

cause additional tissue damage, whereas insufficient immune responses fail to effectively control pathogen proliferation. Therefore, disease outcomes depend not only on pathogen load but also on the regulation of host immune responses (Chandran et al., 2023).

3.2 Environmental factors

Environmental factors play a crucial role in shrimp health and disease occurrence. Their effects are reflected not only in regulating pathogen survival and transmission, but also in influencing host physiological homeostasis and immune competence. Among various environmental variables, water quality is one of the most critical. Parameters such as dissolved oxygen, pH, partial pressure of carbon dioxide, ammonia, and nitrite directly affect shrimp metabolism, osmoregulation, and immune function. When shrimp are exposed to suboptimal water conditions, either in the short or long term, they exhibit physiological stress responses accompanied by reduced hemocyte function, suppressed phenoloxidase activity, and weakened resistance to infection, thereby increasing mortality risk upon pathogen exposure (Hapsari et al., 2025). In addition, the accumulation of uneaten feed and waste elevates organic load, providing favorable conditions for opportunistic pathogens such as *Vibrio* spp.

Temperature is another key factor influencing disease dynamics. Studies have shown that WSSV exhibits high virulence at approximately 25 °C-28 °C, whereas higher temperatures (e.g., >30 °C) may reduce outbreak severity under certain conditions. However, the impact of temperature depends not only on absolute values but also on the magnitude and rate of fluctuations. Extreme weather events, such as cold spells, heatwaves, and large diurnal temperature variations, can induce significant physiological stress, impair immune function, and trigger the transition from latent to active infections (Chang et al., 2024). Therefore, maintaining stable temperature conditions is often more critical than controlling absolute temperature levels in aquaculture practice.

Salinity is also an important environmental determinant of shrimp health. Deviations from optimal salinity levels increase osmoregulatory stress and disrupt physiological balance, thereby reducing disease resistance. Rapid declines in salinity, often caused by heavy rainfall, large-scale water exchange, or low-salinity farming systems, are closely associated with outbreaks of AHPND and vibriosis (Chang et al., 2024). Recent studies further indicate that low-salinity stress not only affects host osmoregulation but also reduces gut microbiota diversity and alters microbial community functions. These changes can promote the proliferation and tissue invasion of pathogenic *Vibrio* strains, suggesting that salinity influences disease dynamics through multi-level interactions among host, microbiota, and pathogens (Chang et al., 2024).

3.3 Effects of farming systems and stress factors

Farming systems largely determine the levels of biotic and abiotic stress experienced by shrimp and thus represent key management factors influencing disease occurrence. High-density intensive aquaculture systems have significantly increased production efficiency but also elevated pathogen transmission rates, water quality deterioration risks, and chronic stress levels, thereby increasing disease incidence (Hapsari et al., 2025; Kumar et al., 2025). Under high stocking densities, increased contact among individuals facilitates rapid pathogen spread. Meanwhile, the accumulation of uneaten feed and metabolic waste increases environmental load, further promoting the growth of opportunistic pathogens such as *Vibrio* spp.

Site selection and farming infrastructure also influence disease risks. Aquaculture systems established in acid sulfate soils, polluted waters, or ecologically marginal environments may expose shrimp to acidification, heavy metals, or other contaminants, thereby increasing physiological stress and weakening disease resistance (Kumar et al., 2025). In addition, the large-scale transboundary movement of broodstock and seedstock, particularly in the absence of strict quarantine and biosecurity measures, has been identified as a major pathway for pathogen dissemination and a key driver of historical disease outbreaks.

Operational stressors in daily management further contribute to disease occurrence. Activities such as harvesting, grading, transportation, stocking, water exchange, and pond transfer can disrupt physiological and endocrine balance and suppress innate immune functions (Hapsari et al., 2025). In particular, improper management during