et al., 2023). In addition, maintaining the stability of filtration systems is critical; for instance, studies have shown that certain antimicrobial agents can suppress Vibrio without affecting nitrifying bacteria or shrimp health, highlighting the need for disease control strategies compatible with RAS systems.

6.3 Successful cases and integrated control strategies

Sustainable disease control increasingly relies on integrated management approaches. Case studies from Asia indicate that repeated outbreaks of WSSV and AHPND have driven a transition from traditional flow-through pond systems to more closed and controlled systems. By incorporating water storage ponds, wastewater treatment systems, reduced water exchange, and RAS components, higher levels of biosecurity can be achieved (Kumar et al., 2025). In China, the widespread adoption of IMTA and polyculture systems has not only increased production but also reduced wastewater treatment costs and alleviated disease and environmental pressures, demonstrating both economic and ecological benefits (Uddin et al., 2025). Similarly, an IMTA trial in the Philippines showed that co-culturing tiger shrimp with fish, seaweed, and shellfish reduced pathogen loads, prevented AHPND occurrence, lowered WSS outbreaks, and significantly improved total production, net income, and return on investment (Arriesgado et al., 2025). These findings highlight the practical value of IMTA in both disease control and economic performance.

At the technical and management levels, integrated disease control strategies are equally critical. Studies emphasize the need to combine SPF/SPR seedstock, biosecurity measures, molecular diagnostics, and antibiotic-free approaches such as probiotics, immunostimulants, nanotechnology, and biological control methods (Bondad-Reantaso et al., 2023; Noman et al., 2024). Aquaculture systems based on water recirculation and reuse, combined with non-antibiotic antimicrobial strategies, are considered effective pathways to reduce antimicrobial resistance risks and achieve sustainability goals (Bondad-Reantaso et al., 2023; Natrah et al., 2025). In addition, sensor-based automated systems can regulate the application of probiotics and water conditioners based on real-time water quality and microbial data, thereby reducing organic load and pathogen levels, improving water quality, and lowering labor costs (Kumar et al., 2025).

7 Challenges and Future Issues

7.1 Pathogen variation and emerging disease risks

With the continuous expansion of shrimp aquaculture and the increasing intensity of high-density farming and transregional trade, pathogen evolution and emerging disease risks have become major challenges to the sustainable development of the industry. Previous studies indicate that shrimp diseases are not static but represent a dynamic system that evolves under the combined influences of industry expansion, ecological disturbances, and global trade. Viral pathogens, in particular, exhibit high mutation rates and transmission efficiency, and under changing host and environmental conditions, they tend to show increased virulence, expanded host range, and cross-regional dissemination. Since the 20th century, major viral diseases such as white spot syndrome virus (WSSV), yellow head virus (YHV), infectious myonecrosis virus (IMNV), and the recently emerging DIV1 have caused repeated outbreaks and sustained impacts across multiple aquaculture regions. Continuous emergence of new viruses and ongoing evolution of existing ones impose persistent challenges on current diagnostic systems and control strategies.

In this context, the transboundary movement of seedstock and live aquatic products, expansion of aquaculture into new regions, and environmental fluctuations driven by climate change create favorable conditions for pathogen spread and adaptation. Meanwhile, emerging bacterial and microsporidian diseases further increase the complexity of the disease spectrum. Pathogens such as AHPND-causing Vibrio and Enterocytozoon hepatopenaei (EHP) often occur as co-infections, leading to higher mortality and greater challenges in diagnosis and control. Field investigations indicate that multi-pathogen coexistence and alternating outbreaks are common in aquaculture systems. In addition, intensive farming practices, antibiotic selection pressure, and rising water temperatures may accelerate pathogen adaptation and evolution (Nguyen, 2024). Therefore, reliance on single-pathogen-based or fixed control strategies is no longer sufficient. Strengthening molecular epidemiological surveillance, pathogen