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Effects of Early Weaning on Zootechnical performance and Development of Deformities inYellowtail Kingfish (*Seriola lalandi*) larvae

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Les analyses et les conclusions de ce travail d'étudiant n'engagent que la responsabilité de son auteur et non celle de l'Institut Agro Rennes-Angers

Introduction

The European aquaculture sector has undergone major transformations over the past two decades, moving from an ancillary activity to capture fisheries toward a key contributor to food security and sustainable production. Marine aquaculture in particular has benefited from advances in recirculating aquaculture systems (RAS), improved biosecurity, and the pursuit of diversification to meet evolving consumer expectations. Within this context, the yellowtail kingfish (*Seriola lalandi*) has emerged as a highly promising species for intensive aquaculture in Europe. Its rapid growth rate, high flesh quality, and adaptability to controlled environments make it a prime candidate for sustainable marine farming. However, the larval phase remains a bottleneck, limiting the full exploitation of the species' potential.

During early larval development, nutrition is a determining factor for growth, survival, and skeletal integrity. In aquaculture, live prey such as rotifers and Artemia have traditionally been used as the main feed sources for marine fish larvae. While nutritionally rich and well accepted, these feeds are expensive to produce, require considerable labor, and present variability in nutrient composition. Moreover, they carry microbiological risks and may be nutritionally deficient in essential fatty acids or vitamins. For these reasons, research and industry have long sought to develop nutritionally balanced microdiets that can replace or complement live feeds. However, the transition from live to dry feed (weaning phase) remains a critical and delicate period that often results in mortality and deformities if conducted too early.

Early weaning offers potential benefits in reducing production costs and simplifying hatchery operations but is constrained by the physiological immaturity of larvae. Their digestive system lacks full enzymatic capacity, and their behavioral feeding responses are not yet adapted to inert feed particles. Thus, the timing and manner of introducing microdiets are decisive for success. The aim of this study, carried out in collaboration with The Kingfish Company, was to evaluate the biological consequences of early weaning in yellowtail kingfish larvae by comparing three feeding strategies: a conventional live-feed protocol, a gradual co-feeding regime, and an ultra-early weaning treatment based solely on microdiets. The goal was to assess how these approaches affect survival, growth, and deformity incidence, and to identify viable strategies for improving hatchery efficiency without compromising fish quality.

Results

Above all, limitations due to a lack of replicates per condition and essential grading steps to limit cannibalism result in statistical weakness. The results obtained should therefore be treated with caution and cannot lead to solid conclusions.

Survival followed a biphasic trend common to marine fish larvae: an initial decline during the swim bladder inflation period (4–7 days after hatching), followed by a second, more pronounced drop around the onset of weaning. During the first week, larvaes are stressed due to swimbladder inflation phase. To keep a good swimbladder inflation ratio, it has been decided to keep only livefeed for all condition. Due to this choice, survival remained comparable across treatments between 4 and 7 DAH, averaging between 60–70%. By 17 days post-hatch, differences became apparent. The Control group, which received only live prey, maintained the highest survival (≈42%), whereas the Mix and Dryfeed groups displayed lower values (≈28% and 26%, respectively). This suggests that larvae exposed to microdiets during early feeding experienced additional stress or nutritional inadequacies, leading to increased mortality. Over the full 45-day period, survival rates decreased sharply: 7.9% for Control, 3.7% for Mix, and only 0.1% for Dryfeed. These results highlight that an exclusively dry feeding regime introduced prematurely is unsustainable under current conditions.

Growth dynamics exhibited similar patterns of divergence. Up to 16 DAH, all treatments showed limited growth and between 27 and 45 DAH, growth accelerated, particularly following the grading operations that reduced density and size heterogeneity. By the end of the trial, the Mix condition exhibited the largest weighted mean size 25.13 ± 4.25 mm (CV = 16.9%, *N* = 9,579), slightly exceeding that of the Control 23.37 ± 6.18 mm (CV = 26.4%, *N* = 20,877), while the Dryfeed group lagged behind 21.84 ± 4.69 mm (CV = 21.5%, *N* = 372). Variability within treatments was notable: coefficients of variation ranged between 13% and 26%, reflecting the persistence of size heterogeneity and unequal feeding success among individuals. The higher mean size observed in the Mix group likely reflects the selective survival of more robust individuals combined with improved nutrient assimilation once larvae had adapted to the inert diet. The very low survival in the Dryfeed condition implies that only the most resilient individuals survived, potentially inflating the apparent mean size.

Morphological assessments revealed substantial differences in deformity incidence among treatments. Three categories of skeletal anomalies were distinguished: incomplete ossification of neural spines, vertebral column deformities (bent or fused vertebrae), and cranial anomalies such as jaw malformations. Control larvae displayed the lowest deformity incidence, generally limited to mild incomplete ossifications. In the Mix condition, deformities were moderate and primarily transient, suggesting partial recovery as larvae matured. In contrast, the Dryfeed treatment produced the highest proportion and severity of malformations, particularly between 35 and 40 DAH, where more than one-third of individuals exhibited structural anomalies. Jaw deformities were also more frequent in this group, indicating that nutritional imbalances during early bone development strongly affected craniofacial morphogenesis.

Boxplot analyses of jaw ratios confirmed this tendency. At 35 DAH, median upper/lower jaw ratios were close to 1 across all treatments, but the proportion of outliers—indicative of malformed individuals—was highest in the Dryfeed group (13.3%), moderate in Control (10%), and absent in Mix. Over time, the number of outliers decreased in all groups, suggesting partial compensation or selective mortality of deformed individuals. Nevertheless, the persistence of jaw ratio variability up to 45 DAH in all treatments implies that deformity risk remains throughout the larval phase.

In summary, early full replacement of live feeds appeared to compromise both survival and morphological quality, while gradual co-feeding achieved a better balance between growth and survival. Although microdiets hold promise for improving operational efficiency, their premature and exclusive use remains biologically detrimental under current formulations. To finish, it's important to remember that due to experiment limitations, all the data obtained from it are not statistically strong and need to be taken with caution.

Discussion

The findings of this experiment highlight the delicate trade-off between operational efficiency and biological feasibility in larval rearing of yellowtail kingfish. The pronounced mortality in the Dryfeed treatment underscores the physiological constraints of early larval stages. At less than three weeks post-hatch, the digestive system of *S. lalandi* is still undergoing differentiation. The absence of a fully functional stomach and limited secretion of digestive enzymes, such as pepsin and trypsin, restrict the capacity of larvae to hydrolyze complex proteins and lipids found in microdiets. Consequently, nutrients may remain poorly absorbed, leading to energy deficits and reduced resistance to environmental or handling stress. In this context, the presence of live prey plays a dual role, both as a highly digestible nutrient source and as a stimulant for feeding behavior and digestive enzyme secretion. Their removal too early disrupts this balance.

The moderate performance of the Mix treatment suggests that gradual co-feeding provides an effective compromise. By introducing microdiets while maintaining live prey availability, larvae are progressively exposed to new textures and particle characteristics. This strategy likely stimulates adaptation of the digestive system and reduces feed rejection. Moreover, co-feeding mitigates the risks associated with nutritional imbalances inherent to microdiets by ensuring continuous access to the micronutrient-rich live prey. This aligns with previous observations in other marine species, such as seabass and barramundi, where co-feeding improved survival and growth compared to abrupt weaning.

The elevated frequency of deformities in the Dryfeed treatment reflects the cumulative impact of nutritional deficiencies, stress, and developmental asynchrony. Micronutrients such as vitamins A, D, E, and trace minerals (e.g., zinc, selenium, manganese) are crucial for bone formation, collagen synthesis, and antioxidant protection. Deficiencies during critical ossification phases can induce irreversible skeletal defects. Additionally, an imbalance in essential fatty acids (particularly DHA and EPA) may alter cell membrane fluidity and disrupt cartilage development. Given that microdiets often suffer from lower digestibility and nutrient bioavailability compared to live feeds, these deficits are likely to explain the higher deformity rates observed. Furthermore, the physical properties of microdiets, particle hardness and sinking behavior, can modify ingestion patterns, leading to underfeeding in some larvae and overfeeding in others, further contributing to size heterogeneity and deformity risk.

Behavioral and social dynamics may also have played a role. As larvae grow, differences in feeding ability and aggressiveness can amplify inequality within tanks, fostering cannibalism and selective mortality. This self-sorting process may explain the higher apparent growth in the Mix group, where only the best-performing individuals survived. While grading operations helped reduce extreme disparities, they could not fully restore experimental independence, highlighting a methodological limitation intrinsic to larval rearing studies.

Another consideration lies in environmental control. Parameters such as oxygen concentration, light intensity, and hydrodynamic conditions can strongly influence larval feeding and swim stability. These factors were kept within operational ranges during the trial but not quantified precisely, preventing statistical analysis of their contribution. However, literature indicates that even minor deviations in light gradients or aeration intensity can affect prey visibility and ingestion success. The absence of precise monitoring likely contributed to variability among tanks and could have exacerbated the sensitivity of the Dryfeed group.

From an applied perspective, the results suggest that complete early weaning is currently unsuitable for *S. lalandi* under commercial conditions. Nevertheless, the performance of the Mix treatment indicates promising potential for optimizing co-feeding regimes. By fine-tuning the onset timing, feed particle size, and enrichment formulations, it may be possible to further reduce dependency on live prey without compromising larval quality. Improvements in microdiet design, such as enhanced buoyancy, digestibility, and encapsulation of sensitive nutrients, could also mitigate current limitations.

Despite the limitations in replication and statistical robustness due to the necessity of grading and tank pooling, this study provides valuable empirical evidence relevant to hatchery operations. It highlights the need to consider not only the biochemical composition of diets but also the behavioral and physiological readiness of larvae. Successful early weaning must therefore integrate nutritional adequacy, feed physical properties, and gradual behavioral conditioning to achieve stable results.

Conclusion

This study demonstrates that while early weaning in yellowtail kingfish larvae holds clear economic and logistical advantages, it remains biologically constrained by larval physiology. Complete replacement of live feeds by dry microdiets from the onset of exogenous feeding resulted in catastrophic survival losses and widespread skeletal deformities, highlighting the unsuitability of such an approach under current technological and nutritional conditions. Conversely, a gradual co-feeding regime integrating microdiets alongside live prey produced a more balanced outcome: survival close to that of the control treatment, improved growth performance, and reduced deformity incidence once larvae adapted to inert feed.

These findings emphasize the importance of synchronizing feeding strategies with larval development. Future optimization should focus on identifying the precise ontogenetic window when larvae acquire sufficient digestive and behavioral maturity to utilize dry feeds efficiently. Advances in diet formulation, particularly regarding digestibility, micronutrient delivery, and feed buoyancy, will be key to achieving earlier yet safe weaning. Equally, refining environmental conditions and automating co-feeding systems could enhance both reproducibility and cost-effectiveness at the hatchery scale.

Beyond its specific implications for *S. lalandi*, this study contributes to the broader understanding of early weaning in marine fish larvae. It reinforces the idea that the success of larviculture depends on harmonizing biological constraints with technological innovations. A balanced co-feeding approach appears to represent the most viable path forward, offering a compromise between sustainability, operational efficiency, and the maintenance of high-quality juveniles. Continued research combining histological, biochemical, and behavioral analyses will be essential to elucidate the mechanisms underpinning these responses and to guide the next generation of feeding protocols for high-value aquaculture species.