]
L. vannamei	-	-	Increased survival	dsRNA	USA	Robalino *et al.*, 2004 [31]
L. vannamei	100%	100%	Increased haemocytes	Probiotics	Mexico	Leyva-Madrigal *et al.*, 2011 [20]
L. vannamei	100%	Increased (35.5% in 10^9 CFU/g group)	The expression of five immune genes-proPO, SOD, LvToll, hemocyanin, and STAT—increased.	Probiotics	Thailand	Wanna *et al*., 2023 [44]
P. monodon	100%	68%	SOD CAT decreased	Probiotics	Korea	Sekar *et al.*, 2016 [34]
L. vannamei	100%	83%	proPO, PE and LGBP gene increased significantly	Probiotics	China	Fu *et al*., 2011 [10]
P. monodon	100%	100%	NA	Plant extract (2%)	India	Balasubramanian *et al.*, 2008 [2]
P. vannamei	100%	65-85%	Total hemocyte count, glucose, oxyhemocyanin, SOD, phenoloxidase activity, and total protein	Olive leaf extract	Iran	Gholamhosseini *et al.*, 2020 [12]
P. monodon	100%	100%	NA	extract of *Cynodon dactylon*	Bangladesh	Howlader *et al*., 2020 [15]
P. monodon	100%	67-83%	NA	Whole cell vaccine	Philippines	Amar *et al.*, 2011 [1]
P. monodon	100%	71.2±3.13%	NA	Whole cell vaccine	Philippines	Amar *et al.*, 2011 [1]
P. monodon	100%	56.6–90%	prophenoloxidase and SOD increased	DNA vaccines	India	Kumar *et al*., 2008 [18]

Conclusion

Due to the mortality in shrimp aquaculture caused by the viral diseases leads serious economic loss to the farmers of particular country which subsequently effects production. Many South East Asia countries are mostly impacted by the WSSV disease particularly in shrimp culture. So, it is better to understand host-pathogen interaction, pathogenesis, virus size, genome, replication cycles and immune response generated in the shrimp against the disease. This can help to develop proactive disease management strategies in combating this pathogen. Contagious nature of WSSV leads the disease difficult to treat or cure in the culture systems. In order to better understand WSSV and other aquaculture diseases, this review has attempted to gather crucial data on host ranges, immunity, genome size, morphology, pathological changes, and management and prevention techniques. This will create and implement long-term solutions that protect aquaculture productivity and viability in the face of disease challenges, more research, cooperation, and innovation are needed in the future.

References

1. Amar EC, Joseph Jr P. Efficacy of an inactivated vaccine and nutritional additives against white spot syndrome virus (WSSV) in shrimp (*Penaeus monodon*). Isr J Aquacult-Bamid. 2011;63.
2. Balasubramanian G, Sarathi M, Venkatesan C, Thomas J, Hameed AS. Oral administration of antiviral plant extract of Cynodon dactylon on a large scale production against white spot syndrome virus (WSSV) in *Penaeus monodon*. Aquaculture. 2008;279(1-4):2-5.
3. Barrat FJ, Elkon KB, Fitzgerald KA. Importance of nucleic acid recognition in inflammation and autoimmunity. Annu Rev Med. 2016;67:323-336.
4. Charoensapsri W, Amparyup P, Hirono I, Aoki T, Tassanakajon A. PmPPAE2, a new class of crustacean prophenoloxidase (proPO)-activating enzyme and its role in PO activation. Dev Comp Immunol. 2011;35(1):115-124.
5. Chen YH, Jia XT, Zhao L, Li CZ, Zhang S, Chen YG, *et al*. Identification and functional characterization of Dicer2 and five single VWC domain proteins of Litopenaeus vannamei. Dev Comp Immunol. 2011;35(6):661-671.
6. Dey BK, Dugassa GH, Hinzano SM, Bossier P. Causative agent, diagnosis and management of white spot disease in shrimp: A review. Rev Aquacult. 2020;12(2):822-865.
7. Durand S, Lightner DV, Redman RM, Bonami JR. Ultrastructure and morphogenesis of white spot syndrome baculovirus (WSSV). Dis Aquat Organ. 1997;29(3):205-211.
8. Flegel TW, Alday-Sanz V. The crisis in Asian shrimp aquaculture: current status and future needs. J Appl. Ichthyol. 1998;14(3-4):269-273.
9. Flegel TW. Major viral diseases of the black tiger prawn (*Penaeus monodon*) in Thailand. World J Microbiol Biotechnol. 1997;13:433-442.
10. Fu LL, Wang Y, Wu ZC, Li WF. In vivo assessment for oral delivery of Bacillus subtilis harboring a viral protein (VP28) against white spot syndrome virus in Litopenaeus vannamei. Aquaculture. 2011;322:33-38.
11. Geley S, Müller C. RNAi: ancient mechanism with a promising future. Exp. Gerontol. 2004;39(7):985-998.
12. Gholamhosseini A, Kheirandish MR, Shiry N, Akhlaghi M, Soltanian S, Roshanpour H, *et al*. Use of a methanolic olive leaf extract (*Olea europaea*) against white spot virus syndrome in Penaeus vannamei: Comparing the biochemical, hematological and immunological changes. Aquaculture. 2020;528:735556.
13. He Y, Yang K, Zhang X. Viral microRNAs targeting virus genes promote virus infection in shrimp in vivo. J Virol. 2014;88(2):1104-1112.
14. Hornung V, Hartmann R, Ablasser A, Hopfner KP. OAS proteins and cGAS: unifying concepts in sensing and responding to cytosolic nucleic acids. Nat Rev Immunol. 2014;14(8):521-528.
15. Howlader P, Ghosh AK, Islam SS, Bir J, Banu GR. Antiviral activity of Cynodon dactylon on white spot syndrome virus (WSSV)-infected shrimp: an attempt to mitigate risk in shrimp farming. Aquacult. Int. 2020;28:1725-1738.
16. Inouye K, Miwa S, Oseko N, Nakano H, Kimura T, Momoyama K, *et al*. Mass mortalities of cultured kuruma shrimp Penaeus japonicus in Japan in 1993: electron microscopic evidence of the causative virus. Fish Pathol. 1994;29(2):149-158.
17. Karunasagar I, Otta SK, Karunasagar I. Histopathological and bacteriological study of white spot syndrome of *Penaeus monodon* along the west coast of India. Aquaculture. 1997;153(1-2):9-13.
18. Kumar SR, Ahamed VI, Sarathi M, Basha AN, Hameed AS. Immunological responses of *Penaeus monodon* to DNA vaccine and its efficacy to protect shrimp against white spot syndrome virus (WSSV). Fish Shellfish Immunol. 2008;24(4):467-478.
19. Lai CY, Cheng W, Kuo CM. Molecular cloning and characterisation of prophenoloxidase from haemocytes of the white shrimp, *Litopenaeus vannamei*. Fish Shellfish Immunol. 2005;18(5):417-430.
20. Leyva-Madrigal KY, Luna-González A, Escobedo-Bonilla CM, Fierro-Coronado JA, Maldonado-Mendoza IE. Screening for potential probiotic bacteria to reduce prevalence of WSSV and IHHNV in Whiteleg shrimp (*Litopenaeus vannamei*) under experimental conditions. Aquaculture. 2011;322:16-22.
21. Li C, Li H, Chen Y, Chen Y, Wang S, Weng SP, *et al*. Activation of Vago by interferon regulatory factor (IRF) suggests an interferon system-like antiviral mechanism in shrimp. Sci. Rep. 2015;5(1):15078.
22. Li F, Xiang J. Signaling pathways regulating innate immune responses in shrimp. Fish Shellfish Immunol. 2013;34(4):973-980.
23. Li L, Xie X, Yang F. Identification and characterization of a prawn white spot syndrome virus gene that encodes an envelope protein VP31. Virology. 2005;340(1):125-132.
24. Luo X, Budihardjo I, Zou H, Slaughter C, Wang X. Bid, a Bcl2 interacting protein, mediates cytochrome c release from mitochondria in response to activation of cell surface death receptors. Cell. 1998;94(4):481-490.
25. MacKenzie SH, Clark AC. Death by caspase dimerization. Protein dimerization and oligomerization in biology; c2012. p. 55-73.
26. Nadala Jr ECB, Loh PC. A comparative study of three different isolates of white spot virus. Dis Aquat Organ. 1998;33(3):231-234.

27. Panyam J, Labhasetwar V. Biodegradable nanoparticles for drug and gene delivery to cells and tissue. Adv. Drug Deliv. Rev. 2003;55(3):329-347.
28. Prabu E, Rajagopalsamy CBT, Ahilan B, Jeevagan IJMA, Renuhadevi M. Tilapia–an excellent candidate species for world aquaculture: a review. Ann Res Rev Biol. 2019:1-14.
29. Rajendran KV, Mukherjee SC, Vijayan KK, Jung SJ, Kim YJ, Oh MJ. A comparative study of white spot syndrome virus infection in shrimp from India and Korea; c2003.
30. Rajeshkumar S, Venkatesan C, Sarathi M, Sarathbabu V, Thomas J, Basha KA, *et al*. Oral delivery of DNA construct using chitosan nanoparticles to protect the shrimp from white spot syndrome virus (WSSV). Fish Shellfish Immunol. 2009;26(3):429-437.
31. Robalino J, Browdy CL, Prior S, Metz A, Parnell P, Gross P, *et al*. Induction of antiviral immunity by double-stranded RNA in a marine invertebrate. J Virol. 2004;78(19):10442-10448.
32. Sánchez-Paz A. White spot syndrome virus: an overview on an emergent concern. Vet Res. 2010;41(6).
33. Schleder DD, Blank M, Peruch LG, Poli MA, Goncalves P, Rosa KV, *et al*. Impact of combinations of brown seaweeds on shrimp gut microbiota and response to thermal shock and white spot disease. Aquaculture. 2020;519:734779.
34. Sekar A, Packyam M, Kim K. Growth enhancement of shrimp and reduction of shrimp infection by Vibrio parahaemolyticus and white spot syndrome virus with dietary administration of Bacillus sp. Mk22. Microbiol Biotechnol Lett. 2016;44(3):261-267.
35. Sivakumar KC, Sajeevan TP, Singh IB. Marine derived compounds as binders of the White spot syndrome virus VP28 envelope protein: in silico insights from molecular dynamics and binding free energy calculations. Comput Biol Chem. 2016;64:359-367.
36. Song X, Zhang Z, Wang S, Li H, Zuo H, Xu X, *et al*. A Janus Kinase in the JAK/STAT signaling pathway from Litopenaeus vannamei is involved in antiviral immune response. Fish Shellfish Immunol. 2015;44(2):662-673.
37. Sritunyalucksana K, Cerenius L, Söderhäll K. Molecular cloning and characterization of prophenoloxidase in the black tiger shrimp, *Penaeus monodon*. Dev Comp Immunol. 1999;23(3):179-186.
38. Stentiford GD, Lightner DV. Cases of white spot disease (WSD) in European shrimp farms. Aquaculture. 2011;319(1-2):302-306.
39. Sun JJ, Xu S, He ZH, Shi XZ, Zhao XF, Wang JX. Activation of toll pathway is different between Kuruma shrimp and Drosophila. Front Immunol. 2017;8:264124.
40. Unajak S, Boonsaeng V, Jitrapakdee S. Isolation and characterization of cDNA encoding Argonaute, a component of RNA silencing in shrimp (*Penaeus monodon*). Comp Biochem Physiol Part B Biochem Mol Biol. 2006;145(2):179-187.
41. Wang B, Li F, Dong B, Zhang X, Zhang C, Xiang J. Discovery of the genes in response to white spot syndrome virus (WSSV) infection in Fenneropenaeus chinensis through cDNA microarray. Mar Biotechnol. 2006;8:491-500.
42. Wang CH, Lo CF, Leu JH, Chou CM, Yeh PY, Chou HY, *et al*. Purification and genomic analysis of baculovirus associated with white spot syndrome (WSBV) of *Penaeus monodon*. Dis Aquat Organ. 1995;23(3):239-242.
43. Wang Q, Poulos BT, Lightner DV. Protein analysis of geographic isolates of shrimp white spot syndrome virus. Arch Virol. 2000;145:263-274.
44. Wanna W, Aucharean C, Kaitimonchai P, Jaengkhao W. Effect of dietary *Pediococcus pentosaceus* MR001 on intestinal bacterial diversity and white spot syndrome virus protection in Pacific white shrimp. Aquacult Reports. 2023;30:101570.
45. Yang F, He J, Lin X, Li Q, Pan D, Zhang X, *et al*. Complete genome sequence of the shrimp white spot bacilliform virus. J Virol. 2001;75(23):11811-11820.