

immunity, and survival, while climate warming is increasing the frequency of damaging thermal exposure in aquaculture environments (Qian et al., 2024; Daunde et al., 2025). For swimming crab specifically, high temperature can disrupt energy metabolism, and severe stress is especially likely when elevated temperature is combined with air exposure, indicating that routine operations such as handling, grading, and transport become riskier during hot periods.

Extreme heat also creates management pressure by pushing crabs toward ecological and physiological thresholds beyond which recovery becomes difficult. In a related portunid crab fishery, juveniles became most susceptible when summer temperatures exceeded 24°C and conditions became clearly detrimental above 26°C, showing how short periods of abnormal warming can impair recruitment and survival. At the behavioral level, elevated temperature increases aggressiveness in *Portunus trituberculatus*, which can aggravate interference, injury, and cannibalism risk under high-density farming conditions (He et al., 2025).

7.2 Limitations in health monitoring and disease early-warning technologies

A major challenge under high-temperature conditions is that health deterioration often develops before farmers can identify it with conventional farm surveillance. Aquatic animal disease diagnostics still rely heavily on visual observation and traditional laboratory methods, while rapid kits and field-deployable tools remain insufficiently mature for routine farm use. Although CRISPR-, biosensor-, and LAMP-based tools are being developed, current field applications still face limitations in sensitivity and specificity, reducing their reliability for early warning during fast-moving heat-associated disease events (Bohara et al., 2023).

The second limitation is that effective early warning under heat stress requires integrated environmental forecasting, yet such systems remain uncommon in aquaculture practice. Temperature-sensitive marine diseases can be monitored using surveillance tools based on environmental temperature outlooks, and these tools can help target monitoring and management actions. However, outbreak risk is driven by nonlinear interactions among temperature, salinity, oxygen, pH, and host-pathogen factors, which makes prediction difficult for traditional approaches even though newer machine-learning systems show promise (Xie et al., 2025).

7.3 Lag in the development of integrated management systems and standardization

Integrated management systems for coping with high temperature in swimming crab farming still lag behind the needs of increasingly intensive production. Intensification raises stress through crowding, waste accumulation, and water-quality deterioration, and successful high-density culture depends on continuous balancing of biological and environmental variables that many farms still cannot achieve consistently (Emerenciano et al., 2022). This means that heat management cannot be treated as a single-factor issue, because elevated temperature interacts with oxygen, water quality, stocking density, and biosecurity failures to amplify health risks (Hapsari et al., 2025).

Standardization also remains limited because existing intelligent and integrated systems are still fragmented, species-specific, or insufficiently translated into broadly applicable farm protocols. Recent intelligent aquaculture systems can dynamically regulate temperature and oxygen using real-time stress feedback and can reduce chronic stress or disease incidence while improving operational performance, but these results mostly come from experimental systems in fish or shrimp rather than standardized frameworks for swimming crab culture (Nie et al., 2025). Likewise, integrated multi-trophic models such as shrimp-crab polyculture improve resource use and water-quality management potential, yet adoption depends strongly on local conditions, indicating that unified standards for high-temperature health management remain underdeveloped (Chang et al., 2020).

8 Conclusions and Future Perspectives

Current research shows that high temperature disrupts health homeostasis in *Portunus trituberculatus* at multiple levels, including energy metabolism, behavior, and cellular protection. Elevated temperature increases lactate accumulation, depresses ATP-related energy status, and can create a mismatch between energy demand and supply, especially when crabs are also exposed to air, which helps explain stress-induced mortality during culture and handling. In parallel, temperature elevation intensifies agonistic interactions and cannibalism risk, with fighting