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OPTIMIZATION OF ASIAN CLAM POSITIONING MODEL FOR IMPROVED WATER QUALITY IN NILE TILAPIA CULTURE UNDER THE YUMINA BUMINA SYSTEM

Perancangan Model Posisi Kerang Kijing untuk Peningkatan Kualitas Air Budidaya Nila pada Sistem Yumina Bumina

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ABSTRACT

The Yumina Bumina aquaponic system an indigenous innovation grounded in Integrated Multi-Trophic Aquaculture (IMTA) offers a sustainable approach to Nile tilapia (*Oreochromis niloticus*) cultivation through the integration of water spinach (*Ipomoea aquatica*) and the freshwater mussel *Anodonta woodiana*. This study aimed to evaluate the effects of four spatial configurations of *A. woodiana* on water quality and tilapia growth over a 30-day period. A Completely Randomized Design was employed with four treatments: (A) mussels positioned upstream of the plant unit, (B) downstream of the plant unit, (C) within the recirculation pipe, and (D) an integrated configuration combining all positions, with outcomes subjected to rigorous statistical analysis. Results indicated that although Treatment C yielded the lowest ammonia concentration (1,10 ± 0,85 mg/L), Treatment A achieved the highest daily weight gain (15.74%/day) and the lowest total dissolved solids (TDS; 388,4 ppm). Conversely, Treatment C led to the highest nitrite accumulation (3,74 mg/L) and elevated TDS levels, posing a potential risk of osmoregulatory stress in fish. No significant differences were observed in %Total N content in either tilapia or water spinach across treatments (*p* > 0.05), indicating that growth variation was primarily driven by physiological environmental stability rather than nitrogen availability. These findings confirm that positioning *A. woodiana* as a pre-filter upstream of the plant zone (Treatment A) establishes an optimal, gradual nutrient flow, minimizes environmental stress, and maximizes fish growth. This study provides strategic hydraulic design recommendations for sustainable, IMTA-based aquaponic systems.

Keywords: *Anodonta woodiana*; *Oreochromis niloticus*; Specific Growth Rate; Yumina Bumina; Water Quality

ABSTRAK

Sistem akuaponik Yumina Bumina, sebagai inovasi lokal berbasis *Integrated Multi-Trophic Aquaculture* (IMTA), menawarkan pendekatan berkelanjutan untuk budidaya ikan nila (*Oreochromis niloticus*) melalui integrasi tanaman kangkung dan kerang kijing (*Anodonta woodiana*). Penelitian ini bertujuan mengevaluasi pengaruh empat konfigurasi posisi kerang kijing terhadap kualitas air dan pertumbuhan ikan nila selama 30 hari. Penelitian ini menggunakan Rancangan Acak Lengkap dengan empat perlakuan, (A) kerang sebelum unit tanaman, (B) setelah unit tanaman, (C) di dalam pipa aliran, dan (D) konfigurasi terintegrasi yang hasilnya diuji secara statistik. Hasil menunjukkan bahwa meskipun perlakuan C menghasilkan konsentrasi amonia terendah (1,10 ± 0,85 mg/L), perlakuan A menghasilkan laju pertumbuhan berat harian tertinggi (15,74%/hari) dan total padatan terlarut (TDS) terendah (388,4 ppm). Perlakuan C justru menyebabkan akumulasi nitrit (3,74 mg/L) dan TDS tertinggi, yang berpotensi menimbulkan stres osmoregulasi pada ikan. Tidak terdapat perbedaan signifikan dalam kandungan %Total N pada ikan maupun kangkung antar perlakuan, hal ini mengindikasikan bahwa variasi pertumbuhan lebih dipengaruhi oleh stabilitas lingkungan fisiologis daripada ketersediaan nitrogen. Temuan ini menegaskan bahwa penempatan kerang kijing sebagai pre-filter sebelum zona tanaman (perlakuan A) menciptakan aliran nutrien bertahap yang optimal, meminimalkan stres lingkungan, dan memaksimalkan pertumbuhan ikan. Studi ini memberikan rekomendasi desain hidrolika strategis untuk sistem akuaponik berkelanjutan berbasis IMTA.

Kata Kunci: *Anodonta woodiana;* Kualitas Air; Laju Pertumbuhan Spesifik; *Oreochromis niloticus*; Yumina Bumina

INTRODUCTION

The culture of Nile tilapia (*Oreochromis niloticus*) has become a major pillar in efforts to meet animal protein requirements in Indonesia and other developing countries, considering its rapid growth potential, tolerance to varying environmental conditions, and high market demand. However, aquaculture intensification often results in a decline in water quality, primarily due to the accumulation of metabolic wastes such as ammonia (NH_3), nitrite (NO_2), and phosphorus, which originate from uneaten feed and fish excretion (Goda *et al.*, 2023). The accumulation of these substances not only suppresses fish growth rates and survival, but can also lead to eutrophication and environmental pollution if effluent water is not properly managed (Osman *et al.*, 2021; Schmautz *et al.*, 2021).

In this context, aquaponic systems, particularly the Yumina Bumina model as a locally developed innovation based on Integrated Multi-Trophic Aquaculture (IMTA), offer a highly promising solution (Marda *et al.*, 2024). This system integrates fish culture with vegetable crops and extractive organisms, such as freshwater mussels, within a single closed cycle (recirculating system) to maximize nutrient utilization and minimize waste (Goda *et al.*, 2023). The basic principle is to utilize fish waste as fertilizer for plants, while plants and filter organisms function as natural biofilters that purify the water before it is returned to the fish culture tanks (Selek *et al.*, 2017). Research by Abo-Taleb *et al.* (2021) demonstrated that the integration of extractive species can significantly improve feed utilization efficiency and nutrient retention.

The freshwater mussel (*Anodonta woodiana*), as a filter-feeding organism, possesses an exceptional capacity to purify water through the filtration of organic and inorganic particles, including plankton, bacteria, and detritus (Goda *et al.*, 2023; Suendi *et al.*, 2022). Previous studies have demonstrated that mussels can effectively reduce ammonia, nitrate, and total dissolved solids (TDS) concentrations in aquaponic systems (Santoso and Sunadji, 2020; Estim *et al.*, 2019) and promote significant growth performance (Marda *et al.*, 2024). However, the effectiveness of mussels as biofilters is strongly influenced by factors such as population density, water temperature, and, most importantly, their placement position within the system. Mussel positioning determines the extent of their exposure to nutrient loads and particulate matter requiring filtration, as well as their interactions with plants and nitrifying microorganisms (Yildiz *et al.*, 2017; Heise *et al.*, 2021).

METHODS

Time and location

This study was conducted for 30 days in August 2025 at Universitas Antakusuma, Pangkalan Bun, Central Kalimantan, utilizing comprehensive and representative aquaculture research facilities. Analysis of ammonia, nitrate, and nitrite concentrations in the culture water was carried out at the Fish Nutrition Laboratory, Faculty of Fisheries and Marine Sciences, Institut Pertanian Bogor (IPB University), which is a nationally accredited laboratory for water quality testing and aquaculture nutrient parameters.

Research Design

This study applied a Completely Randomized Design (CRD) consisting of four treatments, including one control, each replicated three times to ensure statistical validity. The treatments included: (A) placement of mussels (*Anodonta woodiana*) before the yumina bumia (as a control), (B) placement after the yumina bumia, (C) placement inside the yumina bumia, and (D) an integrated configuration with mussels placed before, inside, and after the yumina bumia. The complete experimental design scheme is presented in Figure 1.

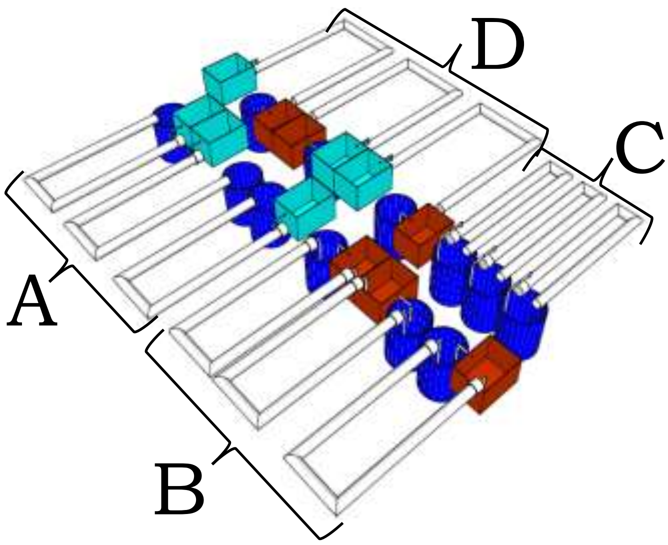

Figure 1. Research design

Data analysis

Statistical analysis was performed using IBM SPSS Statistics software. The Shapiro-Wilk method was used to test for normality of data distribution, while Levene's test for homogeneity of variance was used. Data that met the assumptions of normality and homogeneity were analyzed using one-way ANOVA, followed by a post-hoc Tukey's Honestly Significant Difference (HSD) test to identify significant differences between treatments. If the data did not meet one or both of these assumptions, the Kruskal-Wallis non-parametric analysis was used as an alternative, with the Mann-Whitney test used to compare treatment pairs pairwise. The statistical significance level was set at $\alpha = 0.05$.

RESULTS

Laju pertumbuhan berat harian (LPBH) dan laju pertumbuhan panjang harian (LPPH)

The Kruskal-Wallis test results showed highly significant differences between treatments for Daily Weight Growth Rate (DGR) ($p < 0.001$) and DGR ($p = 0.012$). Treatment A had the highest DGR (15.74%/day) and the highest DGR (0.1732 cm/day), followed by D, B, and C.

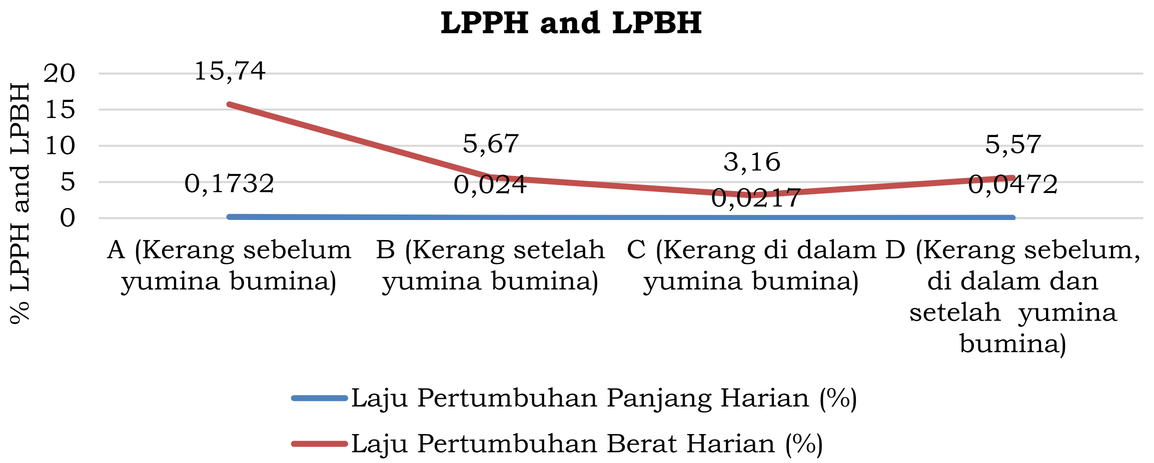

Figure 2. Comparison of daily length growth rate (LPPH) and daily weight growth rate (LPBH) of tilapia in four treatments of yumina bumina clams during 30 days of maintenance.

%Total N in kale and fish

Statistically, there was no significant difference in %Total N between treatments, either in kale plants or in tilapia. All treatments were given the same letter notation (a), indicating that the placement position of the mussels did not significantly affect the total nitrogen accumulation in either organism.

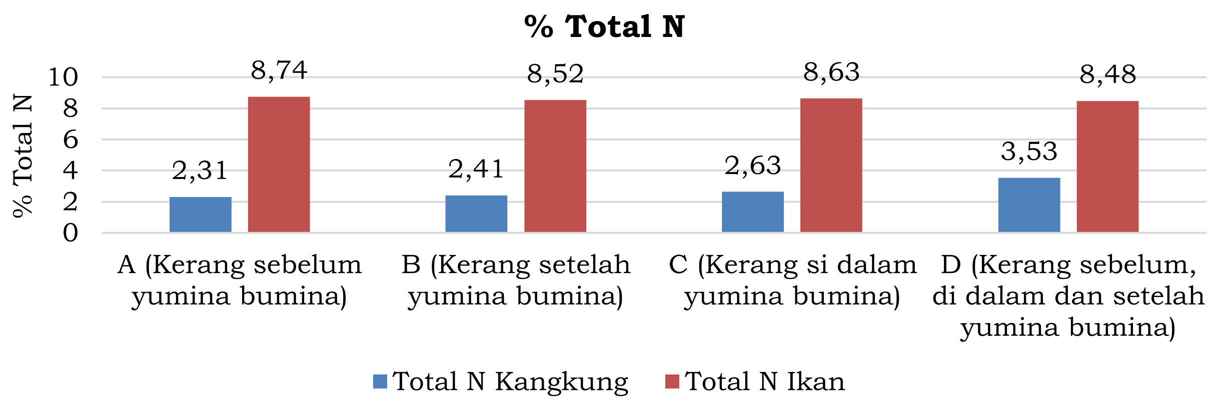

Figure 3. Percentage of total nitrogen (N) in water spinach and tilapia in four treatments of Yumina Bumina clam application (before, after, inside, and a combination of before–inside–after) during a 30-day maintenance period.

DISCUSSION

This study aimed to evaluate the effects of four placement positions of freshwater mussels (*Anodonta woodiana*) on water quality and tilapia growth in the innovative Yumina Bumina aquaponic system. The results indicate that the strategic placement of mussels as a primary biofilter, namely before the Yumina Bumina system (Treatment A). Treatment A produced the most optimal culture environment, although it did not always outperform other treatments in absolute water quality parameters. These findings address the research objectives holistically: not only assessing water purification efficiency, but also evaluating the integrative impacts on fish welfare and growth, which are the primary determinants of aquaculture sustainability.

Based on water quality results, Treatment C was recorded as having the lowest ammonia concentration (1.10 ± 0.85 mg/L), reflecting intensive nitrification activity, likely driven by close interactions among mussels, biofilms, and microbiota within the flow pipes. However, this efficiency was accompanied by the consequence of the highest accumulation of Total Dissolved Solids (TDS) (451.89 ± 0.85 mg/L), indicating an increased ionic load and dissolved metabolites resulting from mussel secretions and organic matter mineralization. Elevated TDS levels can increase osmoregulatory stress in fish, which directly diverts energy from growth toward physiological homeostasis (Boyd, 2020). This is consistent with the findings of Gudimov (2021), who reported that intensive filtration by freshwater mollusks can increase conductivity and TDS, negatively affecting feed utilization efficiency if not balanced by appropriate hydraulic management.

On the other hand, although Treatment A exhibited slightly higher ammonia levels (1.23 mg/L), Treatment A produced the highest Specific Growth Rate (SGR) (15.74%/day; $p < 0.001$), far exceeding the other treatments. This indicates that physiological environmental stability is more decisive than chemical efficiency alone. In Treatment A, mussels functioned as a mechanical pre-filter that reduced particulate loads before water entered the plant zone. Plants (water spinach) subsequently absorbed dissolved nutrients (NH_4^+, NO_3^-) efficiently under more stable and particle-free flow conditions. This synergy created an environment with minimal chemical fluctuations, stable DO (>18 mg/L), and low TDS (388.4 ppm), which collectively reduced chronic stress in fish. As explained by Yildiz *et al.* (2017), environmental stress, even at sub-lethal levels, can suppress immune function, reduce appetite, and inhibit fish growth, regardless of nutrient availability.

The finding that %Total N content in fish and water spinach did not differ significantly among treatments further strengthens the argument that differences in fish growth were not caused by variations in nitrogen availability, but rather by holistic environmental quality. Tilapia in all treatments received the same feed, so differences in SGR more accurately reflect feed conversion efficiency (FCR) influenced by environmental stress, rather than nutritional deficiencies. This aligns with the principle of nutrient retention efficiency in Integrated Multi-Trophic Aquaculture (IMTA), where the primary objective is not merely waste removal, but the creation of ecosystems that minimize energy loss through stress (Goda *et al.*, 2024; Neori *et al.*, 2004).

Furthermore, the mussel position in Treatment C (within the Yumina Bumina system) created a microhabitat characterized by turbulent flow and direct contact with raw waste, which may have enhanced filtration activity but also resulted in the highest nitrite accumulation (3.74 mg/L). Nitrite, although an intermediate product of nitrification, is toxic because it induces methemoglobinemia, a condition in which the oxygen-binding capacity of blood is severely reduced (Boyd, 2020). Treatment A, with more laminar flow and stepwise interactions among mussels → plants → fish, allowed the conversion of ammonia → nitrite → nitrate to occur gradually and stably, thereby avoiding the accumulation of harmful nitrite. This demonstrates that hydraulic design in aquaponic systems is as important as biological components, a principle emphasized in recent studies by Love *et al.* (2015) on aquaponic commercialization.

In terms of originality, this study provides an important contribution: the mere presence of natural biofilters is insufficient; their strategic position within the system flow determines their integrative effectiveness. These findings reinforce the initial results of Marda *et al.* (2024) while extending beyond conventional approaches that focus solely on "whether mussels are effective," by answering "where mussels should be placed to maximize ecosystem synergy."

The practical recommendation is clear: freshwater mussels should be positioned as primary filters before the plant zone, rather than within or after it, to create a gradual and stable nutrient flow as a key determinant of sustainability in both household-scale and commercial aquaponic systems.

CONCLUSION

This study demonstrates that the effectiveness of freshwater mussels (*Anodonta woodiana*) as biofilters in the Yumina Bumina aquaponic system is determined not merely by their presence, but by their strategic placement within the system flow. Placement of mussels before the Yumina Bumina system (Treatment A) produced optimal synergy between early mechanical filtration and nutrient absorption by plants, creating a physiologically stable culture environment. Although other configurations (particularly Treatment C) exhibited chemical efficiency in reducing ammonia, their negative impacts on nitrite and TDS accumulation inhibited fish growth. These findings emphasize the core principle of IMTA: aquaculture sustainability depends on holistic ecosystem balance, rather than solely on waste removal. Therefore, aquaponic system hydraulic design must consider trophic sequencing and physiological interactions among biological components to maximize productivity and fish welfare.

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