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OPTIMIZATION OF FEEDING STRATEGY AND ENVIRONMENTAL MONITORING IN SHORT-CYCLE BARRAMUNDI (*Lates calcarifer*) GROW-OUT USING COMMERCIAL DIETS

Optimasi Strategi Pemberian Pakan dan Pemantauan Lingkungan Pada Pembesaran Ikan Kakap Putih (*Lates calcarifer*) Siklus Pendek Menggunakan Pakan Komersial

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ABSTRACT

The integration of feeding strategies, monitoring systems, and environmental assessments within short-cycle aquaculture systems is crucial for achieving optimal productivity and sustainability in coastal ecosystems. However, very few studies have been conducted on the interplay of these factors within shorter production cycles. The current study aimed to investigate the growth performance, feed efficiency, and survival rate of *Lates calcarifer* cultured for 30 days in offshore floating net cages under an at-satiation feeding strategy supplemented with probiotics and multivitamins. Observational data were collected from field trials conducted at Balai Besar Perikanan Budidaya Laut (BBPBL) in Lampung, Indonesia. Fish were administered feed bi-weekly, while essential water quality parameters were recorded weekly. Key findings included a specific growth rate of 1.4% per day, absolute weight gain of 36.8 g, a feed conversion ratio of 1.4, and an average survival rate of 82.8%. Throughout the study period, water quality parameters remained optimal. These results suggest that short-cycle barramundi farming facilitates efficient and sustainable production when combined with adaptive feeding schedules informed by consistent environmental monitoring. This research offers practical recommendations for small-scale marine aquaculture enterprises, highlighting the importance of advanced precision feeding frameworks and digital technologies in coastal aquafarming regions.

Keywords: Barramundi (*Lates calcarifer*), Feeding strategy, Feed conversion efficiency, Floating net cages, Short-cycle aquaculture

ABSTRAK

Integrasi antara strategi pemberian pakan, sistem pemantauan, dan evaluasi lingkungan dalam sistem akuakultur siklus pendek sangat penting untuk mencapai produktivitas dan keberlanjutan yang optimal di ekosistem pesisir. Namun, sangat sedikit penelitian yang telah dilakukan terkait interaksi ketiga faktor tersebut dalam siklus produksi yang lebih singkat. Penelitian ini bertujuan untuk mengkaji performa pertumbuhan, efisiensi pakan, dan tingkat kelulushidupan ikan *Lates calcarifer* yang dibudidayakan selama 30 hari di keramba jaring apung lepas pantai dengan menerapkan strategi pemberian pakan at-satiation yang dilengkapi dengan probiotik dan multivitamin. Data observasi dikumpulkan dari kegiatan budidaya lapang yang dilaksanakan di Balai Besar Perikanan Budidaya Laut (BBPBL) Lampung, Indonesia. Ikan diberi pakan dua kali sehari, sementara parameter kualitas air utama diukur setiap minggu. Hasil utama menunjukkan laju pertumbuhan spesifik sebesar 1,4% per hari, pertambahan bobot mutlak sebesar 36,8 g, rasio konversi pakan (FCR) sebesar 1,4, dan tingkat kelulushidupan rata-rata sebesar 82,8%. Selama periode penelitian, parameter kualitas air tetap berada dalam kisaran optimal. Temuan ini menunjukkan bahwa budidaya kakap putih siklus pendek dapat menghasilkan produksi yang efisien dan berkelanjutan jika dikombinasikan dengan jadwal pemberian pakan adaptif yang didukung oleh pemantauan lingkungan secara konsisten. Penelitian ini memberikan rekomendasi praktis bagi usaha budidaya laut skala kecil, serta menekankan pentingnya pengembangan kerangka kerja pemberian pakan presisi dan teknologi digital di wilayah pesisir.

Kata Kunci: Kakap putih (*Lates calcarifer*); Siklus pendek; Strategi pemberian pakan; Efisiensi pakan; Pemantauan kualitas air

INTRODUCTION

The barramundi, also known as Asian seabass (*Lates calcarifer*), is gaining significance in aquaculture, particularly in Indonesia, due to its rapid growth and high market demand. Offshore floating net cages are favored for their spatial and environmental benefits, yet successful grow-out performance hinges on optimal feeding strategies and environmental conditions. Studies have explored alternative feed ingredients to reduce costs and environmental impacts. For instance, the use of poultry by-product meal and *Hermetia illucens* larvae has been shown to enhance fillet quality and shelf life without compromising nutritional value, suggesting a sustainable alternative to traditional fishmeal diets (Chaklader *et al*., 2023). However, replacing fishmeal with tuna hydrolysate at high levels can negatively impact growth and liver health, indicating the need for careful optimization of feed composition (Siddik *et al*., 2018). Palm oil has also been investigated as a substitute for fish oil, showing promise in improving growth rates and survival in Asian seabass larvae. However, it alters their fatty acid profiles (Safiin *et al*., 2022). Peanut meal, when processed to reduce antinutritional factors, can partially replace fishmeal, supporting growth and health under hypoxic conditions (Vo *et al*., 2020). Environmental sustainability in aquaculture is crucial, with offshore systems offering reduced impacts on water quality and primary production compared to coastal farms. However, challenges such as organic enrichment of sediments and interactions with wild fish remain (Price *et al*., 2015; Holmer, 2010). In Indonesia, interventions such as improved feed conversion ratios and sustainable farming practices could help mitigate environmental impacts, although achieving national production targets requires further innovation (Henriksson *et al*., 2019). Submerged cage systems offer opportunities to alleviate challenges associated with surface-based aquaculture but require additional research to optimize conditions for species such as barramundi (Sievers *et al*., 2022). Overall, integrating sustainable feed practices and environmental management is essential for advancing barramundi aquaculture in Indonesia (Braña *et al*., 2021).

The challenge of optimizing barramundi aquaculture in floating net cage systems amidst variable open-water environments is multifaceted, involving both environmental and operational considerations. Traditional fixed-rate feeding strategies often fail to adapt to daily fluctuations in water quality parameters, such as temperature, dissolved oxygen, and salinity, leading to inefficiencies like overfeeding and increased production costs due to feed waste. (Price *et al*., 2015; Jansen *et al*., 2016). The integration of environmental parameters into decision-making processes for feed administration is crucial, as highlighted by the need for

GIS-based site suitability models that consider physical environmental conditions and cage engineering design to optimize site selection and cage type for specific marine environments. Moreover, the potential of submerged cages, which can mitigate some environmental challenges faced by surface-based systems, is being explored; however, they present unique biological challenges depending on fish physiology (Falconer *et al*., 2013). The use of probiotics and multivitamins in commercial feeds during short-term marine cage cultures lacks sufficient empirical support, indicating a gap in standardized, evidence-based feeding strategies tailored to rapid production cycles (Luna *et al*., 2019). Advances in feed formulation have reduced the adequate trophic level of farmed species, suggesting that feed strategies should be dynamic and responsive to specific farmed properties rather than relying on historical or wild trophic levels (Cottrell *et al*., 2021). Furthermore, the implementation of integrated multitrophic aquaculture (IMTA) systems can help assimilate waste nutrients, thereby minimizing environmental impacts and enhancing sustainability (Price *et al*., 2015). The development of expert systems and genetic algorithms for determining optimal feeding strategies can further enhance economic efficiency and environmental sustainability by enabling the precise timing and combination of feeds (Luna *et al*., 2019). Overall, a holistic approach that incorporates environmental monitoring, adaptive feeding strategies, and innovative aquaculture technologies is essential for optimizing production in floating net cage systems under variable open-water conditions (Braña *et al*., 2021).

The integration of feeding techniques with environmental control in a short-cycle grow-out system for *Lates calcarifer*, commonly known as barramundi, cultured in floating net cages offshore, can be effectively managed by employing an at-satiation feeding regime with commercial diets that contain probiotics and multivitamins. Probiotics have been shown to enhance growth performance, feed efficiency, and disease resistance in aquaculture, making them a valuable addition to barramundi diets. They improve the gut microbiota, which plays a crucial role in nutrition metabolism and immune response, thereby supporting fish growth and health (Wuertz *et al*., 2021; Hasan *et al*., 2023). The use of probiotics in aquaculture is part of a broader trend towards sustainable practices, as they help reduce the need for antibiotics and mitigate environmental impacts by improving feed conversion ratios and reducing waste outputs (Hancz, 2022; Mohapatra *et al*., 2013). Additionally, probiotics can enhance the resilience of fish to environmental stressors, which is particularly beneficial in offshore aquaculture systems, where oceanic conditions can vary significantly (Mohapatra *et al*., 2013). The application of probiotics, such as *Carnobacterium maltaromaticum*, has been shown to significantly improve growth rates and feed conversion ratios in fish, while also reducing pathogenic bacteria, which aligns with the goals of sustainable and efficient marine cage farming (Gołaś & Potorski, 2022). Furthermore, the integration of innovative aquaculture techniques, such as Integrated Multitrophic Aquaculture (IMTA) and Biofloc Technology (BFT), can help close nutrient cycles and reduce environmental impacts, thereby supporting the sustainability of marine aquaculture systems (Lothmann & Sewilam, 2022). Observational data from practical aquaculture experiences, such as those gained from internships at facilities like the Balai Besar Perikanan Budidaya, provide valuable insights into the real-world application of these strategies, reinforcing their effectiveness and adaptability in diverse marine environments (Bentzon-Tilia *et al*., 2016). Overall, the combination of probiotics, sustainable feeding practices, and innovative aquaculture techniques offers a comprehensive approach to enhancing the growth performance and sustainability of barramundi farming in offshore systems.

The current state of research in barramundi aquaculture highlights a significant gap in integrating real-time environmental data and adaptive decision-making within short-cycle production frameworks, particularly in open marine cage environments. While recirculating aquaculture systems (RAS) have been extensively studied for their environmental control and efficiency, they do not fully capture the variability and challenges of open marine systems, which are crucial for optimizing short-term empirical models in tropical offshore aquaculture regions (Braña *et al*., 2021; Li *et al*., 2023). The environmental impacts of aquaculture, such as eutrophication and chemical pollution, are well-documented. Sustainable practices, including polyculture and offshore facilities, are being explored to mitigate these effects (Braña *et al*., 2021; Bohnes *et al*., 2019). However, the focus has been mainly on long-term grow-out cycles and controlled environments, leaving a gap in understanding the dynamics of short-cycle production in more variable marine settings (Tičina *et al*., 2020). The potential for precision aquaculture frameworks in these high-potential but under-researched systems is significant, as they could leverage real-time data and adaptive management to enhance sustainability and productivity (Elvines *et al*., 2024). Moreover, the integration of at-satiation feeding, dietary supplementation, and water quality monitoring in compressed production periods remains underexplored despite its potential to improve efficiency and reduce environmental impacts (Senff *et al*., 2020; Varga *et al*., 2020). The use of biochemical tools to trace waste dispersal and understand food web interactions in marine systems could further support environmental management and sustainable expansion of aquaculture in dynamic coastal areas (Elvines *et al*., 2024). Overall, there is a clear need for targeted research and development of innovative technologies and practices that address the unique challenges of short-cycle marine aquaculture, thereby contributing to the broader goals of sustainable aquaculture and food security (Clough *et al*., 2020; Brugere *et al*., 2019).

The study on *Lates calcarifer*, or Asian seabass, cultured in floating net cages during a short-cycle grow-out period, provides a significant contribution to marine aquaculture by integrating feeding strategies with environmental monitoring. This approach is particularly novel as it utilizes real operational data from the Balai Besar Perikanan Budidaya (BBPBL) in Indonesia, contrasting with previous studies that were limited to controlled environments or longer durations. The study's focus on at-satiation feeding enhanced with probiotics and multivitamins aims to improve feed utilization and growth efficiency, which is crucial given the high cost of nutrition in aquaculture operations (Ngoh *et al*., 2015). The real-time monitoring of water quality parameters, such as temperature, salinity, dissolved oxygen, and pH, is essential for understanding variable culture performance over time, aligning with findings that emphasize the importance of environmental monitoring in sustainable aquaculture practices (Braña *et al*., 2021; Price *et al*., 2015). This integrated approach not only fills a gap in the literature but also offers practical recommendations for optimizing short-cycle production systems, which is vital for advancing sustainable and scalable marine aquaculture in Indonesia. The study's findings are supported by broader research on sustainable aquaculture practices, such as the use of integrated multitrophic aquaculture (IMTA) systems, which have been shown to reduce environmental impacts and improve fish welfare by maintaining stable water quality and supporting habitat conservation. (Lee *et al*., 2022; Chang *et al*., 2019). Additionally, the study's emphasis on probiotics and multivitamins aligns with the growing interest in enhancing aquaculture sustainability through innovative feed strategies, as seen in other research focusing on the nutritional and physiological impacts of different feed types on fish growth and health (Ngoh *et al*., 2015). Overall, this research contributes to the ongoing efforts to balance aquaculture growth with environmental sustainability, a critical consideration given Indonesia's significant role in global seafood production and the ecological challenges posed by the expansion of aquaculture (Henriksson *et al*., 2019).

RESEARCH METHOD

Study Site and Duration

The study was conducted at BBPBL (Balai Besar Perikanan Budidaya Laut) Lampung, located in Hanura Village, Teluk Pandan Subdistrict, Pesawaran Regency, Lampung Province, Indonesia (5°31′39″S, 105°14′56″E). The grow-out trial was conducted in floating net cages located in coastal marine waters from January 9 to February 9, 2024, spanning 30 days. This facility is well known in the country for its contributions to developing marine aquaculture and possesses proper infrastructure for seed production, grow-out systems, and applied research.

Experimental Design

This arrangement involves studying the barramundi in *Lates calcarifer* underwater farming, where fish are grown in a controlled environment (*a nurturing sea*) using scientific methods. In total, 450 fish were kept in a rectangular floating net cage with dimensions of 3 × 3 × 3 and a mesh size of 1.5 to 2 inches. Furthermore, each fish weighed approximately 70.7 grams and was about 16 centimeters in length. The feeding schedule for these fish involved twice-daily feeding sessions at set times on commercial basal diets, which consisted of sequentially delivered sinking pellets high in protein by 46% (Megami). Moreover, dietary supplements such as Progol or Biovit could be added, considering the nutritional needs that are met through probiotics and multivitamins.

Feeding Procedure

An at-satiation feeding strategy was employed whereby feed was apportioned stepwise until the fish ceased active feeding behavior (Glencross, 2006). Manually distributed feed minimized waste and enabled precision control. Daily fish feed consumption was noted and recorded. Regular inspections and cleanings of the cage netting were conducted to reduce fouling and improve water exchange.

Environmental Monitoring

For this study, the sampling and measurement of temperature (°C), salinity (ppt), dissolved oxygen (mg/L), and pH were conducted weekly during the designated 30-day period. The instruments used to carry out the measurements include, but are not limited to, a DO meter, refractometer, thermometer, and pH test kit. Moreover, samplings were conducted from 08:00 to 09:00, which increased the precision of data collection.

Growth Performance Assessment

Fish sampling was conducted on days 1, 10, 20, and 30. For each sampling date, a random subsample of thirty fish was selected, and their body weight was measured in grams using a digital scale. Their total length was measured in centimeters using a measuring board. To minimize cannibalism that might arise from size disparity among juvenile fish, grading was performed on day 10. Using formulas (Effendie, 1997). survival rate (SR), specific growth rate (SGR), absolute length gain, absolute weight gain, feed efficiency (FE), and feed conversion ratio (FCR), we computed separately as per standard practice:

$$\text{Absolute Weight Gain (g)} = \text{Final Weight} - \text{Initial Weight}$$

$$\text{Absolute Length Gain (cm)} = \text{Final Length} - \text{Initial Length}$$

$$\text{Specific Growth Rate (\%/day)} = \left[\frac{\ln \text{Final Weight} - \ln \text{Initial Weight}}{\text{Days}} \right] \times 100$$

$$\text{Survival Rate (\%)} = \left[\frac{\text{Final fish count}}{\text{nitial fish count}}\right] \times 100$$

$$\text{Feed Efficiency (\%)} = \left[\frac{\text{(Final Weight + Dead Fish Weight − Initial Weight)}}{\text{Feed Given}}\right] \times 100$$

$$\text{FCR} = \frac{\text{Feed Given}}{\text{(Final Weight + Dead Fish Weight − Initial Weight)}}$$

Data Collection and Analysis

Direct observation, daily supervision, and physical assessments yielded primary data. Secondary data, including feed composition and specific facility characteristics, were taken from the records and technical documents of BBPBL. Microsoft Excel was used to compile all the data, which was then analyzed descriptively. The growth performance, alongside water quality trends, was interpreted graphically. Given the observational character of the study, no inferential statistics were employed.

RESULT

Under the feeding and environmental management protocols employed, a 30-day short-cycle grow-out period for *Lates calcarifer* in floating net cages demonstrated positive growth performance. Absolute weight gain was 36.8 grams, from 70.7 g to 107.7 g. Similarly, the absolute length gain was 7.3 cm, with fish cultured growing from 16.4 cm to 23.7 cm during the culture period. The specific growth rate (SGR) was recorded at 1.4% per day, indicating efficient and consistent growth within a reasonably short time frame.

Regarding feed utilization efficiency, a notable feed conversion ratio (FCR) of 1.4, along with an efficiency of 59.4%, indicated that the at-saturation feeding strategy, which included probiotics and multivitamins, was effective in the field setting. Additionally, the survival rate was reported as 82.8%, which is relatively high for marine cage culture, particularly for uncontrolled open-water systems. During the trial period, environmental parameters remained constant within optimal ranges. These include temperatures ranging from 28.7°C to 29.7°C, salinity levels between 32 and 33 ppt, consistently exceeding 5.8 mg/L dissolved oxygen, and pH levels between 8.16 and 8.19. The stability these factors provided likely positively influenced the observed performance in survival and growth.

The growth trends in both average length and weight over the sampling intervals are illustrated in the following figures:

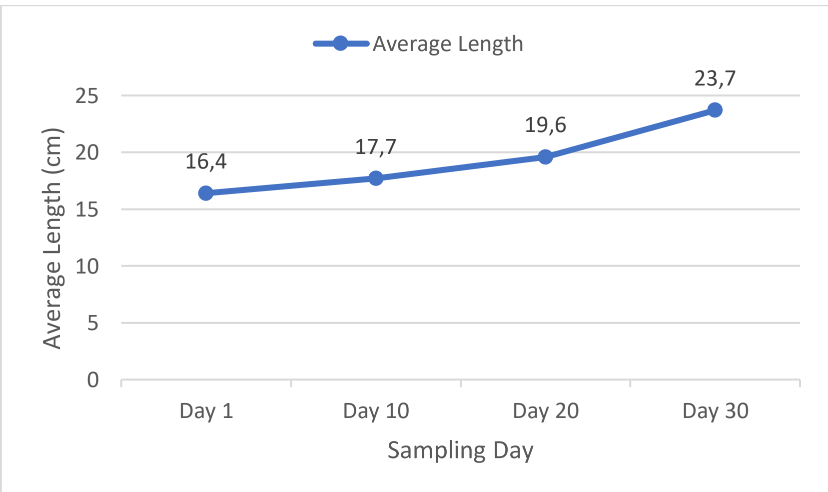

Figure 1. Growth in Average Length

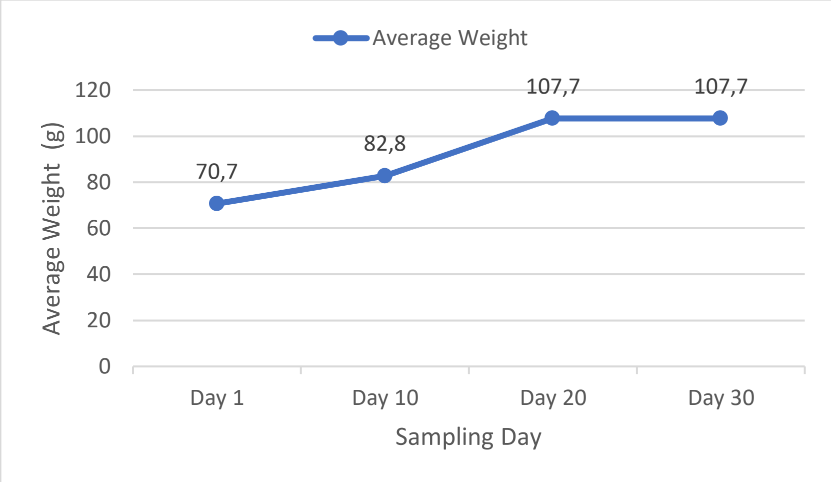

Figure 2. Growth in Average Weight

The results support the notion that a short-cycle production strategy, combined with optimal feed strategies and frequent monitoring of environmental conditions in offshore floating net cages, can lead to efficient and sustainable productivity in marine aquaculture systems.

DISCUSSION

The growth results of *Lates calcarifer* during the 30-day culture period, characterized by an absolute length gain of 7.3 cm, weight gain of 36.8 g, and a specific growth rate (SGR) of 1.4% per day, indicate efficient somatic development, which aligns with findings from various studies on aquaculture feeding strategies. The use of processed poultry by-product meal (PPBM) as a substitute for fishmeal (FM) has been shown to maintain growth performance and feed conversion ratios similar to those of FM-based diets, suggesting that alternative protein sources can support rapid growth when properly formulated and administered (Siddik *et al*., 2019). Additionally, the incorporation of dietary starch has been found to promote hepatic lipogenesis in barramundi, which may contribute to efficient energy utilization and growth under specific dietary conditions (Wade *et al*., 2020). The use of palm oil-based micro diets has also demonstrated improved growth rates and feed conversion efficiency in Asian seabass, further supporting the potential of alternative lipid sources in aquaculture feeds (Safiin *et al*., 2022). However, complete replacement of FM with non-fishmeal ingredients, such as poultry by-product meal, can negatively impact growth and health, as seen in studies where total substitution led to reduced growth performance and adverse histological changes (Chaklader *et al*., 2020). The feed conversion ratio (FCR) of 1.4 and feed efficiency of 59.4% observed in the study suggest that the dietary intake versus growth yield was favorable, comparable to or exceeding values from more extended grow-out periods, which is consistent with findings that optimized feed formulations can enhance growth efficiency (Ngoh *et al*., 2015). The survival rate of 82.8% further underscores the effectiveness of the husbandry protocols, indicating that the fish were resilient to environmental variability —a critical factor in aquaculture success (Noble *et al*., 2014). Overall, these findings underscore the importance of balanced dietary formulations and effective environmental management in achieving rapid and stable biomass accumulation in *Lates calcarifer*, thereby challenging traditional long-cycle systems by demonstrating superior performance and fish health in short-cycle systems (Siddik *et al*., 2018).

The research findings on *Lates calcarifer*'s growth and feed efficiency during a 30-day culture period have significant theoretical and practical implications for the marine aquaculture industry, particularly in the context of short-cycle aquaculture. Theoretically, these findings refine current estimations of growth and feed efficiency in euryhaline marine species, emphasizing the potential for shorter production cycles, which is crucial in regions with limited resources or seasonal variability. This aligns with the broader trend in aquaculture towards more sustainable practices, such as the use of probiotics and multivitamins to enhance feed efficiency and growth performance, as demonstrated in studies on other species like the red drum and European seabass, where dietary supplements improved growth and health outcomes (Yamamoto *et al*., 2022; Petereit *et al*., 2022; Mardiana *et al.,* 2024). Practically, the implementation of at-satiation feeding strategies, combined with probiotics and multivitamins, can significantly boost productivity for small to medium-sized producers while conserving economic and environmental resources. This approach is supported by the potential of innovative techniques, such as Integrated Multitrophic Aquaculture (IMTA) and Biofloc Technology (BFT), which aim to close nutrient cycles and reduce environmental impacts by effectively utilizing waste nutrients (Lothmann & Sewilam, 2022). Additionally, routine water quality measurements and flexible management systems that adapt to real-time environmental conditions are crucial for optimizing feed delivery and ensuring sustainable aquaculture practices (Price *et al*., 2015; Braña *et al*., 2021). These strategies not only enhance production performance but also promote responsible governance in coastal areas, aligning with the industry's shift towards circular economy approaches that prioritize environmental sustainability and resource efficiency (Greene *et al*., 2022). Overall, integrating these findings and practices can lead to more resilient and sustainable aquaculture systems that are capable of meeting the growing global demand for seafood while minimizing their ecological footprint.

The study in question, which involved grow-out trials spanning 30 days, presents several limitations that are crucial for accurately interpreting its findings. The short duration of the trials limits the ability to assess long-term growth patterns, disease vectors, and cumulative environmental impacts, which are essential for understanding the full implications of dietary interventions in aquaculture (Ayala *et al*., 2023). The absence of comparator treatment controls further complicates the interpretation of results, as it prevents the establishment of causation and limits the ability to draw robust conclusions about the efficacy of the dietary supplements used (Ross & Zaidi, 2019). The use of a single floating net cage unit raises concerns about external validity. It reduces the statistical power of the study, making it difficult to generalize the findings to other settings or populations (Ritskes-Hoitinga & Pound, 2022). Additionally, the lack of control over environmental factors such as water current velocity and biosecurity measures introduces potential biases that could affect the study's generalizability (Victora *et al*., 2005). These limitations underscore the importance of considering contextual factors and methodological rigor in research design to ensure the validity and applicability of study findings (Ritskes-Hoitinga & Pound, 2022; Victora *et al*., 2005). Addressing these constraints in future studies may involve longer trial periods, the inclusion of control groups, and the use of multiple experimental units to enhance the reliability and relevance of the research outcomes (Ross & Zaidi, 2019; Ayala *et al*., 2023). Understanding and acknowledging these limitations is crucial for situating the study's results within their proper context and informing future research efforts in aquaculture and related fields (Ross & Zaidi, 2019; Victora *et al*., 2005).

Incorporating diverse feeding strategies and supplementation protocols into controlled experimental frameworks is crucial for understanding the causal effects of dietary interventions on aquaculture growth performance and feed efficiency. The integration of different types of feeders and varying feeding frequencies, as demonstrated in studies on European sea bass and tilapia, highlights the importance of optimizing feeding schedules to enhance growth rates and economic returns (Rodde *et al*., 2020; Billah *et al*., 2020). For instance, feeding tilapia and common carp five days a week at specific times yielded the highest growth rates and financial returns, underscoring the importance of feeding frequency in aquaculture systems (Billah *et* *al*., 2020). Additionally, the use of automated feeders and real-time data logging systems can significantly enhance decision-making precision by allowing for adaptive responsiveness to changing environmental conditions, thereby aligning with Industry 4.0 principles (Luna *et al*., 2019). The scalability and ecological robustness of these strategies can be assessed by replicating studies across multiple cage units and diverse coastal environments, which would provide insights into environmental adaptability (Rodde *et al*., 2020; Hoerterer *et al*., 2022). Extending growth cycles beyond 30 days, as suggested in studies on turbot and Atlantic salmon, would further elucidate the sustainability and physiological impacts of dietary interventions over short and long-term periods (Hoerterer *et al*., 2022; Kousoulaki *et al*., 2022). Moreover, the shift towards sustainable feed ingredients, such as plant-based proteins and insect meals, has been shown to maintain growth performance while reducing environmental impact. However, challenges remain in achieving the same growth rates as traditional fish meal and oil diets (Hoerterer *et al*., 2022; Kousoulaki *et al*., 2022; Boucher *et al*., 2012). The integration of genetic selection for dietary adaptation, as seen in rainbow trout, can further enhance the sustainability of aquaculture by improving growth and survival rates on plant-based diets (Boucher *et al*., 2012). Overall, these strategies collectively contribute to a more intelligent and sustainable aquaculture system that leverages technological advancements and innovative feeding protocols to optimize growth performance and feed efficiency while minimizing environmental impact (Luna *et al*., 2019; Shaw *et al*., 2023).

The study on short-cycle barramundi grow-out in coastal communities highlights a sustainable aquaculture model that can significantly impact food security and economic livelihoods, particularly in under-resourced regions. This model, which utilizes commercial feeds and requires minimal environmental supervision, aligns with the broader goals of sustainable aquaculture by promoting high productivity without intensive capital investment, thus fostering inclusive economic development (Parappurathu *et al*., 2023; Troell *et al*., 2023). Its emphasis on environmental stewardship underscores the ethical dimension of this approach, as it minimizes feed wastage and nutrient discharge into marine ecosystems, promoting responsible resource utilization (Braña *et al*., 2021; Macaulay *et al*., 2022). However, as digital technologies become more prevalent in aquaculture, new ethical concerns arise, particularly regarding data governance, equitable access to innovative farming technologies, and the risk of technocratic capture, which could exacerbate inequalities within the sector (Kluger & Filgueira, 2021; Clough *et al*., 2020). Addressing these issues requires expanding digital access and building capacity among coastal communities to ensure that technological advancements benefit all stakeholders equally (Quimby *et al*., 2023; Selim *et al*., 2021).

Furthermore, integrating traditional institutions and co-management approaches can enhance food sovereignty and social resilience, as demonstrated in small-scale fisheries and mariculture in Samoa, where local values and community engagement play crucial roles in sustainable development (Quimby *et al*., 2023) The adoption of innovative systems, such as bio floc technology and integrated multitrophic aquaculture (IMTA), can further enhance sustainability by optimizing resource use and reducing environmental impacts (Mugwanya *et al*., 2021; Greene *et al*., 2022). Overall, the study's outcomes underscore the potential of sustainable aquaculture to contribute to the Sustainable Development Goals (SDGs) by enhancing food security, promoting economic opportunities, and improving environmental health, while also highlighting the need for inclusive and equitable technological integration (Troell *et al*., 2023; Greene *et al*., 2022).

CONCLUSION

This research demonstrates that a short-cycle grow-out strategy for *Lates calcarifer* cultured in offshore floating net cages yields satisfactory growth performance, feed efficiency, and survival rates, utilizing an at-satiation feeding management system enhanced by probiotics and multivitamins. Over 30 days, barramundi demonstrated a specific growth rate of 1.4% per day, a favorable feed conversion ratio of 1.4, and an 82.8% survival rate. These outcomes suggest that the strategy is both biologically viable and operationally efficient. In conjunction with these benchmarks, routine environmental monitoring provided stringent control over water quality, likely contributing to the observed performance outcomes. The results of this study have significant practical value for small- and medium-scale aquaculture businesses, aiming to optimize production in changing open-ocean conditions while minimizing the need for expensive infrastructure components.

Due to the study's limited scope and timeframe, incorporating controlled, comparative trials to assess the impact of various feeding intervals, dietary additives, and digital monitoring devices is suggested for future work. Expanding the approach to multiple sites and production cycles would improve the external validity and comprehensive nature of the research outcomes. Moreover, adopting precision aquaculture technologies simultaneously with advancing digital education and infrastructure in coastal communities can facilitate a shift towards more inclusive, sustainable, and ethically responsible marine aquaculture systems.

REFERENCES

Ayala, M. D., Balsalobre, N., Chaves-Pozo, E., Sáez, M. I., Galafat, A., Alarcón, F. J., & Arizcun, M. (2023). Long-Term Effects of A Short Juvenile Feeding Period with Diets Enriched with the Microalgae *Nannochloropsis Gaditana* on the Subsequent Body and Muscle Growth of Gilthead Seabream, Sparus Aurata L. *Animals*, *13*(3), 482. Https://Doi.Org/10.3390/Ani13030482

Bentzon-Tilia, M., Sonnenschein, E. C., & Gram, L. (2016). Monitoring and Managing Microbes in Aquaculture–Towards A Sustainable Industry. *Microbial Biotechnology*, *9*(5), 576-584. Https://Doi.Org/10.1111/1751-7915.12392

Billah, M. M., Uddin, M. K., Samad, M. Y., Hassan, M. Z., Anwar, M. P., Talukder, I., & Haque, A. N. A. (2020). Impact of Feeding Schedule on the Growth Performances of Tilapia, Common Carp, and Rice Yield in an Integrated Rice-Fish Farming System. *Sustainability*, *12*(20), 8658. Https://Doi.Org/10.3390/SU12208658

Bohnes, F. A., Hauschild, M. Z., Schlundt, J., & Laurent, A. (2019). Life Cycle Assessments of Aquaculture Systems: A Critical Review of Reported Findings with Recommendations for Policy and System Development. *Reviews In Aquaculture*, *11*(4), 1061-1079. Https://Doi.Org/10.1111/RAQ.12280

Boucher, R. L., Boucher, R. L., Boucher, R. L., Dupont-Nivet, M., Vandeputte, M., Vandeputte, M., Vandeputte, M., Kerneis, T., Goardon, L., Labbé, L., Chatain, B., Bothaire, M. J., Larroquet, L., Médale, F., & Quillet, E. (2012). Selection for Adaptation to Dietary Shifts: Towards Sustainable Breeding of Carnivorous Fish. *Plos One*. Https://Doi.Org/10.1371/Journal.Pone.0044898

Braña, C. B. C., Cerbule, K., Senff, P., & Stolz, I. K. (2021). Towards Environmental Sustainability in Marine Finfish Aquaculture. *Frontiers in Marine Science*. Https://Doi.Org/10.3389/FMARS.2021.666662

Brugère, C., Aguilar-Manjarrez, J., Beveridge, M. C., & Soto, D. (2019). The Ecosystem Approach to Aquaculture 10 Years on–A Critical Review and Consideration of its Future Role in Blue Growth. *Reviews In Aquaculture*, *11*(3), 493-514. Https://Doi.Org/10.1111/RAQ.12242

Chaklader, M. R., Siddik, M. A., & Fotedar, R. (2020). Total Replacement of Fishmeal with Poultry by-Product Meal Affected the Growth, Muscle Quality, Histological Structure, Antioxidant Capacity and Immune Response of Juvenile Barramundi, *Lates Calcarifer*. *Plos One*, *15*(11), E0242079. Https://Doi.Org/10.1371/Journal.Pone.0242079

Chaklader, M. R., Chung, W. H., Howieson, J., & Fotedar, R. (2023). A Mixture of Full-Fat and Defatted *Hermetia Illucens* Larvae and Poultry by-Products as Sustainable Protein Sources Improved Fillet Quality Traits in Farmed Barramundi, *Lates Calcarifer*. *Foods*, *12*(2), 362. Https://Doi.Org/10.3390/Foods12020362

Chang, B.-V., Liao, C.-S., Chang, Y.-T., Chao, W.-L., Yeh, S.-L., Kuo, D.-L., & Yang, C.-W. (2019). Investigation of A Farm-Scale Multitrophic Recirculating Aquaculture System with the Addition of Rhodovulum Sulfidophilum for Milkfish (*Chanos chanos*) Coastal Aquaculture. *Sustainability*. Https://Doi.Org/10.3390/SU11071880

Clough, S., Mamo, J., Hoevenaars, K., Bardocz, T., Petersen, P., Rosendorf, P., & Hoinkis, J. (2020). Innovative Technologies to Promote Sustainable Recirculating Aquaculture in Eastern Africa—A Case Study of A Nile Tilapia (*Oreochromis niloticus*) Hatchery in Kisumu, Kenya. *Integrated Environmental Assessment and Management*, *16*(6), 934-941. Https://Doi.Org/10.1002/IEAM.4295

Cottrell, R. S., Metian, M., Froehlich, H. E., Blanchard, J. L., Sand Jacobsen, N., Mcintyre, P. B., ... & Halpern, B. S. (2021). Time to Rethink Trophic Levels in Aquaculture Policy. *Reviews In Aquaculture*, *13*(3), 1583-1593. Https://Doi.Org/10.1111/RAQ.12535

Effendie. (1997). *Biologi Perikanan*. Yayasan Pustaka Nusatama: Yogyakarta. 163 Hal.

Elvines, D. M., Macleod, C. K., Ross, D. J., Hopkins, G. A., & White, C. A. (2024). Fate and Effects of Fish Farm Organic Waste in Marine Systems: Advances in Understanding Using Biochemical Approaches with Implications for Environmental Management. *Reviews in Aquaculture*, *16*(1), 66-85. Https://Doi.Org/10.1111/Raq.12821

Falconer, L., Hunter, D. C., Scott, P. C., Telfer, T. C., & Ross, L. G. (2013). Using Physical Environmental Parameters and Cage Engineering Design within GIS-Based Site Suitability Models for Marine Aquaculture. *Aquaculture Environment Interactions*, *4*(3), 223-237. Https://Doi.Org/10.3354/AEI00084

Glencross, B. (2006). The Nutritional Management of Barramundi, *Lates Calcarifer*–A Review. *Aquaculture Nutrition*, *12*(4), 291-309.

Gołaś, I., & Potorski, J. A. (2022). The Influence of Commercial Feed Supplemented with Carnobacterium Maltaromaticum Environmental Probiotic Bacteria on the Rearing Parameters and Microbial Safety of Juvenile Rainbow Trout. *Animals*, *12*(23), 3321. Https://Doi.Org/10.3390/Ani12233321

Greene, C. H., Scott-Buechler, C. M., Hausner, A. L., Johnson, Z. I., Lei, X. G., & Huntley, M. E. (2022). Transforming the Future of Marine Aquaculture: A Circular Economy Approach. *Oceanography*, *35*(2). Https://Doi.Org/10.5670/Oceanog.2022.213

Hancz, C. (2022). Hancz, C. (2022). Application of Probiotics for Environmentally Friendly and Sustainable Aquaculture: A Review. *Sustainability*, *14*(22), 15479. Https://Doi.Org/10.3390/Su142215479

Hasan, I., Rimoldi, S., Saroglia, G., & Terova, G. (2023). Sustainable Fish Feeds with Insects and Probiotics Positively Affect Freshwater and Marine Fish Gut Microbiota. *Animals*, *13*(10), 1633. Https://Doi.Org/10.3390/Ani13101633

Henriksson, P. J. G., Banks, L. K., Suri, S. K., Pratiwi, T. Y., Fatan, N. A., & Troell, M. (2019). Indonesian Aquaculture Futures—Identifying Interventions for Reducing Environmental Impacts. *Environmental Research Letters*, 14(12), 124062. Https://Doi.Org/10.1088/1748-9326/AB4B79.

Hoerterer, C., Petereit, J., Lannig, G., Johansen, J., Conceição, L. E., & Buck, B. H. (2022). Effects of Dietary Plant and Animal Protein Sources and Replacement Levels on Growth and Feed Performance and Nutritional Status of Market-Sized Turbot (*Scophthalmus* *maximus*) in RAS. *Frontiers In Marine Science*, 9, 1023001. Https://Doi.Org/10.3389/Fmars.2022.1023001

Holmer, M. (2010). Environmental Issues of Fish Farming in Offshore Waters: Perspectives, Concerns and Research Needs. *Aquaculture Environment Interactions*, *1*(1), 57-70. Https://Doi.Org/10.3354/AEI00007

Jansen, H. M., Reid, G. K., Bannister, R. J., Husa, V., Robinson, S. M. C., Cooper, J. A., ... & Strand, Ø. (2016). Discrete Water Quality Sampling at Open-Water Aquaculture Sites: Limitations and Strategies. *Aquaculture Environment Interactions*, *8*, 463-480. Https://Doi.Org/10.3354/AEI00192

Kluger, L. C., & Filgueira, R. (2021). Thinking Outside the Box: Embracing Social Complexity in Aquaculture Carrying Capacity Estimations. *ICES Journal of Marine Science*, *78*(1), 435-442. Https://Doi.Org/10.1093/ICESJMS/FSAA063

Kousoulaki, K., Sveen, L., Norén, F., & Espmark, Å. (2022). Atlantic Salmon (*Salmo salar*) Performance Fed Low Trophic Ingredients in A Fish Meal and Fish Oil Free Diet. *Frontiers In Physiology*, *13*, 884740. Https://Doi.Org/10.3389/Fphys.2022.884740

Lee, H. T., Chang, Y. C., Liao, C. H., & Hsu, T. H. (2022). Development of Integrated Multitrophic Aquaculture–Based Cage Rearing System in an Underutilized Fishing Port and its Application in Marine Stock Enhancement. *Frontiers In Marine Science*, *9*, 998198. Https://Doi.Org/10.3389/Fmars.2022.998198

Li, H., Cui, Z., Cui, H., Bai, Y., Yin, Z., & Qu, K. (2023). A Review of Influencing Factors on A Recirculating Aquaculture System: Environmental Conditions, Feeding Strategies, and Disinfection Methods. *Journal of The World Aquaculture Society*, *54*(3), 566-602. Https://Doi.Org/10.1111/Jwas.12976

Lothmann, R., & Sewilam, H. (2023). Potential of Innovative Marine Aquaculture Techniques to Close Nutrient Cycles. *Reviews In Aquaculture*, *15*(3), 947-964. Https://Doi.Org/10.1111/Raq.12781

Luna, M., Llorente, I., & Cobo, A. (2022). Determination of Feeding Strategies in Aquaculture Farms Using A Multiple-Criteria Approach and Genetic Algorithms. *Annals of Operations Research*, *314*(2), 551-576. Https://Doi.Org/10.1007/S10479-019-03227-W

Macaulay, G., Barrett, L. T., & Dempster, T. (2022). Recognising Trade-Offs Between Welfare and Environmental Outcomes in Aquaculture will Enable Good Decisions. *Aquaculture Environment Interactions*, *14*, 219-227. Https://Doi.Org/10.3354/Aei00439

Mardiana, T. Y., Linayati, L., Rosediana, D. A., & Yahya, M. Z. (2024). Growth Rate of Barramundi (*Lates calcarifer*) with Feed Added Mangosteen Peel (*Garcinia mangostana*) Flour as A Growth Supplement. *Jurnal Perikanan Unram*, *14*(2), 684-692. Https://Doi.Org/10.29303/Jp.V14i2.819

Mohapatra, S., Chakraborty, T., Kumar, V., Deboeck, G., & Mohanta, K. N. (2013). Aquaculture and Stress Management: A Review of Probiotic Intervention. *Journal of Animal Physiology and Animal Nutrition*, 97(3), 405-430. Https://Doi.Org/10.1111/J.1439-0396.2012.01301.X

Mugwanya, M., Dawood, M. A., Kimera, F., & Sewilam, H. (2021). Biofloc Systems for Sustainable Production of Economically Important Aquatic Species: *A Review. Sustainability*, *13*(13), 7255. Https://Doi.Org/10.3390/SU13137255

Ngoh, S. Y., Tan, D., Shen, X., Kathiresan, P., Jiang, J., Liew, W. C., ... & Orbán, L. (2015). Nutrigenomic and Nutritional Analyses Reveal the Effects of Pelleted Feeds on Asian Seabass (*Lates aalcarifer*). *Plos One,* 10(12), E0145456. Https://Doi.Org/10.1371/Journal.Pone.0145456

Noble, T. H., Smith-Keune, C., & Jerry, D. R. (2014). Genetic Investigation of the Large-Scale Escape of A Tropical Fish, Barramundi *Lates Calcarifer*, from A Sea-Cage Facility in

Northern Australia. *Aquaculture Environment Interactions*, *5*(2), 173-183. Https://Doi.Org/10.3354/AEI00106

Parappurathu, S., Menon, M., Jeeva, C., Belevendran, J., Anirudhan, A., Lekshmi, P. S., ... & Chand, P. (2023). Sustainable Intensification of Small-Scale Mariculture Systems: Farm-Level Insights from the Coastal Regions of India. *Frontiers In Sustainable Food Systems*, *7*, 1078314. Https://Doi.Org/10.3389/Fsufs.2023.1078314

Petereit, J., Hoerterer, C., Bischoff-Lang, A. A., Conceição, L. E., Pereira, G., Johansen, J., ... & Buck, B. H. (2022). Adult European Seabass (*Dicentrarchus labrax*) Perform Well on Alternative Circular-Economy-Driven Feed Formulations. *Sustainability*, *14*(12), 7279. Https://Doi.Org/10.3390/Su14127279

Price, C., Black, K. D., Hargrave, B. T., & Morris Jr, J. A. (2015). Marine Cage Culture and the Environment: Effects on Water Quality and Primary Production. *Aquaculture Environment Interactions*, *6*(2), 151-174. Https://Doi.Org/10.3354/AEI00122

Quimby, B., Roque, A. D., Nébié, E. K. I., Levine, A., Amaama, S. A., Wutich, A., ... & Samuelu, L. E. (2023). Blue Food Sovereignty Benefits Social-Ecological Resilience: A Case Study of Small-Scale Fisheries Co-Management and Mariculture in Samoa. *Human Ecology*, *51*(2), 279-289. Https://Doi.Org/10.1007/S10745-023-00401-4

Ritskes-Hoitinga, M., & Pound, P. (2022). The Role of Systematic Reviews in Identifying the Limitations of Preclinical Animal Research, 2000–2022: Part 1. *Journal of the Royal Society of Medicine*, *115*(5), 186-192. Https://Doi.Org/10.1177/01410768221100970

Rodde, C., Vandeputte, M., Allal, F., Besson, M., Clota, F., Vergnet, A., ... & De Verdal, H. (2020). Population, Temperature and Feeding Rate Effects on Individual Feed Efficiency in European Sea Bass (*Dicentrarchus labrax*). *Frontiers in Marine Science*, *7*, 578976. Https://Doi.Org/10.3389/FMARS.2020.578976

Ross, P. T., & Zaidi, B. N. L. (2019). Limited by Our Limitations. *Perspectives on Medical Education*, *8*(4), 261–264. Https://Doi.Org/10.1007/S40037-019-00530-X

Safiin, N. S. Z., Ching, F. F., & Shapawi, R. (2022). Successful Co-Feeding of Asian Seabass, *Lates calcarifer* Larvae with Palm Oil-Based Microdiets and Live Feeds. *Frontiers in Sustainable Food Systems*, *6*, 836275. Https://Doi.Org/10.3389/Fsufs.2022.836275

Selim, S. A., Glaser, M., Tacke, F. I., Rahman, M., & Ahmed, N. (2021). Innovative Aquaculture for the Poor to Adjust to Environmental Change in Coastal Bangladesh? Barriers and Options for Progress. *Frontiers In Marine Science*, *8*, 635281. Https://Doi.Org/10.3389/FMARS.2021.635281

Senff, P., Blanc, P. P., Slater, M., & Kunzmann, A. (2020). Low-Technology Recirculating Aquaculture System Integrating Milkfish *Chanos chanos*, Sea Cucumber *Holothuria scabra* and Sea Purslane *Sesuvium portulacastrum*. *Aquaculture Environment Interactions*, *12*, 471-484. Https://Doi.Org/10.3354/AEI00377

Shaw, C., Knopf, K., Klatt, L., Arellano, M. G., & Kloas, W. (2023). Closing Nutrient Cycles Through the Use of System-Internal Resource Streams: Implications for Circular Multitrophic Food Production Systems and Aquaponic Feed Development. *Sustainability*, *15*(9), 7374. Https://Doi.Org/10.3390/Su15097374

Siddik, M. A., Howieson, J., Ilham, I., & Fotedar, R. (2018). Growth, Biochemical Response and Liver Health of Juvenile Barramundi (*Lates calcarifer*) Fed Fermented and Non-Fermented Tuna Hydrolysate as Fishmeal Protein Replacement Ingredients. *Peerj, 6,* E4870. Https://Doi.Org/10.7717/PEERJ.4870

Siddik, M. A., Chungu, P., Fotedar, R., & Howieson, J. (2019). Bioprocessed Poultry by-Product Meals on Growth, Gut Health and Fatty Acid Synthesis of Juvenile Barramundi, *Lates calcarifer* (Bloch). *Plos One,* *14*(4), E0215025. Https://Doi.Org/10.1371/Journal.Pone.0215025

Sievers, M., Korsøen, Ø., Warren-Myers, F., Oppedal, F., Macaulay, G., Folkedal, O., & Dempster, T. (2022). Submerged Cage Aquaculture of Marine Fish: A Review of the Biological Challenges and Opportunities. *Reviews In Aquaculture*, *14*(1), 106-119. Https://Doi.Org/10.1111/RAQ.12587

Tičina, V., Katavić, I., & Grubišić, L. (2020). Marine Aquaculture Impacts on Marine Biota in Oligotrophic Environments of the Mediterranean Sea–A Review. *Frontiers in Marine Science, 7*, 217. Https://Doi.Org/10.3389/FMARS.2020.00217

Troell, M., Costa-Pierce, B., Stead, S., Cottrell, R. S., Brugere, C., Farmery, A. K., ... & Barg, U. (2023). Perspectives on Aquaculture's Contribution to the Sustainable Development Goals for Improved Human and Planetary Health. *Journal of the World Aquaculture Society*, *54*(2), 251-342. Https://Doi.Org/10.1111/Jwas.12946

Varga, M., Berzi-Nagy, L., Csukas, B., & Gyalog, G. (2020). Long-Term Dynamic Simulation of Environmental Impacts on Ecosystem-Based Pond Aquaculture. *Environmental Modelling & Software, 134*, 104755. Https://Doi.Org/10.1016/J.ENVSOFT.2020.104755

Victora, C. G., Schellenberg, J. A., Huicho, L., Amaral, J., El Arifeen, S., Pariyo, G., ... & Habicht, J. P. (2005). Context Matters: Interpreting Impact Findings in Child Survival Evaluations. *Health Policy and Planning*, *20*(1), I18-I31. Https://Doi.Org/10.1093/HEAPOL/CZI050

Vo, B. V., Siddik, M. A., Chaklader, M. R., Fotedar, R., Nahar, A., Foysal, M. J., ... & Nguyen, H. Q. (2020). Growth and Health of Juvenile Barramundi (*Lates calcarifer*) Challenged with DO Hypoxia After Feeding Various Inclusions of Germinated, Fermented and Untreated Peanut Meals. *Plos One, 15*(4), E0232278. Https://Doi.Org/10.1371/JOURNAL.PONE.0232278

Wade, N. M., Trenkner, L. H., Viegas, I., Tavares, L. C., Palma, M., Skiba-Cassy, S., ... & Glencross, B. D. (2020). Dietary Starch Promotes Hepatic Lipogenesis in Barramundi (*Lates calcarifer*). *British Journal of Nutrition*, *124*(4), 363-373. Https://Doi.Org/10.1017/S0007114520001051

Wuertz, S., Schroeder, A., & Wanka, K. M. (2021). Probiotics in Fish Nutrition—Long-Standing Household Remedy or Native Nutraceuticals?. *Water*, *13*(10), 1348. Https://Doi.Org/10.3390/W13101348

Yamamoto, F. Y., Ellis, M., Bowles, P. R., Suehs, B. A., Carvalho, P. L., Older, C. E., ... & Gatlin III, D. M. (2022). Dietary Supplementation of A Commercial Prebiotic, Probiotic and Their Combination Affected Growth Performance and Transient Intestinal Microbiota of Red Drum (*Sciaenops ocellatus* L.). *Animals*, *12*(19), 2629. Https://Doi.Org/10.3390/Ani12192629