

refinement of scallop farming, complementing carrying-capacity modeling, offshore expansion, and ecological integration strategies already proposed for this species. In addition, because suspension-cultured scallops strongly influence seston removal, nutrient flux, and benthic-pelagic coupling, selecting an appropriate density also has ecological implications beyond individual growth alone. Overall, studying the effects of different stocking densities on the growth and survival of *C. farreri* is both theoretically meaningful and practically urgent, because it addresses the intersection of animal performance, environmental capacity, and sustainable industry development.

2 Physiological and Ecological Basis of Growth and Development in *Chlamys farreri*

2.1 Filter-feeding mechanisms and energy acquisition pathways

As a suspension-feeding bivalve, *Chlamys farreri* acquires energy by filtering mixed seston from the water column and regulating particle capture, selection, ingestion, and absorption in response to rapidly changing environmental conditions. A functional culture model showed that the species can differentially process phytoplankton, non-phytoplankton organic matter, and inorganic particles through gill retention and pre-ingestive rejection in pseudofeces, indicating that energy intake depends on both food quantity and particle quality rather than chlorophyll alone (Hawkins et al., 2002). This is ecologically important because living phytoplankton contributed less than 20% of suspended particulate organic matter in Sungo Bay, so a substantial fraction of assimilable energy must come from non-phytoplankton organic particles with highly variable energy content.

Feeding performance is further constrained by the interaction between seston structure and environmental temperature. Clearance rate in *C. farreri* varies over an order of magnitude and follows a unimodal response to total particulate volume and chlorophyll concentration, peaking before declining at excessive seston loads, which indicates flexible but capacity-limited feeding regulation (Hawkins et al., 2001). Laboratory energetics experiments likewise showed that filter-feeding rate increases with water temperature and body weight under appropriate thermal conditions, reaches a maximum at about 23°C, and then declines, while assimilation efficiency falls as algal concentration rises, suggesting a trade-off between rapid particle processing and digestive efficiency.

2.2 Growth regulation and metabolic allocation characteristics

Growth in *C. farreri* depends not only on how much energy is acquired, but also on how that energy is partitioned among shell formation, soft tissue growth, maintenance metabolism, and excretion. Multi-tissue metabolomic evidence indicates that growth-associated pathways are distributed across mantle, gill, adductor muscle, and digestive gland, with shared roles for sphingolipid metabolism, fatty acid biosynthesis, and transport processes, while tissue-specific pathways support shell deposition, nutrient absorption, and muscle development (Zhang et al., 2024). Within this system, the gill is especially important because it functions as the primary feeding tissue, initiates nutrient absorption, and helps maintain physiological equilibrium across other soft tissues (Figure 1).

Energy-budget studies show that metabolic allocation changes systematically with temperature and body size, which helps explain density-dependent variation in growth potential. Between 8 and 18°C, respiration, ammonia excretion, and ingestion all increase with rising temperature, but respiration and ingestion peak at 23°C and decline at 28°C, indicating that thermal elevation does not indefinitely promote production. Body size is another key determinant of allocation, because the proportion of energy lost to respiration increases as scallops grow, while the fraction deposited into growth declines; under simulated natural seston conditions, respiration accounted for 42.2%-51.7% of intake, whereas only 12.7%-21.7% was retained for growth.

2.3 Mechanisms of environmental stress response

Environmental stress in *C. farreri* is expressed through coupled metabolic, oxidative, immune, and behavioral responses, with temperature being one of the most important drivers. Metabolomic analysis under 27°C heat stress showed broad shifts in amino acid, carbohydrate, lipid, and nucleotide metabolism, and decreases in pyruvic acid together with increases in citric and fumaric acid indicated altered energy metabolism aimed at sustaining ATP supply during thermal challenge (Dong et al., 2022). Heat exposure also induced oxidative stress, but increased total antioxidant capacity in gill and mantle tissues suggests that the scallop retains some adaptive capacity through antioxidant regulation rather than passive injury alone.