

Original Article

Effects of different carbon sources on the growth of the monkey river prawn, *Macrobrachium lar*, and nitrogen–phosphorus uptake by plants in a biofloc aquaponics system

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Abstract: This study evaluated the effects of different carbon sources on the growth performance of Monkey River prawn, *Macrobrachium lar*, and on nitrogen and phosphorus uptake by leafy vegetables in a biofloc aquaponics system on Ternate Island. A completely randomized design was used with four treatments: molasses, rice bran, tapioca, and a carbon-free control, each with three replicates. Juvenile *M. lar* (0.035 ± 0.001 g) were stocked at 30 prawns per 100 L tank and reared for 6 weeks, while water spinach, lettuce, and pakcoy were grown in media beds receiving recirculating effluent. Molasses significantly increased absolute growth and survival of *M. lar* compared with other treatments, although specific growth rate was similar to the control, and feed conversion ratio did not differ among treatments. Water quality variables remained within acceptable ranges for freshwater prawns and were not affected by the carbon source. Carbon source and plant species significantly influenced plant nitrogen content, with the highest N percentages generally observed in mustard green and celery under the control treatment, whereas molasses tended to reduce tissue N, indicating stronger microbial competition for dissolved inorganic nitrogen. Phosphorus content was less responsive to main effects but showed significant carbon–plant interactions, with pakcoy under rice bran and control exhibiting the greatest P accumulation. These results demonstrate that molasses-driven biofloc enhances *M. lar* production, while careful selection of plant species and carbon sources can improve nutrient recovery, supporting the development of sustainable biofloc aquaponics for freshwater prawns in small-island environments.

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Introduction

Crustacean aquaculture, particularly freshwater prawns, makes an important contribution to global animal protein supply (Yamin et al., 2021; FAO, 2022), but intensive farming systems still face major challenges related to the accumulation of nitrogen and phosphorus wastes that deteriorate water quality and impose environmental burdens on receiving waters (Rustadi et al., 2022; Islam et al., 2023). To meet growing demands for sustainable production, researchers have developed various technological approaches to minimize water use and optimize nutrient recycling in closed or semi-closed culture systems (Khanjani et al., 2024; Liu et al., 2025).

One of the most prominent innovations is biofloc technology (BFT) (Crab et al., 2012; Khanjani et al., 2024), which promotes the growth of heterotrophic and photoautotrophic microorganisms that convert inorganic nitrogen (Yu et al., 2024) originating from feed residues and excreta into microbial biomass that can be reutilized as natural food for fish or shrimp. Biofloc systems have been shown to enhance survival, growth, and feed efficiency in shrimp (Islam et al., 2023; Fadaei et al., 2024) while simultaneously lowering concentrations of toxic nitrogenous compounds in the water column, although accumulation of suspended solids and phosphorus may still constrain performance in highly intensive

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operations (Liu et al., 2025).

Integrating BFT with aquaponics has emerged as a promising solution to close nutrient cycles (Grabner and Junge, 2009; Delaide et al., 2016; Goddek et al., 2019) using nitrogen- and phosphorus-rich effluents from prawn tanks to support plant growth, thereby allowing dissolved wastes to be taken up by plants while maintaining adequate water quality for cultured organisms. Biofloc aquaponics systems have been reported to reduce water exchange (Samadan et al., 2023a; Sopawong et al., 2023), improve feed and nutrient use efficiency, and produce both aquatic animals and vegetables in a single integrated system (Rakocy et al., 2020), supporting more environmentally friendly food production, although system performance ultimately depends on the dynamic balance among waste production, microbial activity in the biofloc, and plant nutrient uptake capacity (Nair et al., 2025).

A key factor in BFT is the management of the carbon-to-nitrogen (C:N) ratio (Crab et al., 2012; Bagi et al., 2023; Samadan et al., 2023b; Liu et al., 2024) through the addition of organic carbon sources such as molasses, tapioca flour, or cereal by-products to stimulate heterotrophic bacteria that assimilate inorganic nitrogen into biomass. Recent studies indicate that not only the C:N ratio but also the carbon-to-phosphorus ratio and the qualitative characteristics of the carbon source can strongly affect nitrogen and phosphorus removal efficiency in biofloc systems (Samadan et al., 2023c), with direct consequences for nutrient availability to plants in integrated configurations. Moreover, plant species and plant organs used in aquaponics differ in their capacity to take up N and P, making the selection of suitable vegetables crucial to optimizing biofloc aquaponics performance (Samadan et al., 2025).

The Monkey River prawn, *Macrobrachium lar*, is a large freshwater prawn with considerable economic value and culture potential in the Indo-Pacific region (Cavalli et al., 2020; Samadan et al., 2024; Findra et al., 2025), but information on its growth performance in biofloc systems, particularly when combined with aquaponics, remains very limited (Samadan et al.,

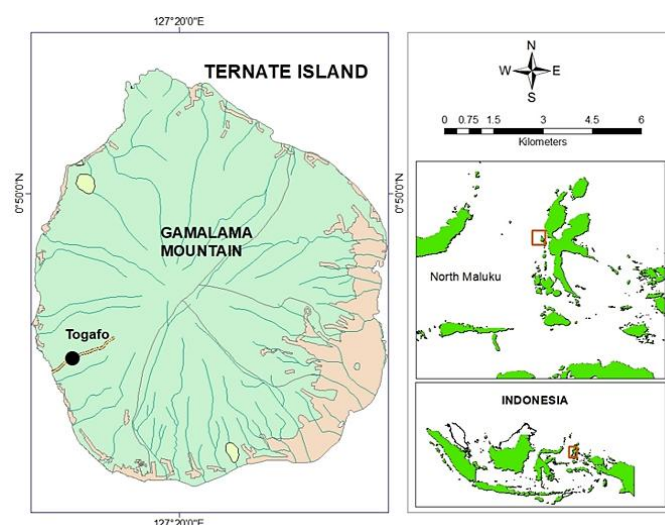


Figure 1. Sampling site of freshwater prawns in Ternate Island.

2023a, 2025). Most BFT research on freshwater prawns has focused on *Macrobrachium rosenbergii* or other crustaceans (Fadaei et al., 2024), leaving a knowledge gap regarding the response of *M. lar* to different carbon sources and the resulting nutrient dynamics in integrated systems, while data on the effectiveness of different plant species for N and P removal in biofloc aquaponics with freshwater prawns are also scarce and often system-specific. Therefore, studies are needed that simultaneously evaluate the effects of different carbon sources on the growth performance of the Monkey River prawn, *M. lar*, and assess the effectiveness of different plant species in removing nitrogen and phosphorus in biofloc aquaponics systems. Therefore, this study aimed to evaluate the effects of different carbon sources on the growth performance of *M. lar* and on nitrogen and phosphorus uptake by leafy vegetables in a biofloc aquaponics system.

Materials and Methods

Sample collection: Prawn samples were collected from two locations on Ternate Island (Fig. 1), where a freshwater stream flows directly into the sea but remains unaffected by tidal salinity due to its steep gradient, and a small, isolated river system composed of disconnected pools with no direct connection to the sea. The locations represent exclusively freshwater environments.

Experimental system and animals: This study was conducted in a small-scale, semi-open recirculating biofloc aquaponics system comprising several culture tanks for Monkey River prawns, biofloc units, and plant grow beds (Samadan et al., 2025). Each prawn tank had an effective water volume of 100 L, and the entire system was continuously aerated to maintain dissolved oxygen above 3 mg L⁻¹. Juvenile *M. lar* were collected from natural freshwater habitats, transported in oxygenated plastic bags, and acclimated to the rearing conditions for 7 days before the start of the experiment (Samadan et al., 2024). During acclimation, temperature, pH, and total ammonia nitrogen (TAN) were maintained within the optimal range previously reported for this species.

Experimental design and carbon source treatments: The experiment followed a completely randomized design with four carbon-source treatments and three replicates per treatment. The carbon sources tested were molasses, tapioca flour, and rice bran, plus a control without added carbon, applied to achieve a target C:N ratio of 10:1 in the culture water based on estimated nitrogen input from the feed (Samadan et al., 2023b). Each tank was stocked with 30 juvenile *M. lar* with an initial mean weight of 0.035±0.001 g, and prawns were reared for 6 weeks. A commercial sinking pellet containing 30% crude protein was offered at 5% of biomass per day, divided into four equal meals.

Biofloc management and aquaponics configuration: Biofloc was developed and maintained by providing strong aeration with blowers and air diffusers positioned at the bottom of each tank to keep solids in suspension and ensure thorough mixing (Samadan et al., 2023a, 2025). Carbon sources were dissolved in water and added as needed, based on TAN measurements and feed inputs, to maintain the desired C:N ratio and promote heterotrophic bacterial growth. The aquaponics unit consisted of 12 media beds filled with expanded clay (hydroton), in which the selected vegetable species were cultivated at a uniform spacing of 15 cm. Water from the prawn tanks flowed into the plant beds and was then returned to the culture tanks via the recirculating system.

Plant species and culture conditions: Several leafy vegetables were used to evaluate their ability to remove nitrogen and phosphorus from the biofloc aquaponics water. Uniform seedlings of water spinach, *Ipomoea aquatica*, lettuce, *Lactuca sativa*, and pakcoy, *Brassica rapa* var. *chinensis*, were transplanted into the media beds (Samadan et al., 2025). Plants were grown under natural light without any external fertilizer addition (Delaide et al., 2016), relying solely on nutrients supplied by the prawn culture water. Plant health was visually monitored, and dead or severely damaged plants were replaced during the first week of the experiment to maintain uniform plant density.

Water quality monitoring and nutrient analyses: Water quality parameters, including temperature, pH, and dissolved oxygen, were measured every 7 days in each tank using a multiparameter meter. TAN, nitrite (NO₂⁻-N), nitrate (NO₃⁻-N), orthophosphate (PO₄³⁻-P), and total suspended solids (TSS) were analyzed twice weekly using standard spectrophotometric methods (APHA, 2017). Water samples (20 mL) were collected from mid-depth in each tank and plant bed and stored at 25°C until analysis. Concentrations of dissolved inorganic nitrogen and phosphorus were used to characterize nutrient dynamics in the system and to calculate the removal or uptake efficiency of N and P.

Growth performance of *Macrobrachium lar*: At the beginning and end of the trial, all prawns in each tank were counted and bulk-weighed after a 5 h fasting period to minimize variation in body weight due to gut contents. Growth performance was evaluated using standard indices, including weight gain (WG), specific growth rate (SGR), feed conversion ratio (FCR), and survival rate (SR), calculated from initial and final biomass and total feed consumption (Cavalli et al., 2020; Samadan et al., 2025). Intermediate sampling was carried out every 7 days on 10 prawns per tank to monitor growth and adjust feeding rates.

Nitrogen–phosphorus uptake: Plants from each bed were cut at the media surface, separated by species, and weighed to obtain fresh biomass. Subsamples were dried, finely ground, and analyzed for total

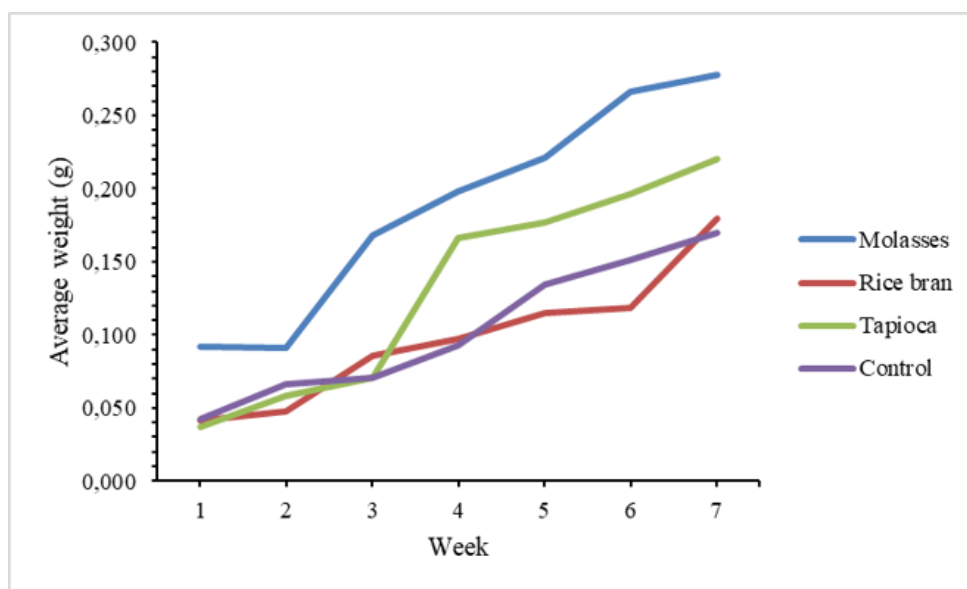


Figure 2. Average weight gain of prawns during rearing.

nitrogen (Kjeldahl method) and total phosphorus (acid digestion followed by spectrophotometric determination). Nutrient uptake rates of N and P were calculated from nutrient contents in plant biomass and changes in water N and P concentrations over the rearing period, expressed per unit bed area or per unit plant dry mass (Delaide et al., 2016; Fadaei et al., 2024).

Statistical analysis: All data were first checked for normality and homogeneity of variance using the Shapiro–Wilk and Levene tests, respectively. When assumptions were met, the effects of carbon source treatments on prawn growth performance were analyzed by one-way analysis of variance (ANOVA), whereas the effects of carbon sources and plant species on N and P uptake were analyzed using two-way ANOVA. When significant differences were detected ($P < 0.05$), Duncan's multiple range test was applied for post-hoc comparison of means. Data are presented as mean $\pm$ standard error (SE), and all statistical analyses were performed using R software version 4.5.2.

Results

Effect of carbon sources on growth performance of *Macrobrachium lar*: Average body weight of *M. lar* increased steadily from week 1 to week 7 in all treatments, indicating positive growth throughout the

rearing period (Fig. 2). From week 3 onwards, prawns cultured with molasses (treatment A) showed the highest and most consistent increase in mean weight, followed by tapioca (C), control (D), and rice bran (B), which remained the lowest for most of the experimental period.

Carbon source had a significant effect on absolute growth ($P < 0.05$) (Fig. 3). Prawns in the molasses treatment attained the highest absolute growth (approximately 0.47 g), which was significantly greater than that of the rice bran, tapioca, and control groups, whose values ranged from about 0.06 to 0.11 g and did not differ from each other ($P < 0.05$).

SGR also differed among treatments ($P < 0.05$) (Fig. 4). The highest SGR was recorded in the control (0.96% day⁻¹), which was not significantly different from molasses (0.79% day⁻¹), whereas rice bran and tapioca resulted in lower SGR values (0.67–0.68% day⁻¹) that were similar to each other. Standard errors were relatively small in all treatments, indicating low variability among replicates. The survival rate of *M. lar* was significantly affected by the type of carbon source ($P < 0.05$) (Fig. 5). Molasses produced the highest survival (78%), which was significantly greater than the survival recorded in the rice bran, tapioca, and control treatments (30–39%), with no significant differences among these three groups. FCR was not significantly influenced by carbon source

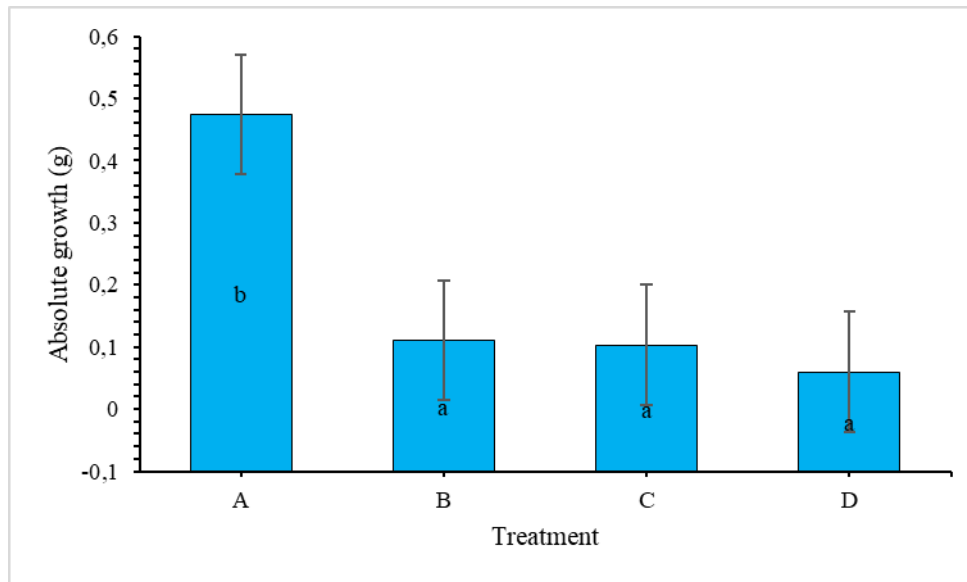


Figure 3. Effect of carbon sources on the absolute growth of shrimp during rearing.

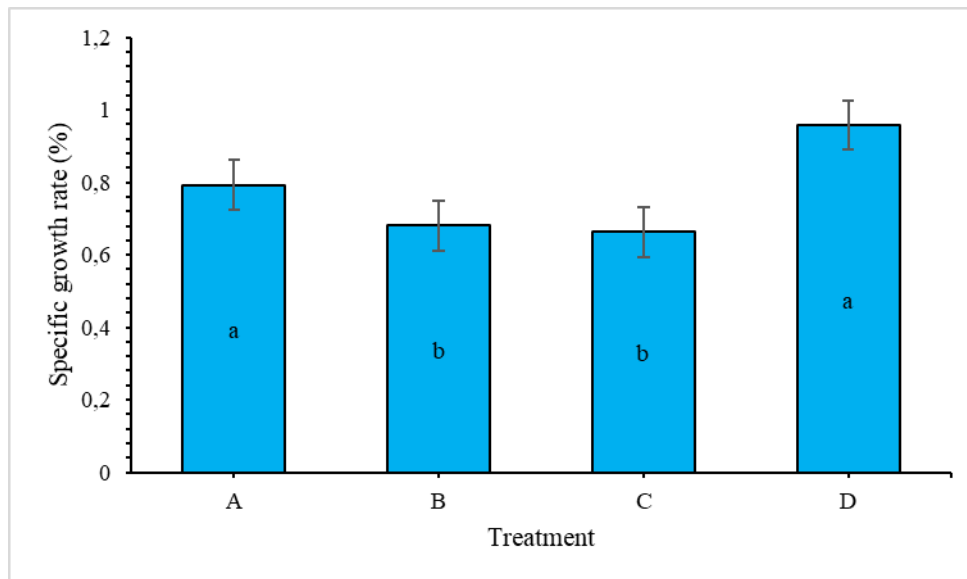


Figure 4. Effect of carbon sources on *Macrobrachium* lar specific growth rate.

($P>0.05$) (Fig. 6). The lowest FCR was observed in the molasses treatment (approximately 0.43), whereas rice bran, tapioca, and control treatments showed higher FCR values (1.15-1.35), but all remained statistically similar.

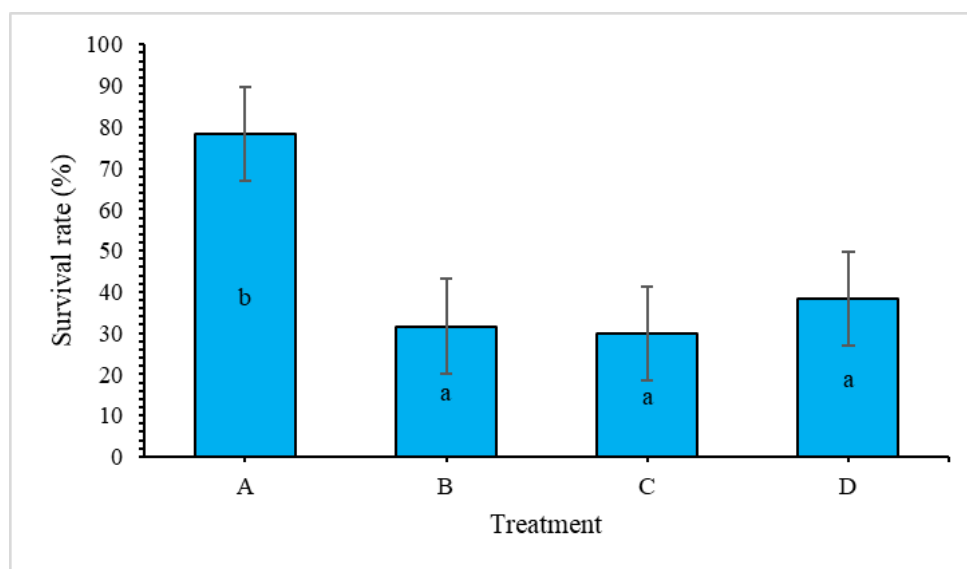
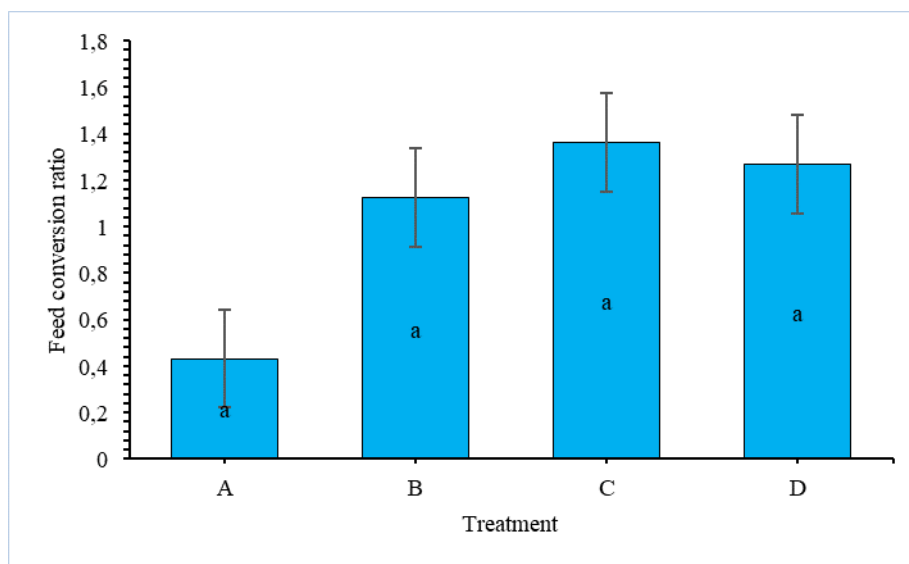
Water quality: Water quality remained within suitable ranges for freshwater prawn culture in all treatments during the experimental period (Table 1). Mean temperature ranged from 30.9 to 31.2°C, dissolved oxygen from 3.2 ± 0.2 mg L⁻¹, and pH from 7.2 to 7.6, while concentrations of NO₃⁻-N, NO₂⁻-N, total hardness, total alkalinity, and ammonia were

almost identical among treatments. No significant differences were detected in any measured water quality parameter between carbon source treatments.

Main effects of carbon sources on nitrogen and phosphorus uptake by plants: Carbon source had a significant effect on plant nitrogen content ($P<0.05$) (Fig. 7). The highest mean N percentage (32.5%) was observed in the control, which differed significantly from molasses (30.2% N), whereas tapioca (30.8% N) and rice bran (31.5% N) showed intermediate values that were not significantly different from either control or molasses. In contrast, the percentage of

Table 1. Water quality during rearing periods.

Treatment	Temperature	DO	pH	NO ₃	NO ₂	Total hardness	Total alkalinity	Ammonia
A	30.9±0.30	3.2±0.2	7.2±0.25	0.11±0.02	0.29±0.04	125±0.11	120±0.20	0.150±.12
B	31.2±0.28	3.2±0.2	7.6±0.31	0.11±0.02	0.29±0.04	125±0.11	120±0.20	0.15±0.12
C	30.9±0.30	3.2±0.2	7.2±0.25	0.11±0.02	0.29±0.04	125±0.11	120±0.20	0.15±0.12
D	31.2±0.28	3.2±0.2	7.6±0.31	0.11±0.02	0.29±0.04	125±0.11	120±0.20	0.15±0.12

Figure 5. Effect of carbon sources on *Macrobrachium lar* specific growth rate.Figure 6. Effect of carbon sources on the feed conversion ratio of *Macrobrachium lar*.

phosphorus in plant tissue did not differ significantly among carbon sources ($P>0.05$) (Fig. 11). The lowest P was observed in the molasses treatment (5.7%), followed by the control group (6.4%), whereas tapioca and rice bran showed higher values (9.7 and 9.2%, respectively), although these differences were not significant.

Effects of plant species on nitrogen and phosphorus (P) uptake: Plant species significantly affected nitrogen content ($P<0.05$) (Fig. 8). Pakcoy exhibited the lowest N percentage (27-28%) and differed significantly from all other species, whereas water spinach showed an intermediate N value (31%), and mustard green and celery had the highest N contents

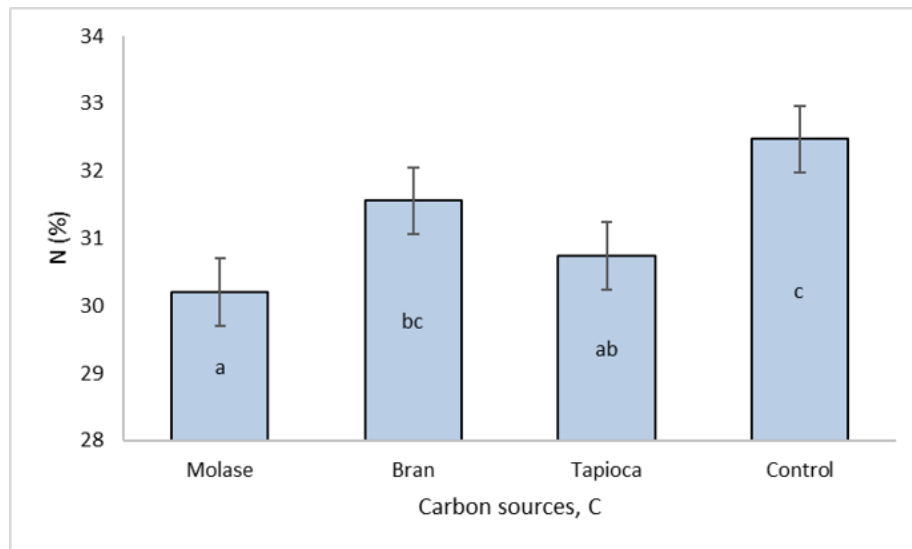


Figure 7. The effect of carbon sources on N uptake.

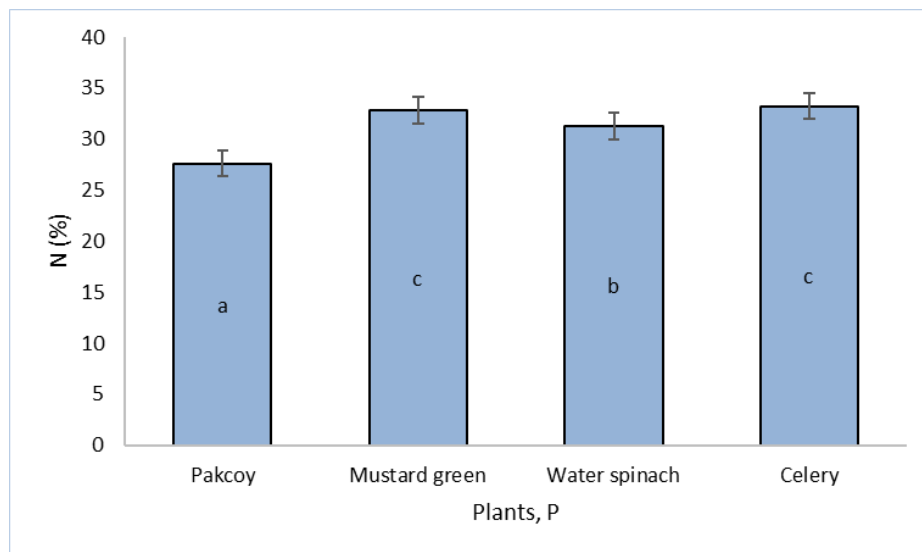


Figure 8. The effect of plant species on N uptake

(32-33%) and did not differ from each other. In contrast, plant species had no significant effect on phosphorus percentage ($P>0.05$). Pakcoy showed the highest phosphorus content (10.2%), followed by celery (8.3%), while water spinach and mustard green had lower phosphorus (6.6% and 5.9%, respectively); however, these differences were not significant.

Interaction effects between carbon sources and plant species: A significant interaction between carbon sources and plant species was detected for plant N percentage ($P<0.05$) (Figs. 9-10). In general, mustard green and celery grown in the control treatment exhibited the highest N contents, whereas combinations of molasses or rice bran with pakcoy or

celery tended to yield lower N%. Across carbon sources, mustard green and celery usually contained more N than pakcoy and water spinach, but the magnitude of these differences depended on the specific carbon-plant combination.

For phosphorus, the interaction between carbon source and plant species was also significant ($P<0.05$) (Fig. 12). Among pakcoy treatments, rice bran and control produced the highest P percentages (17 and 16%, respectively) and differed significantly from molasses and tapioca combinations, which showed lower phosphorus. In mustard green, water spinach, and celery, differences in P percentage among carbon sources were smaller and often not significant,

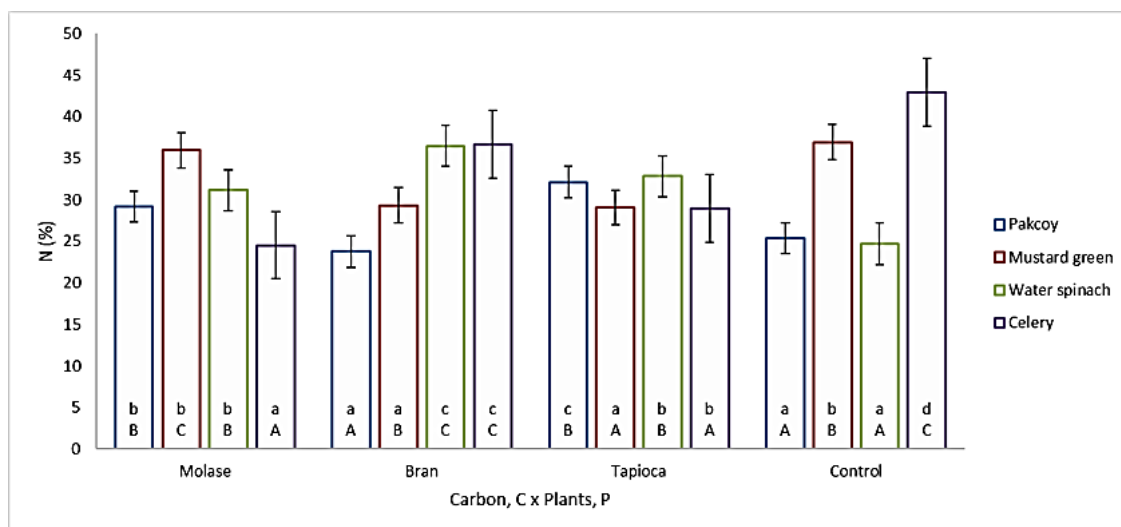


Figure 9. The effect of interactions between carbon sources and plant types on N uptake.

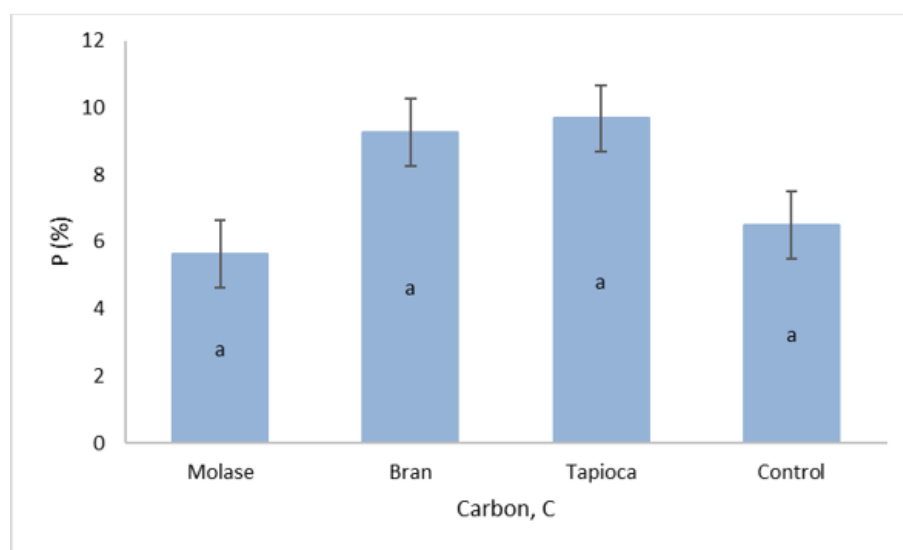


Figure 10. The effect of carbon sources on P uptake.

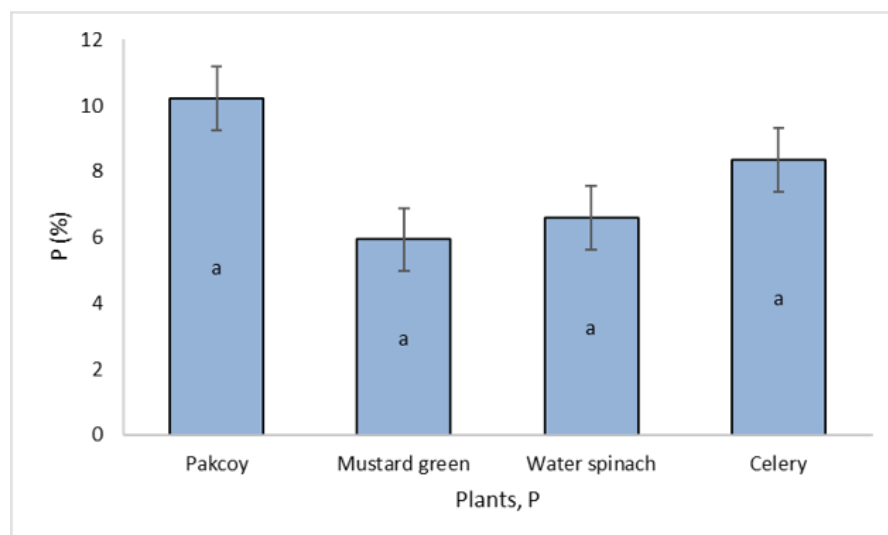


Figure 11. The effect of plant species on P uptake.

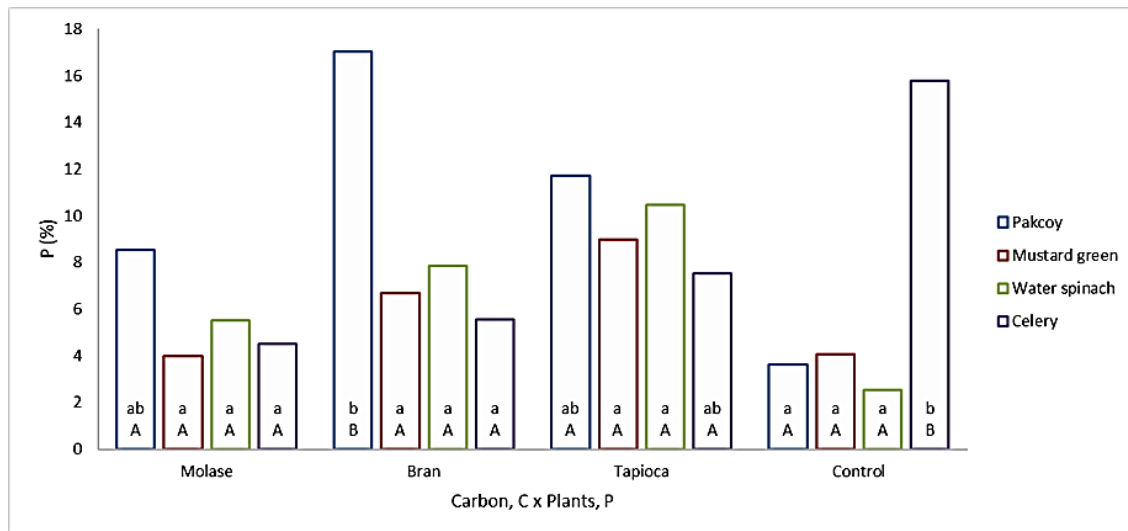


Figure 12. The effect of interactions between carbon sources and plant types on P uptake.

although celery under the control treatment displayed comparatively high P accumulation. Overall, the interaction results indicate that both nitrogen and phosphorus uptake by plants were strongly influenced by the specific pairing of carbon source and plant species within the biofloc aquaponics system.

Discussions

Growth performance of *Macrobrachium lar* under different carbon sources: The present study revealed that adding molasses as an external carbon source improved the growth performance and survival of *M. lar* in a biofloc aquaponics system, whereas rice bran and tapioca produced only modest improvements compared with the carbon-free control. The higher absolute growth and survival rate recorded in the molasses treatment indicate that this readily fermentable carbon source effectively stimulated heterotrophic bacterial growth and biofloc formation (Zhao et al., 2022), thereby enhancing the availability of natural food and stabilizing water quality for *M. lar* (Cavalli et al., 2020; Samadan et al., 2023c). Similar positive effects of molasses on shrimp growth and feed utilization in biofloc systems have been reported for other *Macrobrachium* and penaeid species (Islam et al., 2023; Samadan et al., 2023a,c), where increased microbial biomass contributed to improved protein retention and reduced accumulation of toxic nitrogenous compounds (Graber and Junge, 2009; Rustadi et al., 2022).

In contrast, prawns cultured with rice bran or tapioca exhibited significantly lower absolute growth and survival, despite specific growth rates that were not inferior to the control. Rice bran contains higher levels of fibre and complex carbohydrates (Maica et al., 2021), which may decompose more slowly and contribute to temporary increases in suspended solids and oxygen demand, potentially stressing prawns and limiting growth if supplementation is not carefully balanced with system carrying capacity. Tapioca, although richer in starch, may also differ from molasses in solubility and the rate of microbial assimilation, which can influence how quickly the desired C:N ratio is reached and maintained in the water column (Hari et al., 2004). The lack of significant differences in feed conversion ratio among treatments suggests that molasses's main advantage was not reduced feed quantity (Ekasari et al., 2014), but improved survival and more efficient conversion of feed and biofloc biomass into prawn growth. These findings support earlier evidence that the qualitative characteristics of the carbon source (Dilmi et al., 2022), in addition to the targeted C:N ratio, are critical determinants of biofloc system performance (Bakhshi et al., 2018).

Water quality and biofloc environment: Water quality variables, including temperature, dissolved oxygen, pH, ammonia, nitrite, and nitrate, remained within acceptable ranges for freshwater prawns throughout the trial and did not differ appreciably

among treatments. This indicates that the relatively low stocking density and effective aeration in the recirculating biofloc aquaponics system were sufficient to buffer the additional organic loads supplied by the carbon sources (Fadaei et al., 2024; Samadan et al., 2025), preventing major deterioration of the water environment. Previous reviews have emphasised that well-managed biofloc systems can maintain stable water quality even under high feeding regimes, as long as aeration, alkalinity, and solids management are adequate to support intensive microbial activity.

The absence of large differences in water quality parameters among treatments suggests that the observed improvements in growth and survival under molasses supplementation were more closely linked to the nutritional benefits of biofloc than to gross differences in toxicity (Ekasari et al., 2014). Bioflocs are known to provide a complex assemblage of proteins, lipids, vitamins, and bioactive compounds (Emerenciano et al., 2022) that can be ingested by shrimp and prawns (Samadan et al., 2023c, 2025), thereby acting as a supplemental feed source that improves growth, immune status, and resilience to environmental stress. For *M. lar*, which is naturally omnivorous and associated with benthic surfaces (Fadaei et al., 2024), microbially enriched particles may be particularly important for optimizing growth in recirculating systems where natural benthic productivity is limited. The present results therefore reinforce the view that carbon management in biofloc aquaculture should be evaluated not only in terms of water quality control, but also in terms of the quantity and quality of microbial biomass produced (Samadan et al., 2025).

Nitrogen uptake by different plant species and carbon sources: The study also found that nitrogen accumulation in plant tissues was influenced by both the carbon source and the plant species grown in the aquaponics beds. At the main-effect level, control treatments without added carbon showed the highest plant N%, whereas molasses yielded the lowest values, with tapioca and rice bran occupying intermediate positions. This pattern suggests that

external carbon addition promoted microbial assimilation of dissolved inorganic nitrogen into biofloc biomass (Hari et al., 2004), thereby reducing the proportion of nitrogen directly available for plant uptake (Samadan et al., 2023a); such competition for N between heterotrophic microbes (Ju et al., 2008) and plants has been highlighted in recent aquaponics and biofloc.

Among plant species, mustard green and celery showed higher tissue N% than water spinach and, particularly, pakcoy, indicating interspecific differences in N uptake capacity and internal N allocation (Samadan et al., 2023a). Leafy *Brassicaceae* and *Apiaceae* are known to possess relatively high N demands and can accumulate substantial levels of nitrate-N in their tissues when grown under nutrient-rich conditions (Patloková et al., 2024), which may explain their superior performance in capturing N from the aquaponics effluent (Samadan et al., 2023a; Nair et al., 2025). The significant interaction between carbon sources and plant species for N% shows that the efficiency of N capture is not solely a function of plant identity (Liu et al., 2025), but also depends on how carbon management shapes the form and timing of N availability in the water (Dilmi et al., 2024). For example, combinations involving control water and celery produced the highest N contents, whereas several molasses or rice bran combinations with pakcoy yielded comparatively low values, highlighting the need to match plant species to the nutrient regime generated by specific biofloc management strategies.

Phosphorus uptake patterns and carbon-plant interactions: In contrast to nitrogen, phosphorus uptake (tissue P%) was less clearly affected by the main effects of carbon source or plant species, with most differences remaining non-significant. Nevertheless, numerical trends indicated higher P accumulation in plants supplemented with rice bran and tapioca than in those supplemented with molasses and the control, and higher mean P in pakcoy and celery than in mustard green and water spinach (Samadan et al., 2023a). These tendencies may reflect differences in the P content of the carbon sources

themselves, as cereal-derived by-products such as bran and tapioca flour often contain more inherent P than cane molasses, and the variable capacity of plant species to store P in their tissues under moderate supply.

A more pronounced interaction between carbon sources and plants was observed when P% was analysed at the treatment combination level. Pakcoy cultured under rice bran and control conditions, and celery under control conditions, showed the highest P%, whereas several molasses and tapioca combinations yielded lower values. These results suggest that, similar to N, the synchrony between P release from feed and organic amendments, microbial immobilization in bioflocs, and plant demand strongly influences the ultimate distribution of P among water, biofloc, and plant compartments (Liu et al., 2025). Recent work on integrated biofloc–aquaponics and recirculating aquaculture systems has underscored the potential of tailoring C:P and N:P ratios to favor simultaneous microbial processing and plant nutrient uptake (Rakocy et al., 2020; Samadan et al., 2025), thereby minimizing discharge and improving overall resource efficiency. This study adds to this evidence by showing that both the carbon source and the choice of leafy vegetables can be adjusted to enhance P capture while maintaining satisfactory prawn performance.

Implications for the sustainable culture of *Macrobrachium lar* in biofloc aquaponics: Taken together, the results showed that molasses is a particularly suitable carbon source for the biofloc-based culture of *M. lar*, providing higher growth and survival without compromising water quality, while rice bran and tapioca can be used as alternative sources when appropriate adjustments are made to feeding and solids management (Xu and Pan, 2024). The concurrent evaluation of plant species indicates that mustard green and celery are promising candidates for maximizing N removal (Samadan et al., 2023a), whereas pakcoy and celery may contribute more effectively to P capture, especially when combined with specific carbon regimes (Zhao et al., 2020). Such complementary roles of different

vegetables highlight the opportunity to design multi-species plant assemblages that exploit functional diversity in nutrient uptake within biofloc aquaponics systems (Rakocy et al., 2020; Samadan et al., 2025).

From a broader sustainability perspective, integrating *M. lar* culture with biofloc and aquaponics represents a viable strategy to increase freshwater prawn production in small-island contexts while minimizing water exchange and nutrient discharge (Samadan et al., 2025). Although most previous biofloc research has focused on *M. rosenbergii* and marine shrimp (Samadan et al., 2022, 2023c), the present findings indicate that *M. lar* can also benefit from microbial-based systems when carbon management is optimized (Samadan et al., 2025), thereby filling an important knowledge gap for this emerging Indo-Pacific species. Future studies should explore a wider range of C:N and C:P ratios, evaluate additional low-cost carbon sources and plant species, and incorporate economic analyses to identify configurations that maximize both environmental performance and farm profitability.

Conclusion

The study demonstrated that the application of different carbon sources in a biofloc aquaponics system markedly affected the biological performance of Monkey River prawn, *M. lar*, and the nitrogen and phosphorus uptake by associated vegetable crops. Molasses, applied to maintain a C:N ratio of approximately 10:1, produced the highest absolute growth and survival of *M. lar* without significantly altering key water quality parameters, indicating that readily fermentable carbon can effectively support biofloc development and enhance prawn production in semi-intensive conditions. In contrast, rice bran and tapioca yielded lower prawn performance, suggesting that the qualitative characteristics of the carbon source are as important as the C:N target in designing biofloc systems. Nitrogen and phosphorus distribution between plants and the water column was strongly influenced by both carbon management and plant species, with mustard green and celery showing

greater N accumulation, and pakcoy and celery tending to accumulate more P under specific carbon regimes. These patterns highlight functional differences among leafy vegetables in their capacity to capture nutrients from aquaponic effluents and confirm that pairing appropriate carbon sources with plant species can enhance nutrient removal efficiency. Overall, the results indicate that molasses-driven biofloc aquaponics with carefully selected leafy vegetables offers a promising strategy for sustainable culture of *M. lar*, improving growth and survival while simultaneously recovering dissolved N and P into valuable plant biomass.

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