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White Spot Syndrome Virus and Aquatic Organisms: A Short Review

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ABSTRACT

The white spot syndrome virus (WSSV) poses a serious threat to both cultured and wild aquatic organisms. Despite significant advances in understanding this pathogen, it remains a major concern for farmed species, particularly shrimp. Infected shrimp often exhibit reduced feed intake, discoloration, and characteristic white spots on the cephalothorax. Although WSSV has been known for decades, its transmission pathways and effective preventive measures are not yet fully understood. This knowledge gap continues to limit the development of comprehensive strategies for prevention and control. The present review summarizes recent findings on WSSV biology and highlights current approaches to its prevention.

INTRODUCTION

The white spot syndrome virus (WSSV) was first identified in 1992 during an epizootic among kuruma shrimp (*Penaeus japonicus*) in northern Taiwan **(Chou *et al.*, 1995; Lightner *et al.*, 1998)**. In 1995, the first documented case in the Western Hemisphere was reported from pond-reared northern white shrimp (*Penaeus setiferus*) in south Texas **(Lightner, 1996; Krol *et al.*, 2024)**. This discovery marked the emergence of a previously unknown pathogen capable of causing severe disease in shrimp, with potentially devastating consequences for global aquaculture. Understanding the biology and epidemiology of WSSV and developing effective management strategies is critical for safeguarding the aquaculture industry, which plays a key role in global food security.

WSSV is a double-stranded DNA virus in the family Nimaviridae, responsible for white spot disease, which has caused substantial economic losses in shrimp farming since its emergence **(Lightner *et al.*, 2012; Dashtiannasab, 2020)**. The virus has a rod-shaped to elliptical morphology, measuring approximately 80–120 × 250– 380nm **(Wang *et al.*, 1995; Fauquet *et al.*, 2005)**, and can infect a broad range of hosts, including non-decapod species **(Oidtmann & Stentiford, 2011; Reddy *et al.*, 2013)**. Infected shrimp often experience rapid mortality within 1–2 days **(Dey *et al.*, 2020)**, preceded by clinical signs such as reduced feed intake, discoloration of appendages, swelling, lethargy, cuticle loss, and the presence of white spots on the cephalothorax **(Lo *et al.*, 1996; Hameed *et al.*, 2003; Rout *et al.*, 2005)**. However, these signs are not universally present, as not all infected individuals exhibit visible symptoms **(Chou *et al.*, 1995)**.

This review synthesizes current knowledge on WSSV and evaluates prevention and control measures aimed at reducing the frequency and severity of outbreaks.

GENOME-WIDE ASSOCIATION STUDY (GWAS)

The genome-wide association study (GWAS) is used to examine the relationship between an individual's genotype and phenotype. This approach employs genetic variants such as single-nucleotide polymorphisms (SNPs) to analyze the association between known genes, specific biological pathways, and their relevance to disease susceptibility. One of the most devastating viral pathogens affecting shrimp in aquaculture is the white spot syndrome virus (WSSV). In a GWAS conducted by **Fagutao *et al.* (2008)**, peptidoglycan polysaccharides—structural components of the cytoplasmic membrane—were found to play an important role in shrimp defense against WSSV infection.

Additionally, various peptide proteins are expressed in shrimp cells at different levels during WSSV infection **(García *et al.*, 2009; Antony *et al.*, 2011; Jeswin *et al.*, 2013)**. In contrast, suppression of certain peptides, such as penaeidin class 5, through gene-silencing mechanisms can increase susceptibility to WSSV infection in *Penaeus monodon* **(Woramongkolchai *et al.*, 2011)**. Expression levels of other proteins, including lysozyme, C-type lectin, and prophenoloxidase 1 and 2, in hemocytes are significantly higher in shrimp that survive 48 hours post-infection compared to those that die within 60 hours **(Jeswin *et al.*, 2013)**, indicating their role in disease resistance. Lysozyme, in particular, has also been linked to WSSV susceptibility in other shrimp species such as blue shrimp **(Mai & Wang, 2010)**.

Another defense mechanism involves viral particles present in shrimp hemolymph, which may inhibit WSSV binding to hemolymph cells, thereby improving survival following infection **(Youtong *et al.*, 2011)**. Shrimp resistance to WSSV infection has been shown to be associated with multiple genetic markers, including SNPs located near genes involved in antiviral defense **(Hayes & Goddard, 2001)**.

1. Selection trials to improve resistance against WSSV

Selective breeding is widely used in aquaculture programs to improve economically important traits such as growth rate, survival rate, disease resistance, and harvest weight. Two primary selection methods are employed: traditional selection (selective breeding) and genomic selection. Table (1) summarizes research outcomes on improving shrimp quantitative traits using both methods.

1.1. Traditional selection (Selective breeding)

Multiple studies have demonstrated that selective breeding can improve shrimp resistance to WSSV, which continues to cause severe financial losses in global shrimp aquaculture. In a study by **Huang *et al.* (2012)**, four generations of *Penaeus vannamei* were selectively bred for WSSV resistance. Three quantitative traits—survival rate, feed coefficient, and harvest weight—showed improvement. The average survival rate increased from 5.57 ± 9.83% in the second generation (G2) to 13.79 ± 11.52% in the fifth generation (G5). Feed coefficient improved significantly (G0 > G4 by 13.86%), and average harvest body weight increased by 34.51% (G4). Similarly, **Prochaska *et al.* (2022)** reported increased survival in *Litopenaeus vannamei* against WSSV through selective breeding.

1.2. Genomic selection

Genomic selection uses genetic markers to select individuals with desirable genotypes for breeding. It is particularly effective for polygenic traits—those influenced by multiple genes—such as disease resistance **(Meuwissen *et al.*, 2001; Meuwissen, 2007; Asoro *et al.*, 2011)**. In the study of **Lillehammer *et al.* (2020)**, genomic selection using SNP markers was applied to study *Litopenaeus vannamei* resistance to WSSV. Results indicated that genomic selection is highly effective in populations with high variability in the "dead or alive" (DOA) trait. Heritability increased in the first generation (G1) compared to the base generation (G0), with G1 individuals showing 13% greater resistance than G0. This level of improvement in a single generation could not be achieved using conventional breeding methods, underscoring the superiority of genomic selection in enhancing resistance to viral and bacterial diseases in commercially important aquaculture species.

In another study, **Trang *et al.* (2019)** applied genetic selection to assess WSSV resistance in the whiteleg shrimp (*Litopenaeus vannamei*) from 2014 to 2017. Heritability estimates were calculated, and survival rates of virus-challenged shrimp were monitored. Families from three generations were tested for viral load using quantitative real-time polymerase chain reaction (qPCR). The difference in viral load between low- and high-resistance families was significant ($P < 0.001$), with higher viral loads in the low-resistance families. Growth performance improved in the G3 generation compared to G4, and survival rate correlated positively with days of survival after infection. Additionally, a correlation between body weight and survival rate was observed. These findings confirm that genetic selection can be an effective strategy to improve WSSV resistance in the whiteleg shrimp.

Table 1. Outcomes of the main research done to improve shrimp' quantitative traits by conventional (traditional) and genomic selection

Type of selection	Species	Main finding	Reference
• Traditional selection	*Penaeus vannamei*	• Four generations (G2-G5) of *P. vannamei* family's resistant to WSSV were generated. • Mean survival rates for the four generations were increased from 5.57±9.83% for G2 to 13.79±11.52% for G5. • The resistant index was higher for selected populations (G4) than for unselected ones (G0 generation). • Harvest weight for G4 was higher than for unselected ones (P<0.05). • The feed coefficient for the G0 population was 13.86% higher than the coefficient of the G4 population.	**Huang *et al.* (2012)**
• Traditional selection	White leg shrimp (*Liptopenaeus vannamei*)	• Survival rate of *L. vannamei* against WSSV was (59.8 ± 20.6%). • A survival rate of 50% was considered ideal.	**Prochaska *et al.* (2022)**

• Genomic selection	White leg shrimp (*Liptopenaeus vannamei*)	Shrimps from G0 and G1 [susceptible line (S-line)], resistant line (R-line), random mating population) were generated. • G1' population heritability to dead or alive (DOA) = 0.41 > G0 'heritability. • Genetic components play a role in the heritability of DOA traits and can be used in selective breeding programs. • Average survival increased from 38% for G0 population to 51% for G1 populations.	**Lillehammer *et al.* (2020)**
• Genomic selection	White leg shrimp (*Liptopenaeus vannamei*)	• Selection for growth improvement achieved for three generations (G1-G3) in three years. • Viral load (WSSV quantity) was higher in families with lower resistance to the virus. • Positive correlation between number of days after infection and survival rate. • Negative correlation between resistance to the virus and shrimps 'body weight.	**Trang *et al.* (2019)**

1.3. Crossbreeding

Crossbreeding is the mating of individuals from different populations to produce offspring with superior traits—such as enhanced growth rate or improved disease resistance—compared to their parents **(Buckley *et al.*, 2014)**. This practice reduces inbreeding depression, which occurs when related individuals are bred, leading to reduced performance in traits such as disease survival. Inbreeding is a major challenge in breeding programs and can cause significant economic losses **(Smith *et al.*, 1998; Croquet *et al.*, 2006)**.

A study by **Gallaga-Maldonado *et al.* (2020)** examined the effect of crossbreeding different lines of *Litopenaeus vannamei* on resistance to white spot disease. Shrimp from two distinct lines—one selected for disease resistance and the other for high growth rate—were crossed, and the parental lines were also mated with their hybrid offspring. Key findings included: (1) disease resistance was significantly higher ($P < 0.05$) in the resistant line compared to the growth line, indicating that individuals carrying resistance-related genes are more suitable for breeding programs aimed at producing resilient, high-value offspring; and (2) shrimp from the resistant lines exhibited higher survival rates and greater biomass than those from the growth lines.

These results suggest that crossbreeding individuals from resistant lines can yield offspring with both higher biomass and better survival rates compared to crossings between growth-line individuals. Such an approach could improve control of WSSV infection in shrimp farming and offer greater economic returns.

VACCINATION

A vaccine is used to stimulate a host’s immune response against one or more pathogens. It is typically composed of an attenuated or killed pathogen, its toxins, or surface proteins. Vaccination is an effective disease-prevention strategy that reduces losses from infectious outbreaks and promotes animal welfare. In aquaculture, several vaccine types have been developed and tested, including live attenuated, inactivated, subunit, and toxoid vaccines.

Vaccines can be delivered through various routes. Injection ensures accurate dosing, requires smaller volumes, and offers long-term protection. However, it is labor-intensive, requires skilled personnel, and can only be performed on hosts above a minimum body size. Immersion is simpler and requires no technical expertise, but it generally provides short-term protection, requires booster doses, and is most suitable for small-scale applications. Oral administration is especially advantageous for shrimp, as it is less stressful, easier to apply, and feasible on a commercial scale. However, oral vaccine antigens must be encapsulated to prevent degradation in the digestive system **(Mutoloki *et al.*, 2015)**.

Previous studies have investigated the potential of using structural proteins—particularly those from the viral capsid and envelope—to stimulate immune responses and protect shrimp against WSSV infection. Among these, VP28 has been widely evaluated as a potential vaccine target **(Satoh *et al.*, 2008; Kwang, 2011; Jia *et al.*, 2016; Solís-Lucero *et al.*, 2016)**. Other viral proteins tested for vaccine potential include VP19, VP24, VP26, VP292, and VP466 **(Feng *et al.*, 2017)**.

FEED ADDITIVES

Feed additives are an important component of aquafeed formulations. They modify the physical and chemical characteristics of the feed and act as performance enhancers once consumed by the animals **(Barrows, 2000)**. Examples include preservatives, pellet binders, pro- and prebiotics, animal and plant extracts, and acidifiers **(Dawood *et al.*, 2015; Ng & Koh, 2016)**. The effects of these additives on growth performance and disease resistance have been extensively studied across various aquatic species **(Balcazar *et al.*, 2006; Kesarcodi-Watson *et al.*, 2008; Merrifield *et al.*, 2010; Ringo *et al.*, 2010a,b)**.

Several feed additives have been evaluated for their role in mitigating white spot disease. For example, carrageenan has been shown to improve the survival of *Litopenaeus vannamei* in experimental trials. It is speculated that carrageenan may enhance gut microbiota health, although no significant differences were observed in weight gain or feed conversion between carrageenan-fed shrimp and controls **(Mariot *et al.*, 2021)**. Brown seaweeds have also been incorporated into shrimp diets without compromising performance, and their inclusion was associated with improved digestion and enhanced resistance to disease challenges **(Schleder *et al.*, 2018; Rezende *et al.*, 2022)**.

Other promising additives include fucoidan, which enhanced the immune response of *Procambarus clarkii* against white spot disease **(Jin *et al.*, 2021)**, and flavonoids—common plant-derived compounds—that improved innate immunity, reduced WSSV copy number, and provided protection against the disease in *P. clarkii* **(Zhang *et al.*, 2021)**. Plant-based immunostimulants, in particular, are considered important antiviral agents for combating white spot disease in shrimp aquaculture **(Peraza-Gomez *et al.*, 2014)**.

Given their potential, further research is needed to identify efficient and cost-effective antiviral substances that can be incorporated into shrimp feed formulations as practical disease management tools.

PREVENTIVE MEASURES

To prevent outbreaks of white spot disease in shrimp farms, it is essential to avoid sourcing shrimp from affected areas or from neighboring farms where the disease has been detected. Routine surveillance using standardized PCR and *in situ* hybridization should be carried out to detect and monitor the presence of the virus within the farm. Stress is a key factor that increases disease susceptibility in farmed animals; therefore, stocking densities in tanks and ponds must be carefully managed to prevent overcrowding **(Dey *et al.*, 2020)**.

CONCLUSION

White spot disease remains a significant threat to the shrimp farming industry. Regularly, massive losses occur upon the onset of this virus. Although great progress has been achieved in understanding the mechanisms of transmission, prevention, and control measures of this disease, more research must be devoted to formulating safe feed additives, effective vaccination, and swift and cost-effective prevention and control procedures.

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