
The effects of *Anabas testudineus* co-Cultivation with *Allium ascalonicum* L. cultivation in an aquaponic system

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Abstract Results indicated significant differences in the growth of *Allium ascalonicum*, with those receiving 100% AB solution showing the highest average height (26.24 ± 3.98 cm) and the largest increased in the number of leaves (33.13 ± 1.77 leaves) by the end of the experiment. Conversely, the group with no AB supplementation exhibited the lowest growth, with average heights of 19.27 ± 1.33 cm and fewer leaves (13.33 ± 1.77). In terms of fresh and dry weight, the group with 100% AB solution achieved the highest values, reflecting the nutrient solution's positive impact on plant growth. For the fish, no significant differences in weight gain, length increase, or survival rates were observed across treatments, with all groups showing a 100% survival rate. Water quality parameters, including dissolved oxygen (DO), pH, and electrical conductivity (EC) showed that the addition of AB solution was not significantly affected DO levels but caused the changes in pH and EC, with the 50% AB group maintaining the highest DO levels throughout the study. Overall, the study demonstrated the potential of using aquaponics for efficient co-cultivation of fish and vegetables, with nutrient supplementation enhancing the growth of both species.

Keywords: Aquaponics system, Growth performance, Nutrient solution concentration, *Anabas testudineus*, *Allium ascalonicum*

Introduction

Agricultural production faces increasing pressure from limited cultivable land, declining natural resources, and environmental problems associated with intensive fertilizer and pesticide use. At the same time, population growth continues to increase food demand, contributing to concerns over soil degradation, water scarcity, and ecosystem contamination. These challenges have increased interest in production systems that use resources more efficiently. Aquaponics is one such approach, combining aquaculture with hydroponics through a recirculating water system. Fish waste supplies nutrients for plant

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growth, while plants help remove nutrients from the water before it returns to the fish culture unit. This nutrient-recycling process can reduce waste and the need for external fertilizer and water inputs (Love *et al.*, 2014).

Water conservation and nutrient reuse are important features of aquaponics. Continuous water circulation allows water to be reused within the system, which is useful where water availability is limited (Goddek *et al.*, 2019). Fish-derived nitrogen, phosphorus, and potassium can also support plant growth and reduce dependence on synthetic fertilizers (Okomoda *et al.*, 2023). The system can be applied in areas with limited land, including urban production sites such as greenhouses and rooftops. Producing fish and vegetables closer to consumers may also support local food production and reduce the need for long-distance transport. However, aquaponics requires investment in tanks, filtration, pumps, and plant-growing units. Its operation also requires appropriate management of water quality, nutrients, fish, and plants, which can be challenging for small-scale producers (Wongkiew *et al.*, 2017).

Several vegetable crops have been grown successfully in aquaponic systems, including lettuce, spinach, and herbs. In this study, green onion (*Allium fistulosum*) was selected because it is widely used as a food crop, has a relatively short production cycle, and can grow under nutrient-rich conditions. Its use may also expand the range of crops suitable for aquaponic production. Recent research has reported the potential of green onion for cultivation in aquaponic systems (Oliveira *et al.*, 2025). Tilapia was selected as the fish component because of its adaptability to controlled culture conditions. In the integrated system, nutrients from fish production can be utilized by plants, while plant uptake contributes to water treatment. Such integration allows fish and vegetables to be produced within the same system and may reduce some external inputs (Okomoda *et al.*, 2023).

Therefore, this study evaluated the growth performance of green onion and tilapia in an aquaponic system. Green onion growth was assessed using plant height and biomass production, whereas tilapia performance was evaluated based on weight gain under the experimental conditions.

Materials and methods

Experimental design

The experiment was arranged in a Completely Randomized Design (CRD) and consisted of two components: shallot cultivation and *Anabas testudineus* rearing. Each component included three treatments (T1, T2, and T3), with each treatment replicated three times, resulting in nine experimental units per component. The treatments differed in the concentration of AB nutrient solution

applied, as follows: T1 was no AB nutrient solution (water only), T2 was 50% AB nutrient solution (600 mL), and T3 received 100% AB nutrient solution (1,200 mL). The nutrient solutions were mixed with water and applied to the respective aquaponic systems according to the assigned treatments. Growth parameters of both shallots and *A. testudineus* were recorded throughout the experimental period.

System preparation and experimental procedures

Aquaponic System for Shallot Cultivation: Nine foam boxes lined with plastic sheets were prepared. Each lid was drilled with 15 holes (7 cm apart) for plant placement. A water pump is circulated water from the fish tanks to the foam boxes and back, forming a closed-loop system.

Shallot Seedling Preparation: One-inch hydroponic sponges were used to hold cleaned shallot bulbs (1.3–1.4 cm). Bulbs were inserted with roots in the sponge and shoots above. Seedlings were grown for 2–3 weeks until reaching 10–15 cm before transplanting into the foam boxes.

Rearing System for *Anabas testudineus*: Nine PE tanks (1 × 1 × 0.4 m) were cleaned and filled with 0.2 m³ water and 800 g of sea salt. Juvenile fish (3–4 cm) were acclimated for one week and fed floating pellets (≥30% protein). During the 45-day trial, fish were fed twice daily (5% body weight), with weekly feeding adjustments. Water quality (nutrients, pH, DO) was monitored weekly.

AB Nutrient Solution Application: The AB solution was added directly to tanks as follows: T1 – no AB solution, T2 – 600 mL (50%), T3 – 1200 mL (100%). Solutions were poured at high-circulation points to ensure even mixing.

Data collection

Growth rate and Yield of *Allium fistulosum* L.

The following parameters were measured for *Allium fistulosum* L.: average stem height, average number of leaves, average bulb size, average fresh weight, average dry weight, and survival rate of green onions. These parameters were measured following the method of Santos *et al.* (2021).

Growth rate of *Anabas testudineus*

Fish were randomly sampled at 30% of the fish in each experimental unit, with two fish sampled from each treatment for measurement. Growth performance data were recorded weekly throughout the 7-week experimental period. The percentage weight gain (PWG), mean length gain (LG), specific growth rate (SGR), average daily growth (ADG), and survival rate (SR) were calculated according to Aalimahmoudi and Mohammadiarm (2019) using the following equations:

$$\begin{aligned}
 \text{PWG (\%)} &= \frac{\text{Final weight} - \text{Initial weight}}{\text{Initial weight}} \times 100 \\
 \text{LG (cm)} &= \text{Final length} - \text{Initial length} \\
 \text{SGR (\%/day)} &= \frac{(\ln \text{ final weight} - \ln \text{ Initial weight})}{\text{Number of days}} \times 100 \\
 \text{ADG (g/fish/day)} &= \frac{\text{body weight gain (g)}}{\text{Number of days}} \\
 \text{Survival rate (\%)} &= \frac{\text{number of surviving at the end of the production cycle}}{\text{Total number at the beginning of the cycle}} \times 100
 \end{aligned}$$

Water quality management

In this study, water quality in the fish culture tanks was monitored weekly to assess its impact on the health and growth of both fish and plants in the aquaponic system. Key parameters measured included Electrical Conductivity (EC), pH, and Dissolved Oxygen (DO). EC was used to monitor nutrient levels, ensuring they were within the optimal range for both fish and plants (Lennard and Goddek, 2019). pH was assessed to maintain stability, as both fish and plants have specific pH requirements for growth (Wang *et al.*, 2023). DO levels were measured to ensure sufficient oxygen for the respiration of both fish and microorganisms, supporting the health of the system (Wongkiew *et al.*, 2017). These parameters were monitored to maintain optimal water conditions for the system's efficiency and sustainability.

Statistical analysis

Data were analyzed using Analysis of Variance (ANOVA) to determine differences between treatment groups. Significant differences between means were determined by Duncan's New Multiple Range Test at a 95% confidence level using statistical software.

Results

Effects of average polant height of Allium ascalonicum L. grown in an aquaponics system with Anabas testudineus

Plant height varied among the three AB nutrient-solution treatments during the 7-week cultivation period (Table 1). During the first two weeks, plant height did not differ significantly among treatments. Significant differences were detected from week 3 onward. In the 0% AB treatment, plant height increased

from 17.45 ± 0.75 cm in week 1 to 22.20 ± 0.78 cm in week 3, followed by a gradual decline to 19.27 ± 1.33 cm in week 7. The 50% AB treatment showed a continued increase in plant height from 16.97 ± 0.36 cm in week 1 to 25.36 ± 1.50 cm in week 6, followed by a slight decrease to 24.98 ± 2.00 cm in week 7. Plants receiving 100% AB had a similar initial height to the other treatments (17.17 ± 0.58 cm) but showed greater values from week 3 onward. Plant height reached 24.96 ± 1.15 cm in week 3 and 26.24 ± 3.98 cm in week 7. At weeks 3–7, the 100% AB treatment was significantly higher than the 0% AB treatment. At weeks 6 and 7, plant height in the 50% and 100% AB treatments did not differ significantly.

Table 1. Presents the Average Plant Height of *Allium ascalonicum* L. Grown in an Aquaponics System Integrated with *Anabas testudineus* over a 7-Week Period

Treatment	Average Height of <i>Allium ascalonicum</i> L. (cm)						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
AB 0%	17.45±0.75	20.35±0.43	22.20±0.78 ^a	22.07±1.25 ^a	21.53±1.64 ^a	21.07±1.87 ^a	19.27±1.33 ^a
AB 50%	16.97±0.36	20.98±1.06	23.88±0.87 ^{ab}	24.40±0.73 ^{ab}	24.37±0.69 ^{ab}	25.36±1.50 ^b	24.98±2.00 ^b
AB 100%	17.17±0.58	21.36±0.97	24.96±1.15 ^b	25.36±1.43 ^b	25.43±1.84 ^b	26.23±2.05 ^b	26.24±3.98 ^b
F-test	ns	ns	*	*	*	*	*
CV (%)	3.18	4.16	6.15	7.44	9.11	11.82	16.89

The means followed by different letters in the same column are significantly different, as determined by Duncan's New Multiple Range Test. Abbreviations: ns = no statistically significant difference at the 95% confidence level, * = statistically significant difference at the 95% confidence level

Effects of average number of leaves of Allium ascalonicum L. grown in an aquaponics system with Anabas testudineus

The number of leaves differed among the AB nutrient-solution treatments throughout the 7-week cultivation period (Table 2). Significant differences were detected among treatments in every week. Plants receiving 0% AB had 12.73 ± 1.38 leaves in week 1. The number increased to 14.33 ± 0.59 leaves in week 2, followed by a gradual decline to 9.30 ± 0.87 leaves in week 7. In the 50% AB treatment, the number of leaves increased from 17.67 ± 0.59 leaves in week 1 to 21.70 ± 1.37 leaves in week 3. Thereafter, the mean decreased and reached 13.33 ± 1.77 leaves in week 7. The 100% AB treatment produced the highest number of leaves during most of the experimental period. The mean increased from 19.47 ± 1.37 leaves in week 1 to 27.33 ± 1.58 leaves in week 3. The values subsequently decreased to 25.40 ± 0.95 , 23.30 ± 2.69 , and 19.97 ± 2.11 leaves in weeks 4, 5, and 6, respectively, and reached 17.07 ± 1.80 leaves in week 7. Based on the Duncan's New Multiple Range Test, the 100% AB treatment differed significantly from the other treatments in weeks 2–4 and week 7. At weeks 1, 5, and 6, the 50% and 100% AB treatments were not significantly different from each other, although both had higher leaf numbers than the 0% AB treatment (Table 2).

Table 2. Average number of leaves of *Allium ascalonicum* L. grown in an aquaponics system integrated with *Anabas testudineus* over a 7-week period

Treatment	Average leaf length of <i>Allium ascalonicum</i> L. (cm)						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
AB 0%	12.73±1.38 ^a	14.33±0.59 ^a	14.30±0.75 ^a	12.93±1.50 ^a	12.60±0.85 ^a	11.13±0.21 ^a	9.30±0.87 ^a
AB 50%	17.67±0.59 ^b	19.93±0.68 ^b	21.70±1.37 ^b	21.23±2.24 ^b	18.87±3.30 ^b	17.13±3.38 ^b	13.33±1.77 ^b
AB 100%	19.47±1.37 ^b	22.97±0.85 ^c	27.33±1.58 ^c	25.40±0.95 ^c	23.30±2.69 ^b	19.97±2.11 ^b	17.07±1.80 ^c
F-test	*	*	*	*	*	*	*
CV (%)	7.04	3.74	6.06	8.31	13.72	14.34	11.66

The means followed by different letters in the same column are significantly different, as determined by Duncan's New Multiple Range Test. Abbreviations: ns = no statistically significant difference at the 95 % confidence level, * = statistically significant difference at the 95% confidence level

Effects of average fresh weight and dry weight of Allium ascalonicum L. grown in an aquaponics system with Anabas testudineus

Both fresh and dry weights of *Allium ascalonicum* L. differed significantly among the three AB nutrient-solution treatments ($p < 0.05$) (Table 3). The plants grown without AB supplementation had the lowest fresh weight (9.98 ± 0.76 g) and dry weight (5.34 ± 0.49 g). Increasing the AB concentration to 50% resulted in higher values, with fresh and dry weights of 17.45 ± 1.21 and 9.94 ± 0.77 g, respectively. Both measurements were significantly higher than those of the 0% AB treatment.

The 100% AB treatment produced the highest fresh weight (21.78 ± 2.61 g) and dry weight (11.68 ± 1.09 g). Duncan's New Multiple Range Test showed that the three treatments differed significantly from one another for both fresh and dry weight, as indicated by the different superscript letters in Table 3. Thus, under the conditions of this experiment, increasing the AB nutrient-solution concentration was associated with higher fresh and dry weights of *A. ascalonicum*.

Table 3. The average fresh weight and dry weight of *Allium ascalonicum* L. grown in an aquaponics system integrated with *Anabas testudineus* over a 7-week period

Treatment	Average fresh weight and dry weight (g)	
	fresh weight	dry weight
AB 0%	9.98±0.76 ^a	5.34±0.49 ^a
AB 50%	17.45±1.21 ^b	9.94±0.77 ^b
AB 100%	21.78±2.61 ^c	11.68±1.09 ^c
F-test	*	*
CV (%)	10.46	9.14

The means followed by different letters in the same column are significantly different, as determined by Duncan's New Multiple Range Test. Abbreviations: ns = no statistically significant difference at the 95 % confidence level, * = statistically significant difference at the 95% confidence level

Effects of growth rate and survival rate of *Anabas testudineus* in the aquaponics system

Growth performance and survival of *Anabas testudineus* were evaluated under three AB nutrient-solution treatments: 0%, 50%, and 100% AB. The measured growth variables did not differ significantly among treatments ($p > 0.05$) (Table 4). Initial body weight ranged from 0.98 ± 0.22 to 1.05 ± 0.41 g among treatments. Final body weight was 9.41 ± 2.42 g in the 0% AB treatment, 9.51 ± 3.30 g in the 50% AB treatment, and 9.54 ± 2.90 g in the 100% AB treatment. Although the 100% AB treatment had the highest numerical final weight, the difference among treatments was not statistically significant. Mean length gain was 3.03 ± 0.63 , 3.23 ± 0.88 , and 3.29 ± 0.82 cm in the 0%, 50%, and 100% AB treatments, respectively. Percentage weight gain ranged from $885.19 \pm 380.28\%$ in the 100% AB treatment to $963.47 \pm 555.06\%$ in the 50% AB treatment. Average daily growth ranged from 0.17 ± 0.05 to 0.17 ± 0.06 g fish⁻¹ day⁻¹, while specific growth rate ranged from 4.21 ± 0.86 to $4.27 \pm 0.63\%$ day⁻¹. None of these variables differed significantly among treatments. Survival was $100.00 \pm 0.00\%$ in all three treatments. Therefore, under the conditions of this experiment, AB nutrient-solution supplementation did not produce a significant difference in the measured growth performance or survival of *A. testudineus* (Table 4).

Table 4. Growth performance and survival of *Anabas testudineus* in an aquaponics system over a 7-week period

Treatment	Growth performance and survival rate						
	Initial weight (g)	Final weight (g)	LG (cm)	PWG (%)	ADG (g/fish/d)	SGR (%/d)	SR (%)
AB 0%	$\pm 0.980.26$	2.42 ± 9.41	0.63 ± 3.03	481.11 ± 958.79	0.05 ± 0.17	0.68 ± 4.25	0.00 ± 100.00
AB 50%	0.22 ± 0.98	3.30 ± 9.51	0.88 ± 3.23	555.06 ± 963.47	0.06 ± 0.17	0.86 ± 4.21	0.00 ± 100.00
AB 100%	0.41 ± 1.05	2.90 ± 9.54	0.82 ± 3.29	380.28 ± 885.19	0.06 ± 0.17	0.63 ± 4.27	0.00 ± 100.00
F-test	ns	ns	ns	ns	ns	ns	ns

The means followed by different letters in the same column are significantly different, as determined by Duncan's New Multiple Range Test. Abbreviations: ns = no statistically significant difference at the 95% confidence level, LG = length gain, PWG = Percentage Weight Gain, ADG = Average daily growth, SGR = Specific growth rate, SR = survival rate, gain * = statistically significant difference at the 95% confidence level

Effects of dissolved oxygen (DO) in fish culture water in the aquaponics system

Dissolved oxygen (DO) in the fish culture water was monitored weekly for 7 weeks under three AB nutrient-solution treatments (0%, 50%, and 100%). The mean DO levels differed significantly among treatments in weeks 1–3 and 5–7, whereas no significant difference was detected in week 4 (Table 5). In week 1, the 50% AB treatment had the highest DO level (11.73 ± 0.85 mg/L), followed by 0% AB (10.13 ± 2.21 mg/L) and 100% AB (9.91 ± 2.09 mg/L). The treatment

means differed significantly among groups. In week 2, DO decreased in all treatments, with values of 7.80 ± 0.37 , 8.48 ± 0.15 , and 8.01 ± 0.41 mg/L for 0%, 50%, and 100% AB, respectively. The 50% and 100% AB treatments did not differ significantly, but both differed from the 0% AB treatment. In week 3, the 50% AB treatment had the highest DO (8.68 ± 0.60 mg/L), while the 0% and 100% AB treatments had similar values of 8.06 ± 0.30 and 7.98 ± 0.26 mg/L, respectively. No significant difference among treatments was detected in week 4, when DO ranged from 8.46 ± 1.07 to 9.23 ± 1.77 mg/L. From week 5 onward, significant differences were again observed. The 50% AB treatment had the highest DO in weeks 5–7, with values of 8.36 ± 0.08 , 8.93 ± 0.05 , and 8.86 ± 0.10 mg/L, respectively. The 0% and 100% AB treatments had lower DO levels during this period. Overall, DO remained within the measured range of 7.80–11.73 mg/L throughout the experiment, with the 50% AB treatment generally showing the highest values.

Table 5. Dissolved oxygen (DO) levels in fish culture water in the aquaponics system during the 7-week experimental period

Treatment	Estimation of dissolved oxygen levels during a 7-week period						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
AB 0%	10.13 ± 2.21^a	7.80 ± 0.37^a	8.06 ± 0.30^b	8.72 ± 1.11^{ns}	8.22 ± 0.42^a	8.26 ± 0.32^b	8.06 ± 0.32^c
AB 50%	11.73 ± 0.85^b	8.48 ± 0.15^b	8.68 ± 0.60^a	9.23 ± 1.77^{ns}	8.36 ± 0.08^a	8.93 ± 0.05^a	8.86 ± 0.10^a
AB 100%	$2 \pm 9.91.09^c$	8.01 ± 0.41^b	0.26 ± 7.98^b	1.07 ± 8.46^{ns}	0.177 ± 7.90^b	0.34 ± 8.30^b	0.26 ± 8.33^b

Values are presented as mean $\pm$ SD. Means followed by different lowercase letters within the same column differ significantly according to Duncan's New Multiple Range Test (DMRT). ns = not significant ($p > 0.05$).

Effects of pH levels in fish culture water in the aquaponics system

Water quality in the aquaponics system, in which fish were reared under different concentrations of AB nutrient solution, was assessed by monitoring pH levels. Water samples were collected in triplicate and measured weekly over a 7-week experimental period. The results showed statistically significant differences in pH among treatments in some weeks ($p < 0.05$). In week 2, the 0% AB treatment had the highest pH (8.86 ± 0.00), followed by the 50% AB treatment (8.41 ± 0.34), whereas the 100% AB treatment had the lowest pH (8.10 ± 0.35). The differences among treatments were statistically significant. In week 4, the 0% and 50% AB treatments had the same mean pH (8.53 ± 0.00) and were significantly higher than the 100% AB treatment (8.29 ± 0.34). No significant differences among treatments were observed in weeks 1, 3, and 5. In week 6, the 0% AB treatment had the highest pH (8.51 ± 0.02), whereas the 50% AB treatment had the lowest value (8.22 ± 0.21); the 100% AB treatment (8.37 ± 0.38) was intermediate. In week 7, the 0% AB treatment again showed the highest pH (8.55 ± 0.04), followed by the 50% AB (8.36 ± 0.18) and 100% AB treatments (8.21 ± 0.42). Overall, pH varied among treatments during several

weeks, particularly in weeks 2, 4, 6, and 7, whereas no significant treatment differences were detected in weeks 1, 3, and 5 (Table 6).

Table 6. pH levels of the fish culture water in the aquaponics system

Treatment	pH values over a 7-week period						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
AB 0%	5.92±0.38 ^{ns}	8.86±0.00 ^c	8.36±0.13 ^{ns}	8.53±0.00 ^a	8.55±0.50 ^{ns}	8.51±0.02 ^a	8.55±0.04 ^a
AB 50%	5.82±0.42 ^{ns}	8.41±0.34 ^b	8.26±0.40 ^{ns}	8.53±0.00 ^a	8.54±0.01 ^{ns}	8.22±0.21 ^b	8.36±0.18 ^b
AB 100%	0.38±5.99 ^{ns}	8.10±0.35 ^a	0.40±8.26 ^{ns}	0.34±8.29 ^b	0.24±8.22 ^{ns}	0.38±8.37 ^{ab}	0.42±8.21 ^b

Means followed by different lowercase letters within the same column are significantly different according to Duncan's New Multiple Range Test (DMRT) at the 5% significance level. ns indicates no significant difference among treatments ($p > 0.05$).

Effects of electrical conductivity (EC) in fish culture water in the aquaponics system

Electrical conductivity (EC) of the fish culture water was measured weekly for 7 weeks to examine changes in water quality under different concentrations of AB nutrient solution. Measurements were taken from three replicates in each treatment. EC was used to indicate changes in the amount of dissolved ions in the culture water. The EC values differed among the three treatments during the experiment. The 100% AB treatment had the highest EC in every week, with values ranging from $1,173.66 \pm 113.50$ to $1,778.33 \pm 48.29$ $\mu\text{S}/\text{cm}$. Its highest value was recorded in week 3. The 50% AB treatment showed lower values than the 100% AB treatment, ranging from $1,018.66 \pm 102.83$ to $1,619.33 \pm 82.52$ $\mu\text{S}/\text{cm}$. The 0% AB treatment generally had the lowest EC values, ranging from 658.66 ± 96.09 to $1,180.66 \pm 160.00$ $\mu\text{S}/\text{cm}$. In week 2, the EC was $1,180.66 \pm 160.00$ $\mu\text{S}/\text{cm}$ in the 0% AB treatment, $1,577.55 \pm 277.32$ $\mu\text{S}/\text{cm}$ in the 50% AB treatment, and $1,720.22 \pm 724.35$ $\mu\text{S}/\text{cm}$ in the 100% AB treatment. In week 3, the corresponding values were 658.66 ± 96.09 , $1,619.33 \pm 82.52$, and $1,778.33 \pm 48.29$ $\mu\text{S}/\text{cm}$, respectively. EC decreased in all treatments in week 4 and then increased again during weeks 5–7. The results indicate that increasing the concentration of AB nutrient solution was associated with an increase in EC of the fish culture water. The 100% AB treatment had the highest EC throughout the experiment, while the 0% AB treatment generally had the lowest values (Table 7).

Table 7. EC values of fish culture water in the aquaponics system

Treatment	EC levels measured over a 7-week period						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
AB 0%	1120.33±10 8.09 ^b	1180.66±16 0.00 ^b	658.66±96 .09 ^c	1055.33±34 .00 ^b	1069.66±80 .60 ^c	1086.00±89 .03 ^c	1146.00±12 3.59 ^c
AB 50%	1410.00±45 3.00 ^{ab}	1577.55±27 7.32 ^{ab}	1619.33±8 2.52 ^b	1018.66±10 2.83 ^b	1262.66±10 7.36 ^b	1324.33±10 9.94 ^b	1408.33±14 4.15 ^b
AB 100%	30±1488.33 1.44 ^a	1720.22±72 4.35 ^a	4±1778.33 8.29 ^a	11±1173.66 3.50 ^a	10±1379.77 7.03 ^a	14±1479.33 6.14 ^a	14±1546.66 0.80 ^a

Means followed by different lowercase letters within the same column are significantly different according to Duncan's New Multiple Range Test (DMRT) at the 5% significance level. ns indicates no significant difference among treatments ($p > 0.05$).

Discussion

Allium ascalonicum L. in an aquaponic system

The addition of AB nutrients affected the growth of *Allium ascalonicum* L. in the aquaponic system integrated with *Anabas testudineus*. Plants receiving 100% AB nutrients reached the greatest height, measuring 26.24 ± 3.98 cm on day 49, and also produced more leaves than those receiving 50% and 0% AB nutrients. The greater growth observed with AB supplementation is consistent with Nozzi *et al.* (2018) and Ru *et al.* (2017), who reported improved plant growth under nutrient-rich conditions. The availability of nitrogen, phosphorus, and potassium is also important for vegetative development, as described by Somerville *et al.* (2014). In addition, Pantanella *et al.* (2012) noted that both macronutrients and micronutrients contribute to physiological processes associated with photosynthesis and leaf development. Plants grown without additional nutrients had poorer growth than those in the AB treatments. This may indicate that the nutrients supplied through fish waste alone were not sufficient to meet the nutritional requirements of *A. ascalonicum* under the conditions of this experiment. However, this observation differs from the results of Lennard and Leonard (2006), who reported moderate plant growth without external nutrient supplementation. The difference may be related to variation in plant species, nutrient availability, or aquaponic system conditions. Pengseesang *et al.* (2024) also reported that garlic supplementation could improve fish performance, which may have implications for nutrient production and cycling within integrated aquaculture systems. Taken together, the present results indicate that AB nutrient supplementation can support the growth of *A. ascalonicum* when

cultivated with *A. testudineus* in an aquaponic system. Further work should examine the performance of the system over longer culture periods and assess alternative nutrient sources that could reduce dependence on external nutrient solutions.

***Anabas testudineus* in an aquaponic system**

The addition of AB nutrient solution to the aquaponic system did not result in significant differences in the growth performance of *Anabas testudineus* at either the 50% or 100% concentration. Length gain (LG), percentage weight gain (PWG), specific growth rate (SGR), average daily growth (ADG), and survival rate (SR) were comparable among the treatments. This result is in agreement with Lennard and Leonard (2006), who reported that nutrient supplementation had little effect on fish growth when stocking density was sufficient. All fish survived throughout the experiment, with a survival rate of 100% in every treatment. The absence of mortality suggests that the inclusion of AB nutrient solution at the tested concentrations did not have an adverse effect on fish survival under the conditions of this study. A similar observation was reported by Ru *et al.* (2017), supporting the use of nutrient supplementation within an integrated aquaponic system when appropriately managed. Although the fish receiving 100% AB had the highest final weight, the difference among treatments was not statistically significant. This finding indicates that increasing the AB concentration alone was not sufficient to produce a measurable improvement in fish growth. Growth in aquaponic systems can also be affected by other factors, including fish species, feed quality, feeding management, and water quality (Schmautz *et al.*, 2017). Therefore, the response of fish to additional nutrients may depend on the overall culture conditions rather than nutrient concentration alone. Previous studies have also shown that the response to nutrient supplementation can vary among fish species. Gichana *et al.* (2018) reported improved fish growth following nutrient supplementation in their study, whereas *A. testudineus* may respond differently because of its ability to tolerate relatively low-nutrient environments. In addition, Pengseesang *et al.* (2024) reported improved fish growth following garlic supplementation, suggesting that the composition of the diet can be an important factor affecting fish performance. The present findings can also be considered alongside the results reported by Gichana *et al.* (2019) and Lennard and Goddek (2019), which indicate that fish responses in aquaponic systems may vary according to species and culture conditions. In the present experiment, *A. testudineus* showed limited growth response to the additional AB nutrient solution. Thus, the lack of a significant growth response may reflect the relatively low contribution of external nutrient concentration to fish growth compared with

factors such as feed and general culture conditions. Under the conditions of this study, AB supplementation did not improve the measured growth indices of *A. testudineus*, but no negative effect on survival was observed. Further studies could therefore examine different fish species, feed formulations, and fish-to-plant ratios to determine combinations that improve the productivity of integrated aquaponic systems.

Water quality in an aquaponic system

AB nutrient supplementation affected some of the water quality parameters in the aquaponic system, although the magnitude of the response differed among variables. Dissolved oxygen (DO) did not differ significantly among treatments ($p > 0.05$). The 50% AB treatment showed the highest DO values during the experimental period. This pattern may be related to changes in nutrient availability and microbial activity within the system. Lama *et al.* (2025) also discussed the relationship between nutrient conditions and DO in aquaponic systems. However, their report associated higher nutrient availability with reduced DO, which was attributed to oxygen consumption during microbial decomposition. The different response observed in the present study may therefore be related to differences in system conditions and nutrient levels. Changes in pH were more apparent during the early stage of the experiment. The no-AB treatment initially had the highest pH, whereas the values among treatments became more stable by week 5. This observation is consistent with Kasozi *et al.* (2021), who described changes in pH during aquaponic operation, and with Wongkiew *et al.* (2017), who reported stabilization of pH as the system developed. The slight decrease in pH observed in the 100% AB treatment may have been associated with the greater addition of dissolved ions and subsequent changes in the chemical balance of the culture water, as suggested by Chen *et al.* (2023). Electrical conductivity (EC) showed a clearer response to AB supplementation than DO and pH. EC increased as the concentration of AB solution increased, and the 100% AB treatment recorded the highest values. This trend agrees with Lennard and Goddek (2019), who reported an increase in EC with greater nutrient availability in aquaponic systems. The variation in EC observed initially in the 50% AB treatment may have resulted from adjustment of the system following nutrient addition, which is comparable to the changes described by Timmons and Ebeling (2013). Despite the differences among treatments, the measured water quality variables remained within the acceptable range for aquaponic production under the conditions of this experiment. Nevertheless, maintaining an appropriate nutrient balance remains important because excessive nutrient accumulation and high EC may affect system

performance (Lama *et al.*, 2025). Water quality is also influenced by factors beyond nutrient supplementation, including plant species, feed inputs, and stocking density. These factors should therefore be considered when interpreting water quality responses in integrated aquaponic systems (Palm *et al.*, 2019). Overall, AB supplementation had little effect on fish growth but produced a clearer change in EC, while DO and pH showed smaller responses. Further research should examine the interaction among nutrient inputs, microbial activity, plant species, and fish density to better understand water quality dynamics and improve the management of aquaponic systems.

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Conflicts of interest

The authors declare no conflict of interest.

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