

can cause clinical manifestations such as red body disease, septicemia, and hepatopancreatic damage. Among them, acute hepatopancreatic necrosis disease (AHPND), caused by specific strains of *Vibrio parahaemolyticus* carrying virulence plasmids, is of particular concern. In addition, *V. harveyi*, *V. alginolyticus*, *V. cholerae*, and *V. vulnificus* can also act as primary or opportunistic pathogens (Chowdhury et al., 2024). Compared with viral diseases, bacterial infections are theoretically more controllable; however, due to their strong virulence, environmental adaptability, and increasing antimicrobial resistance, disease management is becoming more challenging.

## 2.2 Characteristics and impacts of typical diseases

Among various shrimp diseases, white spot syndrome virus (WSSV) and acute hepatopancreatic necrosis disease (AHPND) are considered the most widespread and economically devastating. WSSV is one of the most representative and highly pathogenic viruses in shrimp aquaculture. It is an enveloped double-stranded DNA virus with a broad host range, capable of infecting multiple decapod crustaceans and establishing persistent low-level infections in hosts. Under favorable conditions, infections can rapidly escalate into outbreaks. Clinical signs of WSSV infection include white calcified spots on the exoskeleton, reddish discoloration, reduced feeding, lethargy, and rapid mortality (Hasan et al., 2024). Studies have shown that WSSV outbreaks can result in cumulative mortality rates of 80%-100% within 3-10 days, demonstrating acute onset, high lethality, and strong transmissibility (Hasan et al., 2024).

Compared with WSSV, AHPND is a rapidly emerging bacterial disease that predominantly affects early culture stages. It is caused by specific strains of *Vibrio parahaemolyticus* carrying virulence plasmids encoding PirAB toxins. These toxins directly damage the hepatopancreas, leading to massive epithelial cell sloughing, necrosis, and functional failure. AHPND typically occurs within 20-30 days after stocking and is characterized by reduced feeding, empty gut, hepatopancreatic atrophy, and discoloration. Due to the lack of obvious external symptoms in some cases, early diagnosis is challenging. In severe outbreaks, mortality rates can exceed 70%, particularly affecting juvenile shrimp. The disease has been reported in multiple countries, including China, Vietnam, Thailand, and Mexico, and its spread is closely associated with seedstock movement, inadequate biosecurity, and environmental stress.

In addition to WSSV and AHPND, diseases such as Taura syndrome (TSV), yellow head disease (YHV), infectious myonecrosis (IMNV), and EHP infection also pose significant threats. Unlike acute high-mortality diseases, EHP infection typically causes chronic impacts, including slow growth, size variation, reduced feed efficiency, and prolonged culture periods, thereby reducing overall productivity. From an industrial perspective, shrimp diseases can be categorized into “acute lethal diseases” and “chronic debilitating diseases,” both of which contribute to economic losses. Moreover, pathogens do not act independently. Studies have shown that co-infection with AHPND and WSSV can exacerbate tissue damage and increase mortality. WSSV exposure can also enhance the susceptibility of *Litopenaeus vannamei* to AHPND-causing *Vibrio* strains. Therefore, disease understanding should extend beyond single pathogens to a framework incorporating multi-pathogen interactions and host stress responses.

## 2.3 Epidemiological Patterns of Diseases

Shrimp diseases exhibit pronounced seasonal patterns, closely associated with water temperature, salinity, water quality fluctuations, and farming-related stress. Studies have shown that WSSV outbreaks are strongly influenced by temperature variations. The virus shows high virulence at temperatures of approximately 25 °C-28 °C, while sudden temperature drops or low-temperature conditions can increase host stress and mortality rates (Hasan et al., 2024). In contrast, *Vibrio* pathogens proliferate rapidly under high temperature, high organic load, and low dissolved oxygen conditions, making bacterial diseases more prevalent during hot seasons. In addition, factors such as heavy rainfall, improper water exchange, and sediment deterioration can cause ammonia accumulation, pH fluctuations, and microbial imbalance, thereby increasing disease outbreak risks (Chowdhury et al., 2024).