

sustainable expansion depends on combining site selection, cultivation engineering, environmental monitoring, breeding, and biosecurity into coherent farm-management frameworks, yet current development is still characterized by uneven technical adoption and unresolved operational bottlenecks (Khan et al., 2024). This fragmentation is especially important for *Porphyra*, because cultivation performance depends on jointly managing environmental variability, seasonal growth dynamics, and infrastructure design rather than optimizing any single component in isolation (Sen et al., 2025).

Standardization is also limited by the diversity of cultivation environments and control methods used across farms. For *NeoPyropia/Pyropia* culture, fixed-pole, floating, and semi-floating raft methods are all used, while epiphyte control can rely on desiccation or pH treatment, indicating that operational practices remain heterogeneous and not yet fully harmonized into common green-production standards (García-Poza et al., 2020). More broadly, seaweed farming studies stress that economically and ecologically sustainable production requires state-of-the-art but practical methods, along with country-specific standards and monitoring protocols, which suggests that green *Porphyra* farming still lacks sufficiently unified technical norms for large-scale replication (Khan et al., 2024).

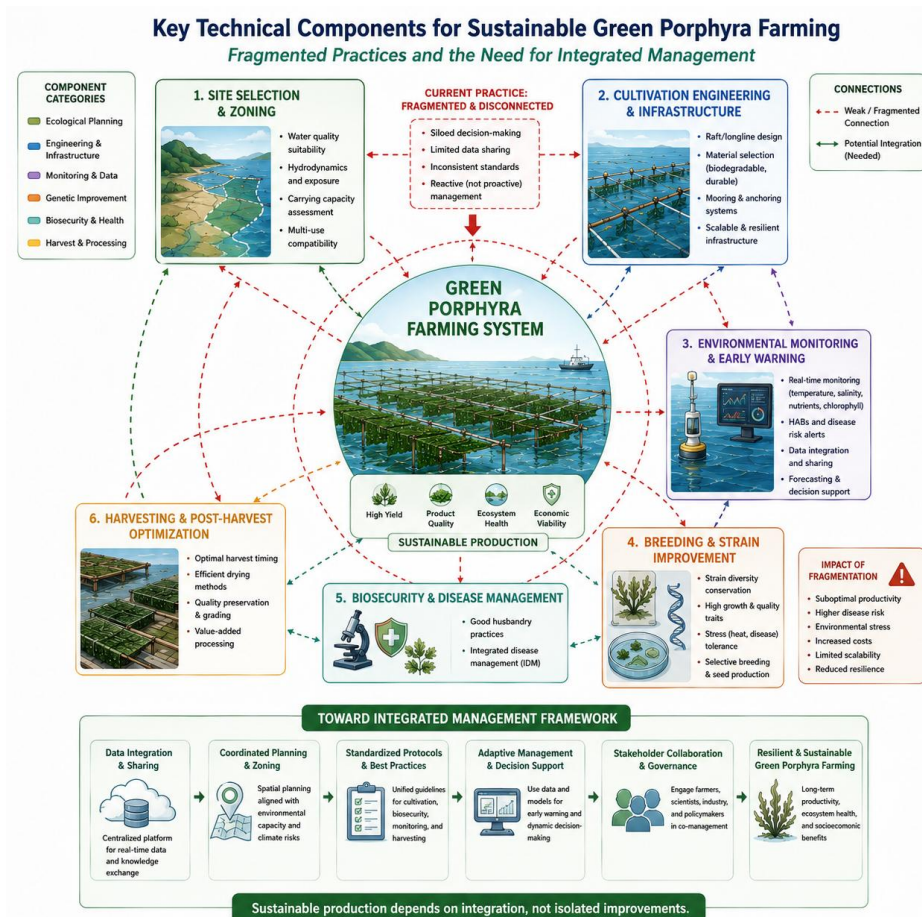


Figure 2 Conceptual framework illustrating the fragmented technological components involved in green *Porphyra* farming systems

7.2 Disparities in awareness and management capabilities among farming entities

A second challenge is the uneven awareness, technical knowledge, and management capacity among different farming entities. Evidence from broader seaweed aquaculture shows that farmers need access to educational programs, technical support, and affordable planting materials and equipment to manage threats and production risks effectively, implying that green transitions are constrained where training and extension systems are weak (Khan et al., 2024). This matters because the sustainable development of aquaculture increasingly depends on integrating technical, environmental, and governance knowledge, yet progress is uneven across producer groups and regions (Mair et al., 2023).