HORTSCIENCE 60(9):1415–1421. 2025. https://doi.org/10.21273/HORTSCI18735-25

Effects of Different Nutrient Solutions on the Growth of *Kaempferia galanga* in Hydroponic Culture

Jun-ai Hui and Yong-xing Chen
College of Horticulture and Landscape Architecture, Zhongkai University of Agriculture and Engineering, Guangzhou, Guangdong, China, 510225

Keywords. hydroponics, Japan garden test nutrient solution, *Kaempferia galanga*, nutrient solution

Abstract. **This study aimed to investigate the effects of different nutrient solutions on the growth, physiological characteristics, and ornamental quality of hydroponically grown *Kaempferia galanga*, and to identify the most suitable nutrient solution for its cultivation. Three nutrient solutions (general, Hoagland, and Japan garden test) were tested, and clear water was used as a control. Physiological indexes, growth parameters, and ornamental effects were analyzed over a 35-day hydroponic period. The Japan garden test nutrient solution exhibited the best overall performance, with significant improvements in chlorophyll content, carotenoid accumulation, crown width, plant height, and ornamental scores. The Hoagland solution also showed notable benefits, while the general nutrient solution and water were less effective. The Japan garden test nutrient solution was the most suitable for the hydroponic cultivation of *Kaempferia galanga*, followed by Hoagland solution. These findings provided a scientific basis for optimizing nutrient solutions to enhance the ornamental and commercial value of *Kaempferia galanga* and related Zingiberaceae plants.**

Kaempferia galanga, a perennial herb of the Zingiberaceae family, is renowned for its ornamental leaves, delicate flowers, and medicinal properties (Gangmei et al. 2025; Pham et al. 2021). Widely cultivated in regions such as Taiwan, Guangdong, and Guangxi, it serves as a valuable plant for medicinal use (Ekowati et al. 2023; Naresh et al. 2024; Wang et al. 2021). In addition, *Kaempferia galanga* plays an important role in gardens and is suitable for flowering groundcover under sparse forests as well as indoor plants and shade flower border materials (Suwardi et al. 2023). Research of *Kaempferia galanga* has primarily focused on tissue culture, cultivation media, fertilizers, and volatile substances; however, limited studies have addressed its photosynthetic characteristics (Chu et al. 2023; Saitama et al. 2024).

Received for publication 16 May 2025. Accepted for publication 30 May 2025.
Published online 31 Jul 2025.
The authors declare that there are no conflicts of interest regarding the publication of this paper.
The data are available at https://doi.org/10.5281/zenodo.15493264.
This study was supported by Guangzhou Science and Technology Plan Project (202002020028, L32020207), Guangdong Science and Technology Plan Project [Yue Ke Nong Zi (2024) no. 200, no. KTP20240709, B124202E6], 2024 Guangdong Graduate Innovation Education Innovation Plan Project (2024SFKC-053), and 2022 School level Graduate Education Reform Research Special Project [Zhongyan Zi (2022) no. 11].
J.-A.H. is the corresponding author. E-mail: gzhja78@126.com.

Hydroponics, a soilless plant cultivation technique, has gained popularity because of its environmental friendliness, water efficiency, and convenience (Ekowati et al. 2023; Sankhalkar and Jamuni 2024). Hydroponic ornamental plants are cultivated in water-based systems with nutrient solutions tailored to their growth stages. However, the success of hydroponics largely depends on the composition and concentration of nutrient solutions (Kailashkumar et al. 2023; Al Meselmani 2022). Hydroponics requires nutrient solutions tailored to the specific needs of plant species to ensure optimal nutrient uptake during growth (Al Meselmani 2022; Rajaseger et al. 2023; Sangeetha and Periyathambi 2024). Despite extensive research of the tissue culture and volatile compounds of *Kaempferia galanga*, studies focused on its hydroponic cultivation are scarce. In particular, the lack of optimized nutrient solutions tailored to its growth and ornamental quality presents a significant research gap. Research of hydroponic cultivation of related Zingiberaceae plants highlights the importance of nutrient solution optimization in improving growth and ornamental qualities (Sahul Hamid et al. 2023). For example, Huang Yingying has indicated that the growth effect of Alpinia zingiberensis in one-quarter strength Hoagland formula nutrient solution is the best and is suitable for hydroponic production. However, limited research has focused on the hydroponic cultivation of *Kaempferia galanga*, particularly regarding nutrient solution optimization.

This study investigated the effects of different nutrient solutions on the growth of *Kaempferia galanga* in hydroponic culture. By comparing and analyzing the growth and physiological characteristics of *Kaempferia galanga* under different nutrient solutions, effects of different nutrient solutions on the ornamental effect were evaluated. Additionally, the nutrient solutions suitable for the growth of *Kaempferia galanga* were screened out, which provided references for the hydroponic application of *Kaempferia galanga*.

Materials and Methods

Kaempferia galanga, characterized by consistent growth and the absence of diseases or pests, was selected from the Baiyun Campus Farm of Zhongkai University of Agriculture and Engineering. The materials were cleaned after transportation to the laboratory and cultured hydroponically in clear water for 7 d. The roots were soaked in 500× chlorothalonil solution for 1 h for disinfection.

The experiment was conducted at the Laboratory of Life Science Building, Baiyun Campus, Zhongkai University of Agriculture and Engineering from Jun to Oct 2023. The illumination intensity was 1500 to 2000 Lux, the illumination time was 12 h/d, and the temperature was 25 to 31 °C.

Concentrations of three nutrient solutions were prepared according to the instructions. The following were the experimental designs of each treatment group: general nutrient solution (referred to as general), Hoagland nutrient solution (referred to as Hoagland), and Japan garden test nutrient solution (referred to as Japan garden test). With clear water as the control, there were four treatments. These treatments were repeated three times and cultured for 2 months.

Determination of physiological indexes

Determination of chlorophyll and carotenoid contents. The 95% ethanol extraction method was used. Fresh leaves (0.05 g) were cut into small pieces and immediately placed in a capped test tube containing 5 mL of 95% ethanol. The test tube was tightly sealed. The optical density (OD) values of the supernatant were measured at 645 nm, 663 nm, 662 nm, 644 nm, and 440 nm, respectively. According to the formula, the relevant data were obtained. The chlorophyll and carotenoid contents were determined by the ethanol extraction method. The calculation formulas were as follows:

$$\text{Chlorophyll a (Ca)} = 12.7\,OD_{663\,nm} - 2.69\,OD_{645\,nm}$$

$$\text{Chlorophyll b (Cb)} = 22.9\,OD_{645\,nm} - 4.68\,OD_{663\,nm}$$

$$\text{Total chlorophyll (Ca + B)} = 8.02\,OD_{663\,nm} + 20.20\,OD_{645\,nm}$$

$$\text{Carotenoid C} = 4.695\,OD_{440\,nm} - 0.268(5.134\,OD_{662\,nm} + 20.436\,OD_{644\,nm})$$

$$\text{Chlorophyll content (mg/g)} = \frac{C \times V \times N}{W \times 1000}$$

Table 1. Scoring standard of the ornamental effects of Zingiber plants.

Indicators	Good (8–10 points)	Better (6–8 points)	Average (5–6 points)	Very poor (less than 5 points)
Overall effect	Good growth, neat plant type, and good coverage	Good growth, neat plant type, and good coverage	The growth condition was general, the plant type was roughly neat, and the coverage was acceptable	The plant type was uneven, easy to lodge, or the plant grew poorly, the plant was short and the coverage was low
Growth status of stems and leaves	The leaves were oily green, and the tips were free from brown, diseases, insect pests, burns, and wrinkles	The leaves were green, the tips of leaves were rarely brown, and there were slight diseases, insect pests, burns, and wrinkles; the plants were not easy to lodge	The leaves were yellow, with a small amount of burns, the leaves were wrinkled and the tips were brown; the leaves were narrow, the plants were soft and easy to lodge, and the landscape was scattered	The leaves were burned, the leaves were wrinkled, and the tips were brown; the leaves were narrow, the plants were skewed and easy to lodge, and the landscape effect was extremely poor
Flowering effect	Flowering neatly, with a large amount of flowers and long flowering period	Flowering was neat, with a large amount of flowers and a long flowering period	The flowering uniformity was average, and the amount of flowers was less	Flowering plants were few, flowers were few or not flowering, and flowering was irregular

$$\text{Pigment content }(mg/g) = C(mg/L) \times V(L)/W(g)$$

pH value determination. The pH of the solution was measured using a pH meter.

Measurement of cell membrane permeability of leaves. The relative conductivity of leaves was measured using a conductivity meter. Fresh leaf samples (0.05 g) were placed in a test tube with 15 mL deionized water, incubated at room temperature for 30 min, and shaken evenly. The initial conductivity (C1) was measured with a DDS11C direct reading conductivity meter. Then, the samples were boiled for 10 min and cooled before the final conductivity (C2) was measured. According to the formula, the relative conductivity was obtained. The plasma membrane permeability of leaves was expressed as relative conductivity calculated as follows: relative conductivity $= C1/C2 \times 100\%$.

Leaf chromaticity. Leaf color was measured using a Minolta CR-400 automatic chromaticity meter (Tokyo, Japan) with an 8-mm measurement spot. Three functional leaves with similar leaf color growth were randomly selected for measurement, and the values of L, A, and B were recorded; L represents luster and brightness (0 = black; 100 = white), A indicates red/green (the larger the value of A, the darker the red; the smaller the value of A, the darker the green), and B represents yellow/blue intensity (higher B = darker yellow; lower B = darker blue).

Growth index determination

Fixed plant leaf measurements of three plants in each treatment were performed. The growth indexes of each treatment were counted at 0, 5, 10, 15, 20, 25, 30, and 35 d, including the number of stem leaves, plant height, fresh weight, leaf sheath length, crown width, yellow leaves, new leaves, leaf length, leaf width, and tiller number of functional leaves. The growth status of plants was evaluated, including leaf burns, leaf color, leaf markings, leaf gloss, and growth status.

Observation and evaluation of the ornamental effect of plants

Table 1 was the scoring standard of the ornamental effect of Zingiberaceae plants. The ornamental effect of Zingiberaceae plants was comprehensively evaluated by three scoring items, overall effect, stem and leaf growth, and flowering effect, with each accounting for 10 points.

Statistical analysis. Data were processed and charted using Microsoft Excel 2016 software, and a variance analysis and correlation analysis were performed using IBM SPSS Statistics 26.0. Duncan's new complex range test was used for the variance analysis.

Results

Effects of different nutrient solutions on physiological indexes

Figure 1 demonstrated *Kaempferia galanga* in different stages of hydroculture treated with different nutrient solutions from day 0 to day 35.

Chlorophyll and carotenoid contents. The chlorophyll and carotenoid contents are presented in Supplemental Table 1. The chlorophyll a content increased significantly across treatments during hydroponics. By day 35, increases compared with values on day 5 were 312.12% (clear water), 230.77% (general), 206.67% (Hoagland), and 152.50% (Japan garden test), with significant increases observed on day 25 or day 30, depending on the treatment.

The chlorophyll b content of *Kaempferia galanga* also showed significant increases during 35 d of hydroponics treatment, and there were significant differences among all treatments. In the clear water treatment, the chlorophyll b content increased by 1136.36% on day 35 compared with that on day 5. The general treatment showed a significant increase of 855.56%, Hoagland treatment showed an increase of 666.67%, and Japan garden test showed an increase of 550.00% by day 35.

The data in Table 2 showed that the total chlorophyll content increased significantly across all treatments, and statistically significant differences were observed. By day 35, increases of 311.36% (clear water), 216.67% (general), 193.65% (Hoagland), and 125.93% (Japan garden test) compared to values on day 5 were observed, with notable increases observed on day 25 or day 30, depending on the treatment.

The chlorophyll a/b ratio of *Kaempferia galanga* initially decreased and then increased over 35 d of hydroponics, with significant differences among treatments. By day 15, the ratio decreased by 23.36% (clear water), 15.61% (general), and 30.97% (Japan garden test); by day 35, reductions were 0.33%, 1.27%, and 12.39%, respectively. With Hoagland treatment, the ratio decreased by 19.74% on day 5 and 3.89% on day 35.

The carotenoid content in *Kaempferia galanga* increased significantly across treatments, with notable differences. By day 35, increases compared with values on day 5 were 290.91% (clear water), 275.00% (general), and 230.77% (Hoagland). The carotenoid content with Japan garden test increased significantly on day 30, and it increased by 130.77% on day 35 compared with the value on day 5.

pH value. As shown in Supplemental Table 1, the pH values of *Kaempferia galanga* in clear water, general, Hoagland, and Japan garden test treatments fluctuated during the 35-d hydroponic treatment, with significant differences among treatments. With the clear water treatment, the pH value increased by 5.25% on day 15, decreased by 5.95% on day 30, and increased slightly by 1.23% on day 35. The general treatment showed a 9.68% increase on day 10, a 1.49% decrease on day 30, and a 9.31% increase on day 35. The pH with Hoagland treatment increased by 6.74% on day 15, decreased by 1.28% on day 30, and increased by 4.92% on day 35. With the Japan garden test treatment, pH increased by 1.05% on day 15, decreased by 4.88% on day 30, and declined further by 1.57% on day 35.

Relative conductivity. As shown in Supplemental Table 1, the relative conductivity of *Kaempferia galanga* in clear water, general, Hoagland, and Japan garden test treatments initially increased and then decreased during 35 d

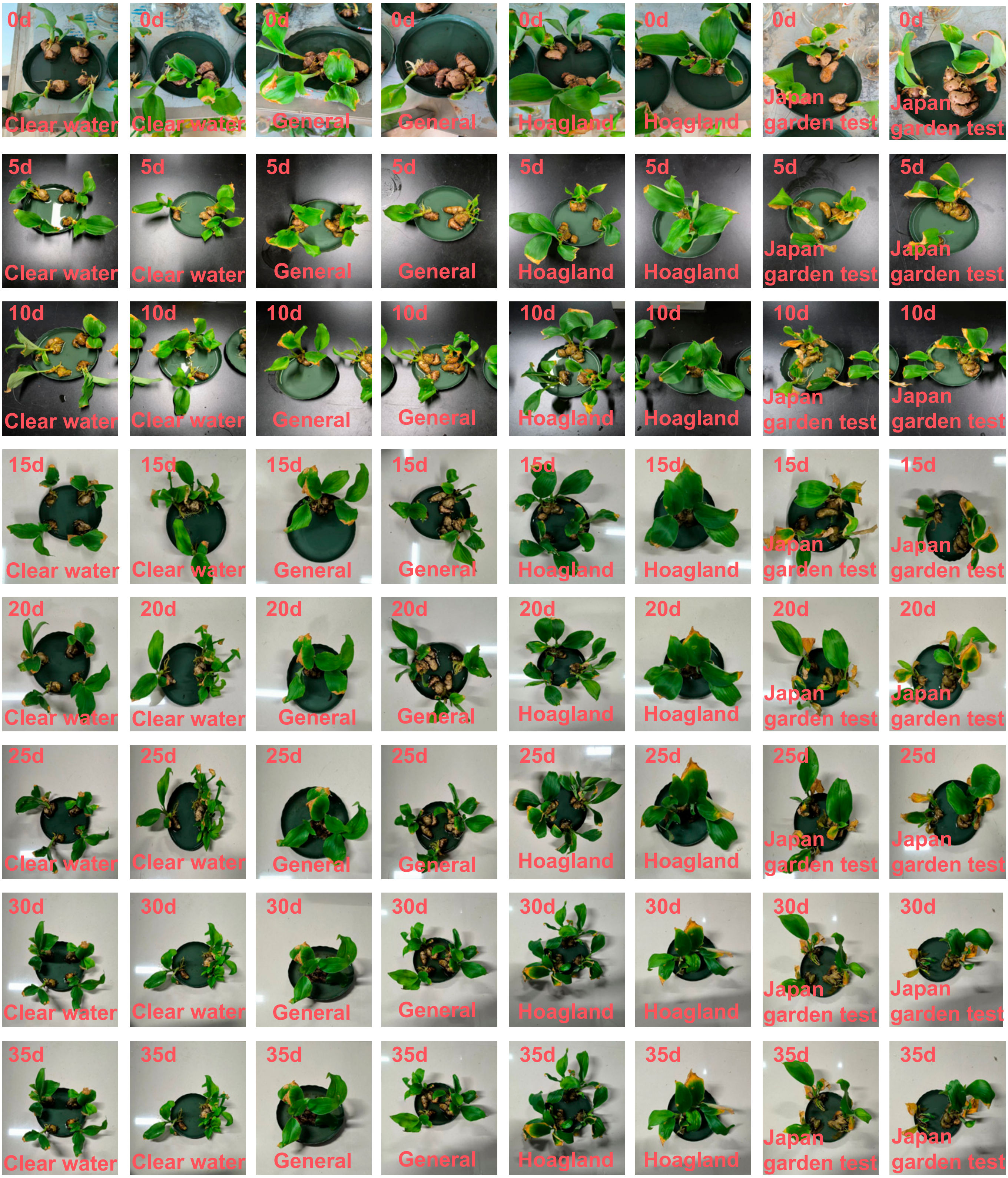

Fig. 1. Photos of *Kaempferia galanga* in different stages of hydroculture treated with different nutrient solutions.

of hydroponics treatment, and there were significant differences among all treatments. The relative conductivity with clear water, general, Hoagland, and Japan garden test increased by 11.99%, 17.28%, 7.91%, and 39.05%, respectively, on day 10 and decreased by 24.38%, 16.23%, 15.24%, and 8.92%, respectively, on day 35.

Leaf chromaticity. According to Supplemental Table 1, during the 35-d hydroponic treatment, the L*, a*, and b* values of *Kaempferia galanga* in the clear water, general, Hoagland, and Japan garden test exhibited significant differences and similar trends of fluctuation. The L* values generally decreased initially and then increased. Clear water, general, and Japan garden test showed reductions of 26.23%, 25.96%, and 23.40%, respectively, on day 25 and 9.82%, 11.67%, and 11.81%, respectively, on day 35. Hoagland's L* value decreased by 24.73% on day 10 and then increased by 1.62% on day 35. The a* values increased at first and then decreased during 35 d of hydroponics. For clear water and general treatments, they increased by 44.31% and 40.04%,

Table 2. Evaluation of the growth status of *Kaempferia galanga* treated with different nutrient solutions.

Indicators	Treat time	Clear water	General	Hoagland	Japanese garden test
Leaf color	0 d	4.3	3.3	3.3	3.3
	35 d	6.3	6.0	6.3	8.7
Leaf markings	0 d	1.3	2.3	1.0	3.7
	35 d	2.0	2.0	3.0	1.0
Blade burn	0 d	2.3	3.3	2.0	4.7
	35 d	2.7	3.7	4.7	1.7
Leaf gloss	0 d	4.3	3.3	3.7	3.0
	35 d	5.3	6.3	6.3	7.3
Growth status	0 d	5.3	4.3	5.0	3.0
	35 d	5.7	8.0	7.7	8.0

respectively, on day 25 and by 8.61% and 7.26%, respectively, on day 35 day compared with those on day 0. Hoagland and Japan garden test showed increases of 55.43% on day 10 and 8.89% and 25.55%, respectively, on day 35. The b* values decreased initially and then increased. Values with clear water and general treatments decreased by 56.48% and 56.54%, respectively, on day 25 and by 12.58% and 18.37%, respectively, on day 35. Values with Hoagland and Japan garden test declined by 60.12% and 71.65%, respectively, on day 10, with subsequent changes of +4.79% and −38.67% on day 35.

Effects of different nutrient solutions on growth indexes

Plant height. As shown in Supplemental Table 2, plant height of *Kaempferia galanga* treated with clear water initially increased and then decreased during the 35-d hydroponic treatment, with no significant difference. In contrast, plant height with general, Hoagland, and Japan garden test increased consistently; however, significant differences were observed with general and Japan garden test, but not with Hoagland. The plant height increased by 15.22% and 8.45% on day 15 and day 35, respectively, with clear water. General, Hoagland, and Japan garden test treatments resulted in increases of 34.22%, 27.26%, and 52.02%, respectively, on day 35, with the Japan garden test showing the greatest effect.

Crown width. The crown width of *Kaempferia galanga* showed a gradual increase across all treatments during the 35-d hydroponic period. Significant differences were observed only with Hoagland. The crown width with clear water, general, and Japan garden test increased by 39.75%, 42.09%, and 52.80%, respectively, on day 35. Crown width with Hoagland increased by 90.13% on day 35, and the effect was the best among all treatments (Supplemental Table 2).

Leaf dimensions. Leaf length increased steadily with all treatments, with significant differences observed for general and Japan garden test treatments, but not for clear water or Hoagland (Supplemental Table 2). On day 35, leaf length increased by 3.38% and 28.61% with clear water and Hoagland treatments, respectively, and by 58.61% and 63.83% with general and Japan garden test treatments, respectively, with Japan garden test treatment being the most effective. Leaf width also showed a steady increase with all treatments, without significant differences. Maximum growth rates were observed on day 30 with clear water (6.09%) and Hoagland (14.11%) and on day 35 with general (36.31%) and Japan garden test (30.59%).

Leaf sheath length. As shown in Supplemental Table 2, the leaf sheath length increased progressively across all treatments during the 35 d, with significant differences observed with all treatments except clear water. The leaf sheath length observed with clear water, general, Hoagland, and Japan garden test increased by 125.40%, 102.74%, 149.51%, and 134.41%, respectively, on day 35 compared with that on day 0.

Stem and leaf number. As shown in Supplemental Table 3, the number of stems and leaves increased gradually across all treatments. Significant differences were observed with all treatments except the clear water treatment. The number of stems and leaves per branch under the clear water treatment increased by 39.52% on day 35 compared with the initial measurement. On days 30, 20, and 25, the number of stems and leaves per branch reached three with the general, Hoagland, and Japan garden test treatments, representing increases of 79.64%, 79.64%, and 50.00%, respectively, compared with day 0.

New leaf number. In the clear water group, new leaf growth was concentrated between days 5 and 20, peaking on day 20. In the general nutrient group, growth occurred mainly between days 25 and 35. Hoagland treatment showed continuous growth from days 5 to 35, with the highest rate on day 30. With the Japan garden test treatment, new leaves grew consistently between days 20 and 30 (Supplemental Table 3).

Number of yellow leaves. The yellow leaf number of *Kaempferia galanga* increased across all treatments, with significant differences observed only in the Hoagland group (Supplemental Table 3). In the clear water group, yellow leaves gradually increased from days 5 to 35, reaching an average of 1.67 by day 30. In the general group, the number increased from 1.33 on day 0 to 2.33 by day 15, with no further increase. In the Hoagland group, yellow leaves increased continuously from 0.67 on day 0 to 4.67 on day 35 (597.01% increase). The Japan garden test also showed continuous increases, with yellow leaves increasing from 2.00 on day 0 to 5.33 on day 30 (166.50% increase).

Tiller number. As shown in Supplemental Table 3, the total tiller number increased gradually over 35 d in the general, Hoagland, and Japan garden test treatments, but no change occurred in the clear water group. The tiller number in the clear water group remained at 2.33, while increases of 50.00%, 99.63%, and 114.59% were observed in the general, Hoagland, and Japan garden test treatments, respectively, by day 35.

Fresh weight. The fresh weight of *Kaempferia galanga* increased in all treatments during the 35-d hydroponic period, with no significant differences among treatments (Supplemental Table 3). Fresh weight increased by 13.57%, 44.14%, 35.72%, and 30.44% in the clear water, general, Hoagland, and Japan garden test treatments, respectively, compared with values on day 0.

Evaluation of growth status

The growth status included leaf color, markings, burn, glossiness, and growth status. The related data were presented in Table 2.

Leaf color. The leaf color showed a gradual deepening trend from fresh green to dark

Table 3. Scoring standard of the ornamental effects of Zingiber plants.

Project	Indicators	Difference (1–2 points)	Poor (3–4 points)	Medium (5–6 points)	Better (7–8 points)	Good (9–10 points)
Overall effect	Plant height	Shorter	Shorter	Medium	Higher	Higher
	Crown width	Small range	Smaller range	Medium	Wider range	Wide range
	Number of tillers	Less	Less	Medium	More	More
	Plant type	Uneven	Scattered	Roughly neat	More neat	Neat
	Growth status	Poor	Poor	General	Better	Good
Growth status of stems and leaves	Leaf shape	Scattered	Poor	General	Better	Graceful
	Leaf color	Yellowish	Yellow–green	Light green	Bright green	Thick green
	Leaf markings	Multiple markings	More markings	Medium	Less markings	No markings
	Blade burn	Severe burns	Severe burns	Medium	Minor burns	No burns
	Leaf gloss	None	Not obvious	General	More obvious	Obvious

Table 4. Scores and rankings of ornamental effects of each treatment.

Project	Indicators	Clear water	General	Hoagland	Japanese garden test
Overall effect	Plant height	4	7	7	8
	Crown width	2	4	9	6
	Number of tillers	2	4	8	7
	Plant type	6	8	8	6
	Growth status	6	8	7	8
Growth status of stems and leaves	Leaf shape	7	8	8	7
	Leaf color	7	6	7	9
	Leaf markings	8	8	7	9
	Blade burn	8	7	6	9
	Leaf gloss	5	6	6	7
Total score		55	66	73	76
Sort		4	3	2	1

green and then to thick green. By day 35, the color scores of each treatment increased by 46.51%, 81.82%, 90.91%, and 163.64% in the clear water, general, Hoagland, and Japan garden test treatments, respectively, compared with values on day 0.

Leaf markings. Leaf markings improved under the clear water and Hoagland treatments, with score increases of 53.85% and 200.00%, respectively, by day 35. In contrast, the general and Japan garden test treatments exhibited reductions in the later period, with scores decreasing by 13.04% and 72.97%, respectively, compared with those on day 0.

Leaf burn. Leaf burn severity did not significantly change under the clear water treatment, but it progressively worsened under the Hoagland treatment and decreased under the Japan garden test treatment. The burn scores increased by 135.00% in Hoagland but decreased by 63.83% in Japan garden test by day 35 compared with those on day 0.

Leaf glossiness. Leaf glossiness of *Kaempferia galanga* displayed a gradual improvement across all treatments, with score increases of 23.26% (clear water), 90.91% (general), 70.27% (Hoagland), and 143.33% (Japan garden test) on day 35 compared with day 0.

Growth status. The growth status of *Kaempferia galanga* remained largely unchanged under clear water treatment, whereas it improved significantly under general, Hoagland, and Japan garden test, showing a trend from medium to excellent. The growth status scores of each formula treatment increased by 7.55%, 86.05%, 54.00%, and 166.67%, respectively, by day 35 compared with day 0.

Effects of different nutrient solutions on ornamental effects. The ornamental effect of hydroponic *Kaempferia galanga* was comprehensively evaluated using two scoring items: overall ornamental effect and stem and leaf growth. Initially, the scoring system included flowering effect, but because *Kaempferia galanga* is a foliage plant and did not reach the flowering stage during the experiment, the evaluation was adjusted to exclude this criterion. Each scoring item was set up with five indexes, with each index comprising 10 points. Based on these criteria, an ornamental effect scoring system was established to comprehensively evaluate the performance of hydroponic *Kaempferia galanga* under different nutrient solution treatments. The specific scoring standards are shown in Table 3, and the scoring results are shown in Table 4.

The results showed that each nutrient solution treatment promoted the ornamental effect of *Kaempferia galanga* plants in different degrees. Based on the comprehensive evaluation, the Japan garden test ranked first, followed by Hoagland, general, and clear water treatments.

Correlation analysis among different indexes of *Kaempferia galanga* under the Japanese garden test treatment

Chlorophyll a in *Kaempferia galanga* was positively correlated with chlorophyll b, total chlorophyll, and carotenoid content, but negatively correlated with pH value and relative conductivity under the Japanese garden test treatment (Table 5). Chlorophyll b also showed positive correlations with total chlorophyll and carotenoid content, and negative correlations with pH and relative conductivity. Total chlorophyll was positively correlated with carotenoid content, and negatively associated with pH and relative conductivity. The chlorophyll a/b ratio was positively correlated with L* and B*, but negatively correlated with relative conductivity and A*. Carotenoid content was negatively correlated with pH value and relative conductivity. A significant positive correlation was observed between pH and relative conductivity. Furthermore, L* was positively correlated with b* and negatively correlated with A*.

As shown in Table 6, the plant height of *Kaempferia galanga* under the Japanese garden test treatment was positively correlated with crown width, leaf length, leaf width, stem leaf number per branch, new leaf number, yellow leaf number, tiller number, and fresh weight. Crown width was positively correlated with leaf length, leaf width, number of new leaves, number of yellow leaves, number of tillers, and fresh weight. Similarly, leaf length showed positive correlations with leaf width, number of stem leaves per branch, number of new leaves, number of yellow leaves, number of tillers, and fresh weight. Leaf width was positively correlated with yellow leaf number, tiller number, and fresh weight. The number of stem leaves per branch exhibited significant positive correlations with new leaves, yellow leaves, and tillers. Furthermore, yellow leaf number was positively correlated with tiller number and fresh weight. A strong positive correlation was observed between tiller number and fresh weight.

Discussion

This study investigated the effects of different nutrient solutions on the physiological indices, leaf color, plant growth, and ornamental value of *Kaempferia galanga*. The results showed that the Hoagland and Japan garden test nutrient solutions significantly enhanced chlorophyll content, carotenoid content, crown width, number of stems and leaves per branch and leaf, leaf sheath length, number of yellow leaves, leaf color, and leaf surface luster, and that growth was in good condition. Over the 35-d hydroponic period, plants treated with the Japan garden test solution exhibited the best leaf color, greater crown width, and highest ornamental effect scores. Therefore, the Japanese garden test was preferred as the hydroponic nutrient solution for *Kaempferia galanga*, followed by Hoagland nutrient solution.

The findings align with those of prior studies that demonstrated the role of well-balanced nutrient solutions in enhancing plant physiological functions (Ahmadi et al. 2024; Ruiz and Salas Sanjuan 2022). For instance,

Table 5. Correlation analysis of physiological indexes of the Japanese garden test treatment.

Indicators	Chlorophyll a content	Chlorophyll b content	Total chlorophyll content	Chlorophyll content ratio	Carotenoid content	pH value	Relative conductivity	*L**	*a**
Chlorophyll b content	0.966**								
Total chlorophyll content	0.990**	0.985**							
Chlorophyll content ratio	0.023	−0.189	−0.069						
Carotenoid content	0.973**	0.935**	0.958**	0.103					
pH value	−0.487*	−0.484*	−0.504*	−0.018	−0.566**				
Relative conductivity	−0.562**	−0.478*	−0.542**	−0.541**	−0.609**	0.439*			
*L**	−0.084	−0.165	−0.111	0.468*	0.035	0.081	−0.312		
*a**	0.117	0.212	0.155	−0.506*	−0.001	−0.068	0.333	−0.987**	
*b**	−0.134	−0.231	−0.176	0.521**	−0.021	0.126	−0.306	0.978**	−0.990**

*$P < 0.05$ and **$P < 0.01$ indicate levels of statistical significance for Pearson correlation coefficients.

Table 6. Correlation analysis of growth indexes of the Japanese garden test treatment.

Indicators	Plant height	Crown width	Leaf length	Leaf width	Number of stems and leaves per branch and leaf	Leaf sheath length	Number of new leaves	Yellow leaf number	Number of tillers
Crown width	0.659**								
Leaf length	0.866**	0.723**							
Leaf width	0.441*	0.744**	0.647**						
Number of stems and leaves per branch and leaf	0.757**	0.36	0.782**	0.312					
Leaf sheath length	0.351	−0.011	0.243	0.149	0.391				
Number of new leaves	0.473*	0.514*	0.473*	0.272	0.488*	0.139			
Yellow leaf number	0.759**	0.820**	0.800**	0.542**	0.488*	−0.155	0.309		
Number of tillers	0.740**	0.724**	0.728**	0.408*	0.518**	−0.222	0.312	0.948**	
Fresh weight	0.548**	0.880**	0.599**	0.840**	0.256	−0.054	0.334	0.741**	0.672**

*$P < 0.05$ and **$P < 0.01$ indicate levels of statistical significance for Pearson correlation coefficients.

studies have shown that the nitrogen and potassium contents in Hoagland solution significantly increases chlorophyll synthesis and photosynthetic performance (Sahi and Mostajeran 2021; Yue et al. 2022). Consistent with this point, our results revealed a significant increase in chlorophyll a and chlorophyll b contents, as well as better leaf coloration under Hoagland treatment. The exceptional performance of the Japan garden test solution may be attributed to its balanced trace elements (e.g., iron, zinc, magnesium) and plant growth regulators, which likely enhanced nutrient absorption and stress resilience. These factors directly contributed to improved leaf coloration and glossiness as well as reduced relative conductivity, indicating better membrane stability. The observed adaptability to nutrient pH changes further underscored the role of solutions in mitigating nutrient stress (Khan et al. 2023). Compared with the clear water and general nutrient solutions, both the Hoagland and Japan garden test solutions promoted superior plant growth and ornamental value, which aligned with previous studies that indicated that adequate calcium content reduces cell membrane damage and increases antioxidant enzyme activity (Ji et al. 2024). These physiological advantages directly translate into enhanced visual and commercial appeal, making these nutrient solutions highly suitable for the ornamental and economic cultivation of Zingiberaceae plants.

While this study provides valuable insights, several limitations must be acknowledged. The 35-d cultivation period may not fully capture the development of underground rhizomes, which are essential for storage and medicinal value. In addition, the experiment was conducted under ideal environmental conditions, which may not reflect the variability of real-world cultivation systems. The analysis also focused primarily on aerial physiological and ornamental traits and did not assess parameters such as root morphology, rhizome biomass, or microbial interactions.

Future studies should extend the cultivation period and incorporate rhizome-related traits, including morphology, dry matter yield, and essential oil composition. Trials under greenhouse or open-field conditions are also recommended to evaluate the practical applicability of hydroponic systems. Given the promising results of the Japanese garden test nutrient solution, further optimization may benefit both the ornamental and medicinal cultivation of *Kaempferia galanga* and potentially other Zingiberaceae species.

Conclusion

This study demonstrated that nutrient solutions significantly influenced the growth and ornamental quality of *Kaempferia galanga*. Among the treatments, the Japan garden test nutrient solution exhibited the best performance because it achieved the highest scores for plant color, crown width, and overall ornamental value, followed closely by the Hoagland solution. These findings provided a scientific basis for selecting and optimizing nutrient solutions, thus offering practical guidelines for hydroponic cultivation of *Kaempferia galanga* and related Zingiberaceae plants with high ornamental and commercial potential. Further investigations of rhizome development traits may help expand the potential for integrated ornamental and medicinal cultivation applications.

References Cited

Ahmadi A, Vojodimehrabani L, Razmi N. 2024. The effect of pumice application and foliar spraying with algae extract and Hoagland solution on growth traits and yield of soybeans (*Glycine max*). J Agric Sci Sustain Prod. 34(2):47–67. https://doi.org/10.22034/SAPS.2023.58293.3107.

Al Meselmani MA. 2022. Nutrient solution for hydroponics. Recent research and advances in soilless culture. IntechOpen. http://dx.doi.org/10.5772/intechopen.101604.

Chu H, Hung N, Hanh N, Nguyen K, Tam N. 2023. Effect of fertilizers on growth and essential oil productivity of Coriandrum sativum L. and *Kaempferia galanga* L. in Vietnam. https://doi.org/10.15625/vap.2023.0013.

Ekowati J, Widyowati R, Norhayati, Jain SK. 2023. Chemopreventive Practices in Traditional Medicine. In: Izah SC, Ogwu MC, Akram M (eds). Herbal medicine phytochemistry. Reference series in phytochemistry. Springer, Cham. https://doi.org/10.1007/978-3-031-21973-3_28-1.

Gangmei D, Sanabam R, Singh NS. 2025. Phytochemical and medicinal significance of Kaempferia: a review of its origin, distribution, and morpho-taxonomy in India. Genet Resour Crop Evol. 72:3845–3874. https://doi.org/10.1007/s10722-024-02198-7.

Ji K, Wei J, Fan Z, Zhu M, Yuan X, Zhang S, Li S, Xu H, Ling Y. 2024. Preservative effects of curcumin on semen of hu sheep. Animals (Basel). 14(6):947. https://doi.org/10.3390/ani14060947.

Kailashkumar B, Priyadharshini K, Logapriya M. 2023. Hydroponic cultivation: Factors affecting its success and efficacy. IJECC. 13(10): 2403–2410. https://doi.org/10.9734/ijecc/2023/v13i102905.

Khan F, Siddique AB, Shabala S, Zhou M, Zhao C. 2023. Phosphorus plays key roles in regulating plants' physiological responses to abiotic stresses. Plants (Basel). 12(15):2861. https://doi.org/10.3390/plants12152861.

Naresh R, Jadav SK, Singh M, Patel A, Singh B, Beese S, Pandey SK. 2024. Role of hydroponics in improving water-use efficiency and food security. IJECC. 14(2):608–633. https://doi.org/10.9734/ijecc/2024/v14i23976.

Pham NK, Nguyen HT, Nguyen QB. 2021. A review on the ethnomedicinal uses, phytochemistry and pharmacology of plant species belonging to *Kaempferia* L. genus (Zingiberaceae). Pharmaceutical Sciences Asia. 48(1). https://doi.org/10.29090/psa.2021.01.19.070.

Rajaseger G, Chan KL, Yee Tan K, Ramasamy S, Khin MC, Amaladoss A, Kadamb Haribhai P. 2023. Hydroponics: Current trends in sustainable crop production. Bioinformation. 19(9):925–938. https://doi.org/10.6026/97320630019925.

Ruiz JL, Salas Sanjuan MDC. 2022. The use of plant growth promoting bacteria for biofertigation; effects on concentrations of nutrients in inoculated aqueous vermicompost extract and on the yield and quality of tomatoes. Biol Agric Hortic. 38(3):145–161. https://doi.org/10.1080/01448765.2021.2010596.

Sahi N, Mostajeran A. 2021. The role of potassium and ascorbic acid on some growth and physiological responses in *Catharanthus roseus*. Iranian J Plant Physiol. 11(2):3599–3615. https://doi.org/10.22034/IJPP.2021.681098.

Sahul Hamid LS, Jalil J, Abdul Wahab SM, Azmi N, Yaakob NS. 2023. Comparative HPLC Analysis of 6-Gingerol and 6-Shogaol in Soil-Based and Soilless-Grown Ginger. J Medicinal Plants By-products. 12(4):319–328. https://doi.org/10.22034/jmpb.2023.362686.1577.

Saitama A, Saptadi D, Maghfoer MD and Widaryanto E., 2024. Potential for production of Kencur (*Kaempferia galanga* L.) secondary metabolites with auxin and cytokinin in vitro. IJAB. 13(4): 717–726. https://doi.org/10.47278/journal.ijab/2024.174.

Sangeetha T, Periyathambi E. 2024. Automatic nutrient estimator: Distributing nutrient solution in hydroponic plants based on plant growth.

PeerJ Comput Sci. 10:e1871. https://doi.org/10.7717/peerj-cs.1871.
Sankhalkar S, Jamuni V. 2024. Hydroponics: A sustainable approach for plant cultivation, p 3–13. In: Hydroponics: The future of sustainable farming. Springer, New York, NY, USA. https://doi.org/10.1007/978-1-0716-3993-1_1.
Suwardi AB, Navia ZI, Mubarak A, Mardudi M. 2023. Diversity of home garden plants and their contribution to promoting sustainable livelihoods for local communities living near Serbajadi protected forest in Aceh Timur region, Indonesia. Biol Agric Hortic. 39(3):170–182. https://doi.org/10.1080/01448765.2023.2182233.
Wang S-Y, Zhao H, Xu H-T, Han X-D, Wu Y-S, Xu F-F, Yang X-B, Göransson U, Liu B. 2021. *Kaempferia galanga* L.: Progresses in phytochemistry, pharmacology, toxicology and ethnomedicinal uses. Front Pharmacol. 12:675350. https://doi.org/10.3389/fphar.2021.675350.
Yue H-F, Zhou M, Hou X-K, Yang X, Zhao H, Xu M-S, Wang L, Liu H-M, Wuyun T-N, Zhu G-P, Li F-D. 2022. Effects of nitrogen, phosphorus and potassium on phenotype, photosynthesis and biomass accumulation at juvenile phase of *Prunus Armeniaca* × *Sibirica*. Pak J Bot. 54(2):577–588. https://doi.org/10.30848/PJB2022-2(11).