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The growth and survival performance of Tinfoil barb (*Barbonymus shcwanefeldii*) grown with Chinese broccoli (*Brassica oleracea*) in a low-tech aquaponics system treated with the application of nitrogen, phosphorus, potassium fertilizer and fish meal

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Abstract

More than half of the nutrients sustaining the optimal plant growth in the aquaponic system are derived from fish waste. However, the use of fish meal and nitrogen, phosphorus, potassium (NPK) fertilizer in promoting growth parameters of the plant and for some fish species in such a system is not well documented. This study aimed to examine the effect of NPK fertilizer on the growth performance of Tinfoil barb (*Barbonymus shcwanefeldii*), a common riverine species as well as Chinese broccoli (*Brassica oleracea*) in a low-tech aquaponic system. A total of ninety fingerlings of Tinfoil barb (*Barbonymus shcwanefeldii*) were randomly distributed into three treatment groups with three replicates. The control group had no fertilizer added while the other groups were treated either with NPK or fish meal. After a 45-day feeding trial, fish, and plants treated with NPK fertilizer demonstrated significantly higher weight gain (4.11±0.01 g) ($P<0.05$) and plant height (15.77±0.15 cm) ($P<0.05$), respectively, compared to fish meal and the control. NPK treatment also resulted in the significantly greatest number of leaves (8.33±0.33) ($P<0.05$), explaining good productivity. NPK fertilizer appears to be a promising growth enhancer for both Tinfoil barb and Chinese broccoli that grow in the aquaponic system.

1. Introduction

Aquaculture is important for increasing fish production, balancing the demand on wild fisheries, and avoiding overfishing of wild fish (Ridzuan *et al*., 2022). In 2020, Malaysia generated 97,209.74 tonnes of freshwater aquaculture production worth RM 766 million and 120,739.51 tonnes of brackish aquaculture production (Department of Fisheries Malaysia, 2020). Baganz *et al*. (2022) provide a new definition set encompassing all aquaponic approaches and suggest proposing the new taxonomy 'trans-aquaponics,' which includes integrated aqua-agriculture systems exploiting the aquaponic principle of driving plant cultivation by aquaculture, distinct from aquaponics, and aggregates them under the umbrella term 'aquaponic farming.' In general, an aquaponic system comprises three main components: aquaculture for aquatic animal farming, hydroponics for plant cultivation using soilless agriculture, and microorganisms or bacteria that function in nutrient transformation (Eck *et al*., 2019).

An appropriate ratio of N, P, and K in plant nutrition has a synergistic effect on healthy plant growth and development, ultimately influencing grain yield. NPK are among the nutrients that have been shown to influence the processes of post-embryonic root development, consequently affecting crop yield (Kulcheski *et al*., 2015). Specifically, nitrogen plays a crucial role in promoting plant growth, whereas potassium is important to facilitate the proper absorption of minerals, nutrients, and water. Meanwhile, phosphorus is an extremely important macronutrient that plants need, serving as the main component of ATP,

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which, in turn, is crucial for regulating photosynthesis (Roy *et al*., 2022).

Fish meal has been widely used as the main protein source in the aquafeed industry due to its nutritional properties, including a high content of digestible protein and balanced essential amino acids (EAAs), such as essential fatty acids, phospholipids, cholesterol, minerals, and certain vitamins (Tacon *et al.,* 2009; Masagounder *et al.,* 2016). In aquaponic systems, the use of fish meal serves as the primary nutritional source, providing nutrients to sustain the needs of fish, bacteria, and plants (Lennard and Goddek, 2019). Fish meal is eco-friendly as it consists of organic matter that supplies nutrients to the crop and leaves a substantial residual effect for succeeding crops. Thus, by combining all of these beneficial factors, the application of fish meal in this low-tech aquaponic system is believed to have a positive impact on the existing key components of the aquaponic system, including aquatic animals, plants, and bacteria.

Barbonymus schwanenfeldii is an omnivorous tropical carp found throughout Southeast Asia, notably in Indonesia, Malaysia, and Thailand (Kenthao and Jearranaiprepame, 2020; Dahruddin *et al*., 2021; Soo *et al*., 2021). In Peninsular Malaysia and Sarawak, *B. schwanenfeldii* is known as "lampam sungai" and "tengadak", respectively. This fish is highly popular among locals due to its delicious meat and has gained economic importance. *Barbonymus schwanenfeldii* has become an important species for aquaculture because of its highly valuable meat, high omega-3 fatty acid content, and high market price (Thwe *et al*., 2011; Isa *et al*., 2012; Jaya-Ram *et al*., 2018). However, to date, no research on the performance of this species with the application of NPK fertilizer and fish meal in an aquaponic system has been conducted.

Chinese broccoli (*Brassica oleracea* var. *alboglabra* L.) was selected for cultivation using hydroponics in this aquaponic system. Sun *et al*. (2011) reported that this plant is widely distributed in the regions of China and Southeast Asia and has a high market demand due to its nutritional value. Renowned for its abundance of antioxidants and anticarcinogenic compounds, Chinese broccoli is a popular vegetable among consumers (Yanes-Roca *et al*., 2014; Wang *et al*., 2017). Recognizing its nutritional value, the US Department of Agriculture (USDA) Food and Nutrition Information Center, through the Food Guide Pyramid, recommends Chinese broccoli as one of the vegetables for maintaining a healthy lifestyle (Vargas *et al*., 2022). This study aimed to elucidate the operations of a low-tech aquaponic system with a basic hardware setup, catering to the knowledge gap for beginner-level aquaponic practitioners. The application of fish meal and NPK fertilizer in this study was anticipated to enhance the existing symbiotic processes of aquaponics and hydroponics in aquaponic systems. The primary objective was to compare the effects of these two applications on the growth performance of tinfoil barb (*Barbonymus schwanefeldii*) and Chinese broccoli (*Brassica oleracea* var. *alboglabra* L.).

2. Materials and methods

2.1 Fish collection and acclimatization

A total of 100 Tinfoil barb fingerlings were obtained from the Fisheries Division in Betong, Sarawak and were subsequently placed in a 1-ton rounded PVC tank located in the hatchery of UiTM Mukah, Sarawak. The fish underwent a two-week acclimatization period, during which they were fed at 3% of their body weight twice daily (at 0900 and 1700) using commercial pellets (32% protein). After this acclimatization period, the fish were weighed, yielding an average initial weight of 7.92±0.13 g (Mean±Standard Error of the Mean), and their total lengths were recorded using an EK-6100i / A+D weighing balance and a ruler. Each aquarium was stocked with 10 fish in three treatments, and three replicates were used for each treatment. The experimental design employed in this study was a Completely Randomized Design.

2.2 Aquaponic system

A low-tech aquaponic system was set up 3 weeks before the experiment began. There were three treatments, each with three replicates, consisting of a total of 9 aquaria, each sized at 45 L of water. The water was filled to 90% of the total height, and styrofoam was cut and placed on top of each aquarium. Each aquarium was fitted with a styrofoam lid with three holes on top, and these holes were filled with 2-week-old broccoli plants. The aquaria were cleaned every three days, involving the replacement of 100% of the water and siphoning out any uneaten feed or faeces that had accumulated at the bottom.

2.3 Seed germination and seedlings production

Chinese broccoli seeds were germinated two weeks before the feeding trial began. They were germinated in egg containers, and the seeds were sprayed with AB fertilizer once every three days. Two different mediums, rock wool and cocoa peat, were used for seed germination. After the initial two weeks, the seedlings were meticulously removed from the germination containers and transplanted into the holes of the styrofoam placed on top of each aquarium.

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2.4 Treatment and sampling

Treatment 1 was set as the control with no fertilizer added. Treatment 2 was applied with NPK fertilizer at a rate of 1.0 g per cup containing Brassica plants every week. Treatment 3 was applied with a fish meal at a rate of 1.0 g per cup containing Brassica plants every week. Fish and plant sampling were conducted every two weeks by weighing the live body weight of the fish. During each sampling cycle, 5 fish were transferred using a sieve net and placed in a container filled with dechlorinated water on the weighing balance, and their weights were recorded in g. This process was repeated for another 5 fish, with each aquarium containing a total of 10 fish. For plant sampling, the height of each plant was measured from the base of the plant in the cocoa peat up to the top of the shoot using a ruler. The number of leaves was counted and recorded as well. This experiment was conducted for 45 days.

2.5 Data collection

For initial sampling, every fish was weighted using an electrical balance calibrated to 0.1 g. This step was repeated for the final sampling.

These were the formulas used to calculate the growth parameters of the fish and plant (Seenivasan *et al*., 2014).

Weight gain (g) = mean final body weight (g) – mean initial body weight (g).

Plant height gain (cm) = mean final plant height (cm) – mean initial plant height (cm).

The formula used to calculate the Feed Conversion Ratio (FCR) was as follows (Mzengereza and Kang'ombe, 2015):

Feed Conversion Ratio (FCR) = weight of the feed fed to the fish/weight gained by the fish.

2.6 Data analysis

Data analysis was performed using SPSS 16 software. One-way analysis of variance (ANOVA) was applied to determine whether there were any statistically significant differences ($p<0.05$) among the means of the treatments. The Tukey test was used to identify means that had significant differences at an alpha value of 0.05. All results were presented as Mean±Standard Error (S.E).

3. Results

The effects of NPK fertilizer addition and fish meal on Tinfoil barb (*Barbonymus shcwanefeldii*) fingerling can be observed in Table 1. Tinfoil barb treated with NPK fertilizer exhibited better growth performance, as indicated by significantly higher values of final weight (11.90±0.32 g) and weight gained (4.11±0.01 g) compared to those treated with fish meal. The lowest growth performance was observed in fish from treatment 1, with no fertilizer addition, showing the lowest final weight (10.13±0.06 g) and weight gained (2.36±0.01 g). Although it recorded the poorest performance, it is still not significantly different from treatment 2, which was treated with fish meal, with a final weight of 10.72±0.23 g. The best feed conversion ratio (FCR) was achieved by fish treated with the NPK fertilizer (3.04±0.08), and it was significantly different from fish treated with fish meal (4.94±0.19) and no fertilizer (4.90±0.09). All fish in the three treatments had the same survival rate (90.00±10.00%). Significant differences ($p<0.05$) were observed in final weight, weight gain, feed conversion ratio, final plant height, and final number of leaves (Tables 1 and 2).

The effects of NPK fertilizer addition and fish meal on Chinese broccoli can be observed in Table 2. Plants

Table 1. Growth performance of Tinfoil barb fingerling after 45-day feeding trial with different fertilizers.

Treatment	Initial weight (g)	Final weight (g)	Weight gain (g)	Feed conversion ratio (FCR)	Survival rate (%)
T1	7.77±0.06^{a}	10.13±0.06^{b}	2.36±0.01^{c}	4.90±0.09^{b}	90.00±10.00^{a}
T2	7.79±0.31^{a}	11.90±0.32^{a}	4.11±0.01^{a}	3.04±0.08^{a}	90.00±10.00^{a}
T3	8.19±0.24^{a}	10.72±0.23^{b}	2.53±0.01^{b}	4.94±0.19^{b}	90.00±10.00^{a}

Values are mean±standard error of mean of triplicate. Values with different superscripts within the same column are statistically significantly different, α = 0.05. T1: no fertilizer (control), T2: NPK fertilizer, T3: fish meal fertilizer.

Table 2. Growth performance of Chinese Broccoli after 45-day feeding trial with different fertilizers.

Treatment	Initial plant height (cm)	Final plant height (cm)	Plant height gain (cm)	Initial number of leaves	Final number of leaves
T1	10.50±0.29^{a}	13.4±0.15^{c}	2.90±0.3^{a}	4.00±0.00^{a}	4.67±0.33^{b}
T2	10.9±0.38^{a}	15.77±0.15^{a}	4.87±0.30^{a}	4.33±0.33^{a}	8.33±0.33^{a}
T3	10.73±0.43^{a}	14.43±0.23^{b}	3.7±0.67^{a}	4.22±0.15^{a}	4.67±0.33^{b}

Values are mean±standard error of mean of triplicate. Values with different superscripts within the same column are statistically significantly different, α = 0.05. T1: no fertilizer (control), T2: NPK fertilizer, T3: fish meal fertilizer.

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treated with NPK fertilizer exhibited better growth performance, as indicated by significantly higher values of final plant height (15.77±0.15 cm) and height gained (4.87±0.30 cm) compared to those treated with fish meal. This treatment also achieved the highest final number of leaves (8.33±0.33) compared to the other two treatments. The lowest growth performance was observed in plants in treatment 1 with no fertilizer addition, showing the lowest final plant height (13.4±0.15 cm) and height gained (2.90±0.3 cm). Treatment 1 also achieved the lowest final number of leaves (4.67±0.33) and was significantly different from plants treated with treatment 2 (NPK fertilizer) (8.33±0.33), but not significantly different from plants treated with treatment 3 (fish meal) (4.67±0.33). The proximate composition of the fish meal is summarized in Table 3.

Table 3. Proximate results on the fish meal.

Moisture (%)	72.92±0.82
Ash (%)	9.25±0.06
Lipid (%)	8.03±0.08
Energy (kJ/g)	5.84±0.09
Protein (%)	47.42±0.12

Values are mean±standard error of mean of triplicate.

4. Discussion

The effects of NPK fertilizer addition and fish meal are presented in Table 2. Chinese broccoli treated with NPK fertilizer exhibited better growth performance, as indicated by significantly higher values of final plant height (15.77±0.15 cm) and the final number of leaves (8.33±0.33). This observation aligns with the findings of Villarroel *et al*. (2022), who reported that the addition of fertilizer significantly improved the growth of crops (lettuce) compared to controls without fertilizer. The authors noted that lettuce treated with fertilizer exhibited nearly three times more growth than those without fertilizer. Similarly, Manjula *et al*. (2019) found that the addition of fertilizer enhanced the physical growth, yield, and quality of *Trigonella foenum-graecum* L. plants in aquaponic water.

Meanwhile, Chinese broccoli treated with fish meal exhibited significantly lower growth performance than that treated with NPK fertilizer, showing a final plant height of 14.43±0.23 cm and a final number of leaves of 4.67±0.33. Without fertilizer, Chinese broccoli does not grow well. This was consistent with research by other authors, suggesting that additional minerals should be added to the fish waste in the recirculated waste to encourage optimal growth and generate profit (Kammerer *et al*., 2010). Plants need a variety of macro and micro elements to grow optimally and efficiently. Most of these nutrients come from fish waste in the aquaponics system (Lennard, 2017). However, for fish feeds, the primary source of nutrients for aquaponic systems, do not contain all the essential nutrients for optimal plant growth. Hence, the use of external nutrition in varying amounts is required (Lennard and Goddek, 2019).

Essential nutrients frequently found to be inadequate in aquaponics include calcium, manganese, phosphorus, boron, and iron (Rakocy *et al*., 2006; Suhl *et al*., 2016). According to Nicoletto *et al*. (2018), fish metabolic wastes in aquaponics serve as a source of nutrients for plants. However, it is important to note that these nutrient concentrations are generally lower and unbalanced for most nutrients compared to hydroponic systems, particularly at commercial scales. While nitrate levels are typically sufficient for good plant growth when fish are adequately stocked, potassium (K) and phosphorus (P) levels are generally inadequate for achieving maximum plant growth. Iron and calcium may also be insufficient. As insufficient nutrients can reduce plant yield and quality, nutrient integration should be implemented to support efficient nutrient reuse (Maucieri *et al*., 2019). However, even though fish stocking is optimal for providing nitrogen, the addition of potassium (K) and phosphorus (P) through mineral fertilizers should be applied (Nicoletto *et al*., 2018).

Nutrient loss is a common issue in aquaponics, evident in the lower growth of broccoli treated with no fertilizer, resulting in a final plant height of 13.4±0.15 cm and a final number of leaves of 4.67±0.33. Similar findings have been documented in other crops, such as tomatoes, which require nutrient supplementation for optimal growth in aquaponics. This emphasizes the need for continuous assessment and adjustment of nutrients derived from fish wastewater (Delaide *et al*., 2016; Suhl *et al*., 2016). Nutrient loss occurs through various pathways, including sludge settlement (37% from faeces and 18% from uneaten feed) (Montanhini Neto and Ostrensky, 2015), water renewal (Eck *et al*., 2019), denitrification, ammonia volatilization, and water losses (Wongkiew *et al*., 2018). Denitrification, for instance, can lead to the loss of 25-60% of nitrogen (Hu *et al*., 2015; Zou *et al*., 2016). Nitrogen loss may also occur through anaerobic ammonium oxidation (ANAMMOX), the oxidation of ammonium into dinitrogen gas in the presence of nitrite (Hu *et al*., 2011).

Another significant loss of nitrogen, crucial for plant availability, occurs due to nitrogen consumption by heterotrophic aerobic bacteria in aquaponic systems. In this process, the nitrogen used by these bacteria is lost to nitrifying bacteria, thereby preventing nitrification (Blancheton *et al*., 2013). These bacteria become more prevalent when the C/N ratio increases, as they are

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highly competitive and can colonize the media more effectively than autotrophic nitrifying bacteria (Blancheton *et al*., 2013; Wongkiew *et al*., 2018). The removal of sludge leads to a loss of nutrients, as some essential nutrients, such as phosphorus, often precipitate and become trapped in the removed solid sludge. Loss of nutrients from the aquaponic system is further contributed to by water renewal, even in small percentages. Regarding denitrification, it occurs when denitrifying bacteria are present, and conditions are favourable for their metabolism (Eck *et al*., 2019).

The weight gain of tinfoil barb varied, possibly due to the use of cocoa peat in revitalizing the water and enhancing fish performance, similar to the growth of tilapia using different substrates such as gravel, rice husk, and palm kernel shell (Babatunde *et al*., 2022). The application of multiple substrates might improve fish growth and health. Rice husk and palm kernel shells are considered good potential substitutes for cocoa peat in this research. These biodegradable materials could promote the development of a microbial community that reinforces the conversion of fish waste to nitrate for broccoli while also stabilizing water pH (Wongkiew *et al*., 2018; Heise *et al*., 2021).

The success of an aquaponic system does not solely depend on the type of fertilizer used; the choice of media or substrate also plays a crucial role. The media provides essential support to plant roots, especially for heavier fruit- and vegetable-bearing plants, while also serving as a habitat for beneficial bacteria that enhance plant and fish growth (Rakocy *et al*., 2006; Forchino *et al*., 2017). The fish that achieved the best growth with NPK fertilizer did so due to consistently lower nitrate-N levels and ammonia-N. Broccoli demonstrated continuous absorption of nitrate-N, as observed in research conducted by Fischer *et al*. (2021) on largemouth bass (*Micropterus salmoides*). When nitrate-N production exceeds the plants' uptake capability, nitrate-N levels increase. Different plants have varying proficiency in absorbing and retaining nutrients. Factors such as physiological components, genetic framework, nutrient availability, and basic growth indices collectively influence the growth performance of plants in aquaponic systems (Oladimeji *et al*., 2020). Further research may involve testing various plant species to assess their abilities to sustain nutrients.

5. Conclusion

Tinfoil barb fingerlings and Chinese broccoli treated with NPK fertilizer exhibited better growth performance compared to those treated with fish meal. This was indicated by higher values of final fish weight, increased plant height, and a greater number of plant leaves. Further research should be conducted using a variety of substrates to assess their impact on both fish and plant growth.

Conflict of interest

The authors declare no conflict of interest.

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