

reference curve can support good growth and survival under both tank and pond conditions. In these studies, reducing or increasing feed input around the SFP (for example, 90%-110% of the table) had limited effect on feed conversion ratio, suggesting that fixed-ration strategies can be robust when biomass estimates are reasonable (Van et al., 2017).

However, strictly fixed rations may fail to match real-time appetite, especially as natural food availability and environmental conditions fluctuate. In intensive biofloc systems, experiments that applied several discrete feeding levels (30%-150% of a standard rate) revealed that growth increases with higher feed inputs but feed conversion worsens once a threshold is exceeded, indicating a trade-off between maximum biomass gain and feed efficiency under fixed-rate feeding. These results highlight that while fixed-time and fixed-quantity strategies are practical, they require careful calibration to avoid underfeeding, which limits growth, or overfeeding, which raises costs and nutrient loading (Weldon et al., 2021).

3.2 Multiple small-meal feeding strategy

Shrimp have small stomachs and naturally ingest many small meals, so distributing the daily ration into multiple small feedings aims to better align with their feeding behavior. Controlled studies comparing low (1-2 meals) and higher frequencies (4-6 meals or more) show that more frequent feeding can improve growth and, in some cases, water quality when total ration is maintained. For example, juveniles in biofloc systems fed three, six, or twelve times daily with the same daily ration displayed higher final weight, yield, and protein deposition as frequency increased, while feed conversion ratio decreased (Xu et al., 2020). Similar trials with extruded diets found that once- or twice-daily daylight feeding promoted growth but at the expense of water quality and FCR, whereas higher frequencies reduced ammonia and nitrite levels, indicating environmental benefits of spreading meals (Espinoza-Ortega et al., 2023).

Multiple small-meal strategies can be implemented manually or via automatic feeders and may be particularly valuable when diet formulation or system design constrains performance. Using a low-fish-meal, amino-acid-supplemented diet, offering ten meals per day via automatic feeders enhanced survival, body weight, and FCR compared with two or four manual meals, illustrating that more frequent feeding can compensate for lower fish-meal inclusion by improving intake and nutrient use. On farms, observations of pond management practices similarly emphasize dividing rations into several daily feedings and monitoring consumption, supporting more even distribution and reducing cannibalism, which are key practical characteristics of multiple small-meal feeding (Andriani and Pratama, 2023).

3.3 Intelligent precision feeding strategy

Intelligent precision feeding integrates automatic devices and real-time feedback or predictive models to dynamically adjust feed delivery according to shrimp demand and biomass. On-demand acoustic systems such as AQ1 release feed in response to feeding sounds, allowing shrimp to “request” feed within programmed limits. Pond trials comparing acoustic demand feeding with fixed-schedule timer feeders and standard protocols demonstrate that AQ1 systems consistently produce larger shrimp, higher yields, and greater crop value, without worsening FCR or survival, indicating more precise matching of feed input to appetite. Follow-up work under semi-intensive conditions similarly found that automatic feedback systems operating in real time outperformed standardized timer-based schedules, reinforcing the performance advantage of demand-driven feeding (Reis et al., 2020).

Beyond behavior-based feedback, recent developments incorporate machine-learning biomass prediction into intelligent feeders. In recirculating systems, data-driven models using water-quality and management data can predict shrimp biomass with high accuracy, enabling feeders to calculate appropriate ration sizes and stabilize water quality. Automated feeding trials that varied the number and distribution of meals show that when combined with optimized schedules, these systems improve growth and FCR compared to manual feeding, while also reducing labor costs and enabling higher feeding frequencies (Liang et al., 2025). Overall, intelligent precision strategies are characterized by continuous or high-frequency feed delivery, sensor or acoustic feedback, and algorithm-guided ration adjustment, aiming to maximize growth and profitability while minimizing waste.