

ARTICLE

Nanosilica enhances growth, leaf epidermal traits, and disease resistance in *Aglaonema* cultivars

Nanosilica potencializa o crescimento, as características epidérmicas das folhas e a resistência a doenças em cultivares de *Aglaonema*

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Abstract

Aglaonema is a high-value ornamental foliage plant showing considerable variation in growth and physiological responses among cultivars. Silica is a beneficial element that enhances plant growth, strengthens tissues, improves photosynthetic efficiency, and increases resistance to biotic and abiotic stresses. The effects of foliar application of nanosilica (SiO₂) on growth, leaf epidermal characteristics, and disease resistance of *Aglaonema* were evaluated. The experiment was conducted using a split-plot design arranged in a randomized complete block design, with four nanosilica concentrations (0, 0.3, 0.6 and 0.9 g L⁻¹) as main plots and sixteen cultivars as subplots. Significant differences among cultivars were found in plant height, number of leaves, leaf length, chlorophyll a, chlorophyll b, total chlorophyll, chlorophyll a/b ratio, and carotenoid content. Nanosilica at 0.3 g L⁻¹ produced the highest in plant height, stomatal density, chlorophyll a/b ratio, and carotenoids, while 0.6 g L⁻¹ enhanced epidermal thickness and chlorophyll content. The highest concentration, 0.9 g L⁻¹, increased leaf length and width, stomatal index, and reduced incidence and severity of *Lepidosaphes beckii*, *Ceroplastes rubens*, *Pseudococcidae*, anthracnose, and stem rot. Interactions between cultivars and nanosilica were significant for leaf width, epidermal thickness, stomatal index, and stomatal density. Correlation analysis showed positive relationships among leaf size, plant height, stomatal density, and chlorophyll content. Considering consumer preference for compact plants with broad leaves and high resistance to pests and diseases, the foliar application of nanosilica at 0.9 g L⁻¹ is deemed the most suitable concentration.

Keywords: Araceae, beneficial element, micromorphology, nanotechnology, ornamental plant, plant resistance.

Resumo

Aglaonema é uma planta ornamental de alto valor, com variação no crescimento e nas respostas fisiológicas entre cultivares. A sílica é um elemento benéfico que melhora o crescimento, fortalece tecidos, aumenta a eficiência fotossintética e resistência a estresses bióticos e abióticos. Este estudo avaliou os efeitos da aplicação de nanosilica (SiO₂) no crescimento, características epidérmicas das folhas e resistência a doenças da *Aglaonema*. O experimento foi conduzido em delineamento de parcelas subdivididas, disposto em delineamento em blocos casualizados, com quatro concentrações de nanosilica (0; 0,3; 0,6; 0,9 g L⁻¹) como parcelas principais e 16 cultivares como subparcelas. Houve diferenças significativas entre as cultivares para altura da planta, número de folhas, comprimento das folhas, clorofila a, clorofila b, clorofila total, relação clorofila a/b e carotenóides. A nanosilica a 0,3 g L⁻¹ aumentou altura da planta, densidade estomática, relação clorofila a/b e carotenóides, enquanto 0,6 g L⁻¹ elevou espessura epidérmica e teor de clorofila. A concentração alta (0,9 g L⁻¹) aumentou comprimento e largura das folhas, índice estomático, resistência a *Lepidosaphes beckii*, *Ceroplastes rubens* e *Pseudococcidae*, além de reduzir antracnose e podridão do caule. As interações cultivares × nanosilica foram significativas para largura da folha, espessura epidérmica, índice e densidade estomática. A análise de correlação revelou relações positivas entre tamanho da folha, altura da planta, densidade estomática e teor de clorofila. Considerando a preferência do consumidor por plantas compactas, folhas largas e alta resistência a pragas e doenças, a aplicação foliar de nanosilica a 0,9 g L⁻¹ é recomendada como concentração adequada.

Palavras-chave: Araceae, elemento benéfico, micromorfologia, nanotecnologia, planta ornamental, resistência de plantas.

Introduction

Aglaonema is a tropical ornamental plant of the *Araceae* family, nicknamed the “Queen of Leaves”. The beauty of its patterns and color variations is the main attraction for consumers. *Aglaonema* production in Indonesia in 2024 reached 1.42 million plants with a harvest area of 208,050 m². This figure is lower than the 2023 production, which reached 1.59 million plants with a harvest area of 200,6 m² (Wibowo et al., 2024). This condition indicates that an increase in harvest area is not always accompanied by an increase in production, underscoring the importance of growth efficiency and plant quality in cultivation efforts. The demand for *Aglaonema* continues to increase in line with improving community welfare and the development of the ornamental plant market (Saputra et al., 2025). *Aglaonema*, as an ornamental plant both indoors and outdoors, has high economic value. *Aglaonema* prices are volatile and follow complex patterns influenced by consumer trends, stock availability, and market conditions (Sugiarti et al., 2025).

This plant also tolerates low light and humidity, which increases its appeal as an indoor plant. Plant propagation is a significant obstacle for *Aglaonema* ornamental plant producers (Apriany et al., 2023). *Aglaonema* has a low success rate in generative propagation due to asynchronous flowering and low pollen viability. Growers generally propagate *Aglaonema* through cuttings, which is one of the most efficient

propagation techniques (Sarkar et al., 2022). The diversity of growth responses among *Aglaonema* cultivars after cuttings requires more specific fertilization and nutrient management strategies. These responses can include the emergence of several diseases, such as anthracnose, stem rot, or slow root formation due to biotic stress.

Growth and quality can be improved by using silica (Si). Si is a beneficial element that is absorbed by plants in the form of monosilicic acid (Si(OH)₄). The application of silica nanoparticles (SiO₂) measuring 1-100 nm in size has the potential to improve plant quality. SiO₂ can strengthen leaf tissue, increase photosynthetic efficiency, optimize the absorption of macro- and micronutrients, and stimulate plant biochemical defenses against pathogens and pests. Foliar application of SiO₂ can be absorbed directly through stomata, providing higher absorption efficiency than through roots (Niu et al., 2021). Physically, SiO₂ deposited in leaf tissue can increase rigidity and roughen the leaf surface, making leaves less palatable and more difficult for insects to eat (Reynolds et al., 2016).

This study aims to evaluate the effects of foliar SiO₂ application on the growth, leaf epidermal characteristics, and disease resistance of 16 *Aglaonema* cultivars; identify differences in cultivar responses to SiO₂; and determine the effective concentration of SiO₂ for improving growth quality and disease resistance.

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Material and Methods

Experimental design

The study employed a split-plot design arranged in a randomized complete block design (RCBD). The first factor, the main plot, was nanosilica (SiO₂) concentration at four levels: 0 g L⁻¹, 0.3 g L⁻¹, 0.6 g L⁻¹, and 0.9 g L⁻¹. The second factor as subplots was 16 *Aglaonema* cultivars, namely Adelia (A1), Red Borju (A2), Big Papa (A3), Big Roy (A4), Snow White (A5), Venus (A6), Big Roy White (A7), Yok Kanchana (A8), Diven Silver (A9), Silver Queen (A10), Emerald Bay (A11), Lipstik Manilompek (A12), Lipstik Pink (A13), Cochin Tembaga (A14), Siam Aurora (A15), and Striptease (A16). There are 64 treatment combinations, each repeated three times, for a total of 192 experimental units. Each experimental unit consists of a single plant, yielding 192 observation units.

Experimental procedures

A total of 12 plants from each genotype were cut to obtain uniform planting material. The criteria for cuttings were that they had three leaves and no roots. The bottom end of the cuttings was dipped in 70% propineb paste to prevent decay, then coated with *Mozambique tilapia* mud to maintain stability during root formation. The cuttings were planted in a mixture of raw rice husks, dry compost, and bamboo leaves in a 1:1:1 (v/v/v) ratio in 17 cm pots. Plant maintenance included watering once a week, manual weeding, and spraying with an insecticide containing 500 g L⁻¹ profenofos and 1 mL L⁻¹ vitamin B₁. Spraying was carried out every two weeks at a rate of 10 mL per plant for four weeks. Four-week-old cuttings were used as experimental material for foliar application of SiO₂. SiO₂ was sprayed onto the entire plant surface at a rate of 125 mL per plant once a week. The silica nanoparticles used had a particle size of ±10 nm with a purity level of 99.8%. Each treatment solution was added with compound leaf fertilizer with NPK (20-15-15) at 2 g L⁻¹. All research activities were conducted in a greenhouse with an average temperature of 19.43-25.77 °C. Observations were made periodically every two weeks from the start of the SiO₂ application and lasted for 24 weeks.

Aglaonema growth

The variables observed included plant height and leaf number. Plant height (cm) was measured from the base of the stem to the tip of the tallest leaf using a ruler. The number of leaves (sheets) was counted manually by recording each new leaf that emerged and fully opened.

Morphophysiological characteristics of leaves

The variables observed included length, width, epidermal thickness, and leaf moisture content. Observations were made on leaves in the 2nd, 3rd, and 4th positions from the tip based on the Guide to Ornamental Plant Characterization published by the Indonesian Ministry of Agriculture's Agricultural Research and Development Agency (Kartikaningrum et al., 2014). Leaf length (cm) was measured on the longest leaf from the base to the tip of the fully opened leaf. Leaf width (cm) was measured at the widest part of each fully opened leaf. Epidermis thickness (μm)

was observed on the middle part of the leaf cut transversely and observed using an Olympus CX23 microscope at 10× magnification (Ningsih and Daningsih, 2022). Leaf moisture content (%) was based on oven-dried weight at 60 °C until constant moisture content.

Leaf epidermal characteristics

The variables observed included stomatal index (%) and stomatal density (mm⁻²). The underside of the second leaf from the tip was coated with nail polish twice. The first coating was applied to remove dirt or dust from the leaf surface. After the first layer of nail polish was cleaned with a cotton swab, the leaf surface was coated again with nail polish and left to dry for 20-30 minutes. The dried nail polish layer was then removed with a clear cotton swab and placed on a microscope slide for microscopic observation. The stomata sample preparation is observed using an Olympus CX23 microscope at 40× magnification with a field of view diameter of 0.5 mm. The stomata index and density can be calculated using the following equation:

$$I = \frac{S}{E + S} \times 100\%$$

Description: I = stomatal index, S = number of stomata per field of view, and E = number of ordinary epidermal cells per field of view.

$$\text{Stomata density (mm}^{-2}\text{)} = \frac{\text{Total number of stomata}}{\text{Field of view area (mm}^2\text{)}}$$

The field of view area was calculated using the formula for the area of a circle (area = πr²).

Chlorophyll and carotenoid content (μg mL⁻¹)

A total of 0.5 g of fresh leaf tissue was crushed together with 10 mL of 80% acetone until homogeneous. The extract obtained was then incubated for 16-24 hours at 4 °C. After incubation, the extract was centrifuged at 6000 rpm for 7 minutes. The absorbance of the centrifugation supernatant was measured using a UV-1280 spectrophotometer (Shimadzu) at wavelengths of 470, 663.2, and 646.8 nm. Pigment content was then calculated using the equation (Lichtenthaler, 1987):

$$\begin{aligned} C_a &= 12.25 A_{663.2} - 2.79 A_{646.8} \\ C_b &= 21.50 A_{646.8} - 5.10 A_{663.2} \\ C_{a+b} &= 7.15 A_{663.2} + 18.71 A_{646.8} \\ C_{x+c} &= (1000 A_{470} - 1.82 C_a - 85.02 C_b) / 198 \end{aligned}$$

Incidence and severity of plant pests (%)

Incidence is calculated as the percentage of plants affected by pests and diseases among the total number of plants observed.

$$\text{Incidence (\%)} = \frac{\text{Number of affected plants}}{\text{Total number of plants}} \times 100\%$$

The severity of anthracnose disease on leaves is measured using a scale of 0-6 based on the level of leaf damage (Table 1).

Table 1. Description of the anthracnose disease rating scale (Mounika et al., 2017).

Scale	Description	Resistance Class
0	No infection or 0% infection	Resistant
1	1%-5% of leaf area/length covered by disease	Very resistant
2	6%-10% of leaf area/length covered by disease	Tolerant
3	11%-25% leaf area/length covered by disease	Moderately resistant
4	26%-50% leaf area/length covered by disease	Moderately susceptible
5	51%-75% leaf area/length covered by disease	Susceptible
6	76%-100% leaf area/length covered by disease	Highly susceptible

Data Analysis

Data analysis was performed using STAR (Statistical Tool for Agricultural Research) software, Microsoft Excel 2021, and ImageJ. Data were analyzed using the F test at α = 0.05 to determine the effect of treatment. If the F-test results indicated a significant difference, the analysis continued with Tukey's Honest Significant Difference (HSD) test. Correlation analysis was performed to measure the relationship between two or more observed variables.

Results and Discussion

Aglaonema growth

The SiO₂ application also significantly affected plant height (Fig. 1A). The highest average was observed at 0.3 g L⁻¹ (35.14 cm), followed by 0.9 g L⁻¹ (33.91 cm) and 0.6 g L⁻¹ (32.99 cm). Increasing the concentration above 0.3 g L⁻¹ did not provide any significant additional effects. This is in line with the research by Le et al. (2014), which found that increasing the SiO₂ concentration (≥0.5 - 2 g L⁻¹) reduced plant height

due to an imbalance of essential nutrients. Tesfagiorgis et al. (2013) also reported that increased SiO_2 concentration in nutrient solutions caused nutrient imbalance and SiO_2 accumulation in leaves that exceeded C and O elements.

The heights of *Aglaonema* plants show significant differences among cultivars, ranging from 22.81 to 45.53 cm (Fig. 1B). According to the Ornamental Plant Characterization Guide, *Aglaonema* plant height varies among cultivars: short (<30 cm), medium (30–50 cm), and tall (>50

cm) (Kartikaningrum et al., 2014). The results of this study show that there are only two categories of plant height, namely short and medium cultivars. The Snow White (22.81 cm), Adelia (25.13 cm), Venus (26.01 cm), Cochin Tembaga (27.07 cm), and Siam Aurora (27.20 cm) cultivars were classified as short. The other cultivars were in the medium category, with Silver Queen (45.53 cm) as the tallest. The difference in plant height indicates that genetic factors among *Aglaonema* cultivars significantly affect vegetative growth (Mitache et al., 2024).

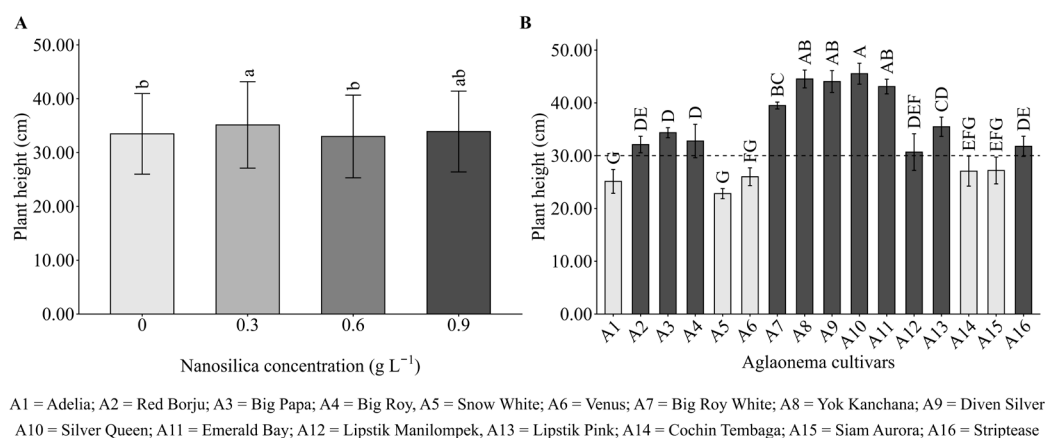


Fig. 1. Growth response of 16 *Aglaonema* cultivars after 24 weeks of SiO_2 application. (A) Plant height response (cm), (B) SiO_2 application response to plant height. Vertical lines (bars) indicate standard error, different letters above the bars indicate significant differences based on Tukey's test ($\alpha = 0.05$).

The number of *Aglaonema* leaves differed significantly among cultivars, ranging from 5.75 to 9.50 (Fig. 2). The highest number of leaves was found in Striptease (9.50) and Siam Aurora (9.25), followed by Red Borju (8.92). The cultivars with the fewest leaves were Cochin Tembaga (5.75), Adelia (6.63), and Big Roy (6.75). The SiO_2 application did not show a consistent pattern of increase in leaf number across cultivars. SiO_2 application had no significant effect on the number of leaves, with

the highest average number of leaves observed in the control (8.31) and a slight decrease at higher concentrations: 0.3 g L^{-1} (8.02), 0.6 g L^{-1} (7.82), and 0.9 g L^{-1} (7.85). This indicates that the primary influence on the number of leaves stems from genetic differences among *Aglaonema* cultivars. In contrast, the addition of SiO_2 did not significantly affect this variable (Sembiring et al., 2025).

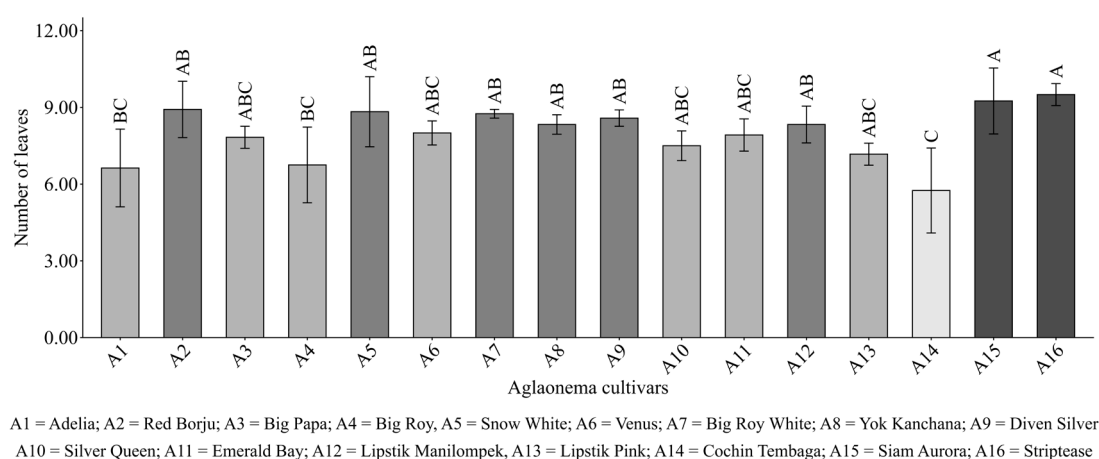


Fig. 2. Response number of leaves in 16 *Aglaonema* cultivars after 24 weeks of SiO_2 application. Vertical lines (bars) indicate standard error, different letters above the bars indicate significant differences based on Tukey's test ($\alpha = 0.05$).

Morphophysiological characteristics of leaves

The length of *Aglaonema* leaves shows significant differences between cultivars, ranging from 13.69 to 25.50 cm (Fig. 3A). Based on the classification by Kartikaningrum et al. (2014), most cultivars fall into the short leaf category (<20 cm), namely Snow White (13.69), Venus (14.08), Cochin Tembaga (14.34), Adelia (14.51), Siam Aurora (14.68), Red Borju (15.68), Striptease (16.14), Lipstik Manilompek (16.70),

Big Papa (17.60), Big Roy (18.00), Lipstik Pink (18.54), and Big Roy White (18.91). Medium-leaf cultivars (20–25 cm) consist of Diven Silver (21.28), Yok Kanchana (22.49), and Emerald Bay (23.27). The long-leaf cultivar (>25 cm) was only represented by Silver Queen (25.50). This variation reflects differences in genetic backgrounds between cultivars (Li et al., 2024).

The application of SiO₂ had no significant effect on leaf length, with the longest leaves on average at a concentration of 0.9 g L⁻¹ (18.12 cm), followed by 0.3 g L⁻¹ (17.91 cm) and 0.6 g L⁻¹ (17.56 cm). The water content of *Aglaonema* leaves ranged from 84.11% to 88.75% (Fig. 3B).

High leaf water content indicates the plant's ability to maintain its internal water status, so that turgor pressure, stomatal function, photosynthesis, and nutrient transport remain optimal. This condition makes plants more tolerant to drought stress (Ghahremani et al., 2023).

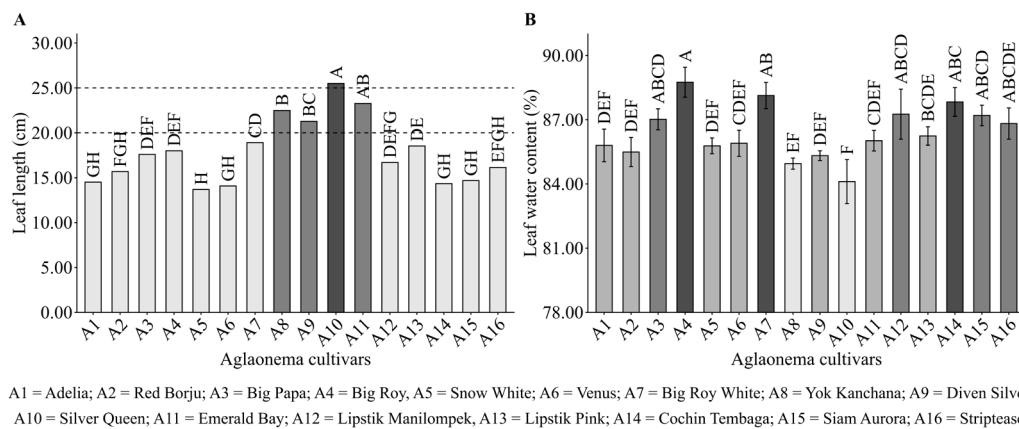


Fig. 3. Morphophysiological response of 16 *Aglaonema* cultivars to 24 weeks of SiO₂ application. (A) Leaf length response, (B) Leaf water content response. Vertical lines (bars) indicate standard error, different letters above the bars indicate significant differences based on Tukey's test ($\alpha = 0.05$).

The interaction between the SiO₂ application and *Aglaonema* cultivars had a significant effect on leaf width, ranging from 4.74 to 11.19 cm (Table 2). According to Kartikaningrum et al. (2014), leaf width is classified into 3 classes: narrow (<6 cm), medium (6-8 cm), and broad (>8 cm). Big Papa showed the largest leaf width (11.19 cm) at a concentration of 0.9 g L⁻¹, although it was not significantly different from

those of other concentrations and *Aglaonema* cultivars. The narrowest leaf width was shown by Siam Aurora (4.74 cm) at a concentration of 0 g L⁻¹, significantly different from 0.3 g L⁻¹ (5.70 cm), but not different from 0.6 g L⁻¹ (5.62 cm) and 0.9 g L⁻¹ (5.14 cm). SiO₂ application had no significant effect on leaf width, with the highest average increase in leaf width at a concentration of 0.9 g L⁻¹ (7.88 cm).

Table 2. Interaction of SiO₂ application and 16 *Aglaonema* cultivars on leaf width (cm) at 24 weeks.

Aglaonema cultivars	Nanosilica concentration (g L ⁻¹)			
	0	0.3	0.6	0.9
Adelia	8.39 ABCDa1	5.80 EFGb	8.81 ABCa	9.37 ABCa
Red Borju	7.89 BCDEa	8.26 ABCDa	8.10 BCa	8.77 BCa
Big Papa	10.33 Aa	10.53 Aa	10.64 Aa	11.19 Aa
Big Roy	7.60 BCDEb	9.70 ABa	9.64 ABa	9.47 ABa
Snow White	5.68 EFa	5.77 FGa	4.88 Fa	5.32 Fa
Venus	6.54 CDEFa	5.68 Ga	5.30 EFa	5.63 EFa
Big Roy White	9.20 ABa	9.19 ABCa	9.38 ABa	8.13 BCDA
Yok Kanchana	8.48 ABCa	8.33 ABCD	8.24 BCa	8.99 ABCa
Diven Silver	7.42 BCDEa	7.22 CDEFGa	6.98 CDEFa	7.01 CDEFa
Silver Queen	8.19 ABCDa	7.98 BCDEFGa	7.96 BCDA	7.81 BCDEa
Emerald Bay	8.72 ABCa	8.09 BCDEFa	8.50 ABCa	8.29 BCDA
Lipstik Manilompek	6.04 DEFa	6.57 DEFGa	5.68 DEFa	5.93 DEFa
Lipstik Pink	7.28 BCDEab	8.13 BCDEab	6.74 CDEfb	8.76 BCa
Cochin Tembaga	8.66 ABCa	7.39 BCDEFGa	7.40 BCDEa	8.39 BCa
Siam Aurora	4.74 Fa	5.70 Ga	5.62 DEFa	5.14 Fa
Striptease	7.49 BCDEa	7.24 CDEFGa	7.76 BCDA	7.89 BCDEa
Average	7.67	7.60	7.60	7.88

¹ Numbers followed by the same lowercase letter in the same column and the same uppercase letter in the same row indicate no significant difference based on Tukey's test ($\alpha = 0.05$).

The interaction between SiO₂ application and *Aglaonema* cultivars significantly affected epidermal thickness. The average epidermal thickness increased from 54.35 μ m (0 g L⁻¹) to 70.72 μ m (0.6 g L⁻¹), followed by 63.05 μ m (0.3 g L⁻¹) and 62.55 μ m (0.9 g L⁻¹) (Table 3). This increase indicates that SiO₂ strengthens epidermal cell walls, thereby increasing leaf strength and reducing water loss. Pink Lipstik

showed the most significant increase in epidermal thickness from 21.22 μ m (0 g L⁻¹) to 106.31 μ m (0.6 g L⁻¹), followed by Big Papa from 45.18 μ m (0 g L⁻¹) to 90.99 μ m (0.3 g L⁻¹), and Striptease from 42.20 μ m (0 g L⁻¹) to 78.08 μ m (0.6 g L⁻¹). Not all cultivars responded similarly. The cultivars Big Roy White, Cochin Tembaga, and Lipstik Manilompek actually experienced a decrease in epidermal thickness at

concentrations of 0.3 and 0.6 g L⁻¹. The increase in epidermal thickness in several cultivars is consistent with Idrees et al. (2024), who reported that SiO₂ is deposited in epidermal cells and guard cells, thereby

strengthening cell walls. SiO₂ is also known to form a protective layer on the leaf surface, making the epidermis thicker and stronger (Kartikaningrum et al., 2014).

Table 3. Interaction of SiO₂ application and 16 *Aglaonema* cultivar on epidermal thickness (µm) at 24 weeks.

Aglaonema cultivars	Nanosilica concentration (g L ⁻¹)			
	0	0.3	0.6	0.9
Adelia	29.55 ^{GHeI}	48.95 ^{FGb}	64.49 ^{EFGa}	49.47 ^{FGab}
Red Borju	42.43 ^{FGc}	66.67 ^{CDEa}	49.35 ^{GHbc}	59.85 ^{DEFab}
Big Papa	45.18 ^{EFGb}	90.99 ^{ABa}	90.89 ^{BCDa}	49.67 ^{FGb}
Big Roy	39.54 ^{FGb}	42.68 ^{FGb}	70.45 ^{EFa}	63.62 ^{CDEFa}
Snow White	72.33 ^{BCb}	79.38 ^{ABCb}	97.92 ^{BCa}	69.57 ^{BCDEb}
Venus	32.01 ^{GHc}	56.60 ^{EFb}	40.41 ^{Hc}	73.68 ^{BCDEa}
Big Roy White	111.40 ^{Aa}	75.79 ^{BCDb}	51.49 ^{GHc}	101.83 ^{Aa}
Yok Kanchana	35.26 ^{GHb}	54.39 ^{EFa}	49.56 ^{GHa}	49.21 ^{FGa}
Diven Silver	65.44 ^{BCDb}	96.03 ^{Aa}	45.68 ^{GHc}	35.05 ^{GHc}
Silver Queen	60.88 ^{CDEb}	58.54 ^{DEFb}	88.33 ^{CDa}	31.47 ^{Hc}
Emerald Bay	67.19 ^{BCDb}	66.74 ^{CDEb}	55.63 ^{FGHb}	96.68 ^{Aa}
Lipstik Manilompek	79.14 ^{Bb}	95.27 ^{Aa}	43.51 ^{Hd}	56.79 ^{EFc}
Lipstik Pink	21.22 ^{Hd}	46.30 ^{CDEc}	106.31 ^{Ba}	85.89 ^{ABb}
Cochin Tembaga	72.05 ^{BCab}	33.30 ^{Gc}	64.49 ^{EFGb}	76.04 ^{BCDa}
Siam Aurora	53.86 ^{DEFb}	45.70 ^{FGb}	127.68 ^{Aa}	24.25 ^{Hc}
Striptease	42.20 ^{FGb}	51.52 ^{EFb}	78.09 ^{DEa}	77.74 ^{BCa}
Average	54.35	63.05	70.27	62.25

¹ Numbers followed by the same lowercase letter in the same column and the same uppercase letter in the same row indicate no significant difference based on Tukey's test ($\alpha = 0.05$).

Leaf epidermal characteristics

The stomatal index is the percentage of stomata compared to the total number of epidermal cells and stomata in a single microscope field of view. The highest average increase in stomatal index was 7.94% (0.9 g L⁻¹), followed by 7.84% (0.3 g L⁻¹) and 7.72% (0.6 g L⁻¹) compared to the control of 7.67% (Table 4). *Aglaonema* cultivars that experienced

an increase in stomatal index were Diven Silver from 6.77% (0 g L⁻¹) to 9.27% (0.6 g L⁻¹), Emerald Bay from 6.75% (0 g L⁻¹) to 9.09% (0.3 g L⁻¹), and Venus from 6.70% (0 g L⁻¹) to 8.70% (0.9 g L⁻¹). Manilompek lipstick showed a decrease in all SiO₂ applications, with the most significant reduction at 0.3 g L⁻¹, from 10.47% to 7.93%.

Table 4. Interaction of SiO₂ application and 16 *Aglaonema* cultivars on stomatal index (%) at 24 weeks.

Aglaonema cultivars	Nanosilica concentration (g L ⁻¹)			
	0	0.3	0.6	0.9
Adelia	7.53 ^{Ba1}	7.79 ^{ABa}	6.63 ^{BCa}	6.07 ^{Ca}
Red Borju	6.48 ^{Ba}	7.95 ^{ABa}	8.06 ^{ABCa}	7.14 ^{BCa}
Big Papa	8.09 ^{ABab}	8.90 ^{ABa}	8.43 ^{ABCab}	6.76 ^{BCa}
Big Roy	7.72 ^{Bab}	6.31 ^{Bb}	7.64 ^{ABCab}	8.72 ^{ABCa}
Snow White	6.89 ^{Ba}	6.92 ^{ABa}	6.01 ^{Ca}	7.15 ^{BCa}
Venus	6.70 ^{Ba}	7.02 ^{ABa}	7.62 ^{ABCa}	8.70 ^{ABCa}
Big Roy White	7.75 ^{ABa}	8.52 ^{ABa}	8.54 ^{ABCa}	6.81 ^{BCa}
Yok Kanchana	7.20 ^{Ba}	7.23 ^{ABa}	6.66 ^{BCa}	7.42 ^{BCa}
Diven Silver	6.77 ^{Bb}	8.41 ^{ABab}	9.27 ^{ABa}	7.82 ^{ABCab}
Silver Queen	7.11 ^{Ba}	8.38 ^{ABa}	7.64 ^{ABCa}	8.26 ^{ABCa}
Emerald Bay	6.75 ^{Bb}	9.09 ^{Aa}	6.64 ^{BCb}	8.45 ^{ABCab}
Lipstik Manilompek	10.47 ^{Aa}	7.93 ^{ABb}	9.57 ^{Aab}	9.10 ^{ABab}
Lipstik Pink	8.80 ^{ABab}	8.81 ^{ABab}	7.50 ^{ABCb}	10.38 ^{Aa}
Cochin Tembaga	9.02 ^{ABa}	7.70 ^{ABa}	7.79 ^{ABCa}	7.72 ^{ABCa}
Siam Aurora	7.92 ^{ABab}	6.91 ^{ABb}	8.06 ^{ABCab}	9.24 ^{ABa}
Striptease	7.57 ^{Ba}	7.62 ^{ABa}	7.41 ^{ABCa}	7.38 ^{BCa}
Average	7.67	7.84	7.72	7.94

¹ Numbers followed by the same lowercase letter in the same column and the same uppercase letter in the same row indicate no significant difference based on Tukey's test ($\alpha = 0.05$).

Stomatal density is the number of stomata per unit area of leaf surface, usually expressed in mm^{-2} . The application of $0.3 \text{ g L}^{-1} \text{ SiO}_2$ increased the average stomatal density to 33.98 mm^{-2} , compared to the control of 33.73 mm^{-2} , but at concentrations of 0.6 and 0.9 g L^{-1} , stomatal density decreased (Table 5). The highest increase in stomatal density occurred in Emerald

Bay (57.70 mm^{-2}), Silver Queen (50.91 mm^{-2}), and Red Borju (10.18 mm^{-2}) at an application of $0.3 \text{ g L}^{-1} \text{ SiO}_2$ compared to the control. Siam Aurora showed a negative response at 0.3 g L^{-1} , with a stomatal density of 25.45 mm^{-2} ; Lipstik Manilompek at 0.6 g L^{-1} (27.15 mm^{-2}) and 0.9 g L^{-1} (28.85 mm^{-2}), both lower than the control.

Table 5. Interaction of SiO_2 application and 16 *Aglaonema* cultivars on stomatal density (mm^{-2}) at 24 weeks.

Aglaonema cultivars	Nanosilica concentration (g L^{-1})			
	0	0.3	0.6	0.9
Adelia	35.64 ^{BCDa1}	32.93 ^{CDab}	28.85 ^{BCab}	23.76 ^{DEb}
Red Borju	23.76 ^{Da}	33.94 ^{CDa}	33.94 ^{BCa}	25.45 ^{CDEa}
Big Papa	27.15 ^{CDa}	25.45 ^{CDEa}	28.85 ^{BCa}	22.06 ^{Ea}
Big Roy	27.15 ^{CDa}	25.45 ^{CDEa}	27.15 ^{BCa}	35.64 ^{ABCDEa}
Snow White	30.55 ^{BCDa}	33.94 ^{CDa}	30.55 ^{BCa}	40.73 ^{ABa}
Venus	25.45 ^{CDa}	16.97 ^{Ea}	20.36 ^{Ca}	23.76 ^{DEa}
Big Roy White	30.55 ^{BCDa}	33.94 ^{CDa}	27.15 ^{BCa}	27.15 ^{BCDEa}
Yok Kanchana	44.12 ^{ABa}	37.33 ^{BCab}	32.24 ^{BCb}	39.03 ^{ABCb}
Diven Silver	50.91 ^{Aa}	56.00 ^{Aa}	54.30 ^{Aa}	49.21 ^{Aa}
Silver Queen	39.03 ^{ABCb}	50.91 ^{ABa}	39.03 ^{Bb}	47.52 ^{Aab}
Emerald Bay	39.03 ^{ABCbc}	57.70 ^{Aa}	28.85 ^{BCc}	44.12 ^{Ab}
Lipstik Manilompek	42.42 ^{ABa}	28.85 ^{CDEb}	27.15 ^{BCb}	28.85 ^{BCDEb}
Lipstik Pink	30.55 ^{BCDa}	33.94 ^{CDa}	25.45 ^{BCa}	35.64 ^{ABCDEa}
Cochin Tembaga	23.76 ^{Dab}	22.06 ^{DEb}	32.93 ^{BCa}	22.06 ^{Eb}
Siam Aurora	42.42 ^{ABa}	25.45 ^{CDEb}	32.24 ^{BCab}	37.33 ^{ABCDa}
Striptease	27.15 ^{CDa}	28.85 ^{CDEa}	23.76 ^{Ca}	28.85 ^{BCDEa}
Average	33.73	33.98	30.80	33.20

¹ Numbers followed by the same lowercase letter in the same column and the same uppercase letter in the same row indicate no significant difference based on Tukey's test ($\alpha = 0.05$).

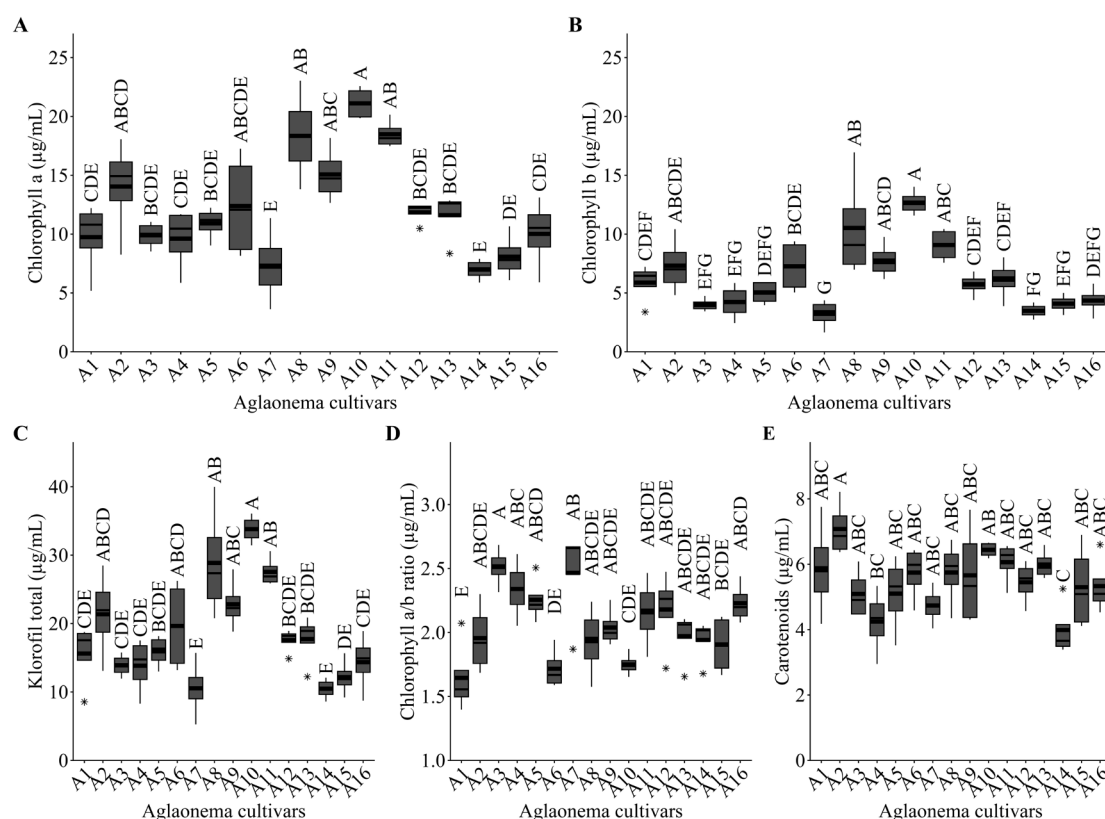
Chlorophyll and carotenoid levels ($\mu\text{g mL}^{-1}$)

The application of SiO_2 increased the average chlorophyll *a*, with the highest increase occurring at a concentration of 0.6 g L^{-1} , namely $14.22 \mu\text{g mL}^{-1}$, compared to the control ($10.83 \mu\text{g mL}^{-1}$), 0.3 g L^{-1} ($11.32 \mu\text{g mL}^{-1}$), and 0.9 g L^{-1} ($12.49 \mu\text{g mL}^{-1}$). In general, SiO_2 application increased chlorophyll *a* level in all *Aglaonema* cultivars, except for the following combinations: Red Borju at 0.3 g L^{-1} ; Big Roy White and Lipstik Manilompek at 0.9 g L^{-1} ; Lipstik Pink and Siam Aurora at 0.3 and 0.9 g L^{-1} ; and Striptease at all concentrations (Fig. 4A). The opposite occurred with chlorophyll *b*: cultivars that decreased chlorophyll *a* showed an increase in chlorophyll *b*, except for Siam Aurora at 0.3 and 0.9 g L^{-1} , which consistently reduced (Fig. 4B). The application of SiO_2 at 0.6 g L^{-1} increased the highest average chlorophyll *b*, namely $7.78 \mu\text{g mL}^{-1}$, compared to the control ($5.54 \mu\text{g mL}^{-1}$), 0.3 g L^{-1} ($5.60 \mu\text{g mL}^{-1}$), and 0.9 g L^{-1} ($6.26 \mu\text{g mL}^{-1}$). Total chlorophyll is a combination of chlorophyll *a* and *b* (Fig. 4C). An increase was observed at 0.6 g L^{-1} ($22.00 \mu\text{g mL}^{-1}$) compared to the control ($16.36 \mu\text{g mL}^{-1}$), 0.3 g L^{-1} ($16.92 \mu\text{g mL}^{-1}$), and 0.9 g L^{-1} ($18.74 \mu\text{g mL}^{-1}$). The cultivars that experienced the most significant average increase in total chlorophyll were Silver Queen ($33.79 \mu\text{g mL}^{-1}$), Yok Kanchana ($28.86 \mu\text{g mL}^{-1}$), and Emerald Bay ($27.55 \mu\text{g mL}^{-1}$).

The chlorophyll ratio is the ratio between chlorophyll *a* and chlorophyll *b* content in a plant tissue (Fig. 4D). Chlorophyll *a* is the primary pigment that plays a direct role in photosynthetic phytochemistry (Jin et al., 2011). Chlorophyll *b* is an accessory pigment that helps capture light and transfer its energy to chlorophyll *a* (Yang et al., 2016). SiO_2 application increased

the average chlorophyll ratio, with the most significant increase at 0.3 and 0.9 g L^{-1} , namely $2.11 \mu\text{g mL}^{-1}$ compared to the control ($2.01 \mu\text{g mL}^{-1}$) and 0.6 g L^{-1} ($2.02 \mu\text{g mL}^{-1}$). A high *a/b* ratio contains more chlorophyll *a* than chlorophyll *b*, generally an adaptation to high light intensity (Tang et al., 2022). *Aglaonema* cultivars that exhibit this characteristic include Big Papa, Big Roy, Snow White, Big Roy White, Diven Silver, Emerald Bay, Lipstik Manilompek, Striptease, Red Borju, and Lipstik Pink (*a/b* > 2). A low *a/b* ratio indicates a higher proportion of chlorophyll *b*, an adaptation to low light conditions (Khan et al., 2023). Cultivars exhibiting this characteristic include Adelia, Venus, Yok Kanchana, Silver Queen, Cochin Tembaga, and Siam Aurora (*a/b* < 2). SiO_2 application increases photosystem II efficiency and chlorophyll *b* content, thereby maintaining optimal light capture and electron transport (40%-80%) at low light intensities (Biswal et al., 2012).

Carotenoids are yellow-orange accessory pigments that assist chlorophyll in the process of photosynthesis (Osório et al., 2020). The application of SiO_2 increased the average carotenoid content, with the highest increase at a concentration of 0.6 g L^{-1} , namely $6.06 \mu\text{g mL}^{-1}$, followed by 0.3 g L^{-1} ($5.49 \mu\text{g mL}^{-1}$) and 0.9 g L^{-1} ($5.46 \mu\text{g mL}^{-1}$), compared to the control at $4.94 \mu\text{g mL}^{-1}$ (Fig. 4E). The cultivars with the highest average carotenoid increases were Red Borju ($7.07 \mu\text{g mL}^{-1}$), Silver Queen ($6.44 \mu\text{g mL}^{-1}$), and Emerald Bay ($6.06 \mu\text{g mL}^{-1}$). Carotenoids are essential for plants with various functions in photosynthesis, pigmentation, abscisic acid phytohormone synthesis, and as indicators of abiotic stress hormones (Sun et al., 2022).



A1 = Adelia; A2 = Red Borju; A3 = Big Papa; A4 = Big Roy; A5 = Snow White; A6 = Venus; A7 = Big Roy White; A8 = Yok Kanchana; A9 = Diven Silver; A10 = Silver Queen; A11 = Emerald Bay; A12 = Lipstik Manilompek; A13 = Lipstik Pink; A14 = Cochin Tembaga; A15 = Siam Aurora; A16 = Striptease

Fig. 4. Chlorophyll and carotenoid levels ($\mu\text{g mL}^{-1}$) in 16 *Aglaonema* cultivars after 24 weeks of SiO_2 application. (A) chlorophyll *a* response, (B) chlorophyll *b* response, (C) total chlorophyll response, (D) chlorophyll *a/b* ratio response, (E) carotenoid response. The line inside the box indicates the mean. The symbol suggests outlier data, and different letters above the box indicate significant differences based on Tukey's test ($\alpha = 0.05$) with $\log(2x + 1)$ transformation (Singh et al., 2022).

Incidence and severity of plant pests (%)

Pests that attacked *Aglaonema* plants during this study included *Lepidosaphes beekii*, *Ceroplastes rubens*, and *Pseudococcidae*. At the same time, the following diseases were found: anthracnose and stem rot. The incidence of pest and disease attacks is shown in Table 6. Pest attacks occurred throughout the study period, with the highest incidence at 24 WAT. In comparison, disease attacks occurred during the early period of the study, up to 12 WAT, and no symptoms were observed in the following weeks. Anthracnose and stem rot are the primary diseases affecting *Aglaonema*. Anthracnose is caused by *Gloeosporium graffi* and *Colletotrichum*, which attack the leaves, while stem rot can be caused by pathogenic fungi and bacteria (Mounika et al., 2017). The pathogens that

cause these diseases can be in a latent phase, living in the host plant tissue without causing symptoms until the plant is in a vulnerable condition or the environment supports pathogen development. Stressed plant cuttings reduce the plant's resistance to pathogens, allowing the disease to develop and cause symptoms. The highest incidence of *Lepidosaphes beekii* infestation was observed in the treatment without SiO_2 at 0 g L^{-1} , while the highest incidences of whiteflies and red mites were observed at 0.3 g L^{-1} . The lowest pest infestation rate was observed at a concentration of 0.9 g L^{-1} . The incidence of disease also showed a similar pattern, with the lowest incidence of anthracnose and stem rot found at a concentration of 0.9 g L^{-1} . This indicates that applying SiO_2 at high concentrations may increase *Aglaonema* plants' resistance to pathogen infection.

Table 6. Incidence of pest and disease attacks in SiO₂ treatments.

Nanosilica concentration (g L ⁻¹)	Incidence (%)				
	Pests (24 WAT)			Disease (12 WAT)	
	<i>Lepidosaphes beckii</i>	<i>Ceroplastes rubens</i>	<i>Pseudococcidae</i>	Anthrachnose	Stem rot
0	15.56	2.22	0.00	13.33	0.00
0.3	6.67	11.11	2.22	6.67	4.44
0.6	11.11	8.89	0.00	15.56	2.22
0.9	2.22	2.22	0.00	4.44	0.00

Note: Weeks after treatment (WAT).

The severity of anthracnose disease in infected plant individuals at each SiO₂ concentration is shown in Table 7; all stem-rot-infected individuals died, with a severity level of 100%. The lowest severity of anthracnose disease was found at a concentration of 0.9 g L⁻¹. The application of SiO₂ at concentrations of 0.3 and 0.9 g L⁻¹ increased resistance to anthracnose. Anthracnose is caused by a hemibiotrophic pathogen, whose resistance is generally mediated by the salicylic acid phytohormone pathway (Kadege et al., 2022). SiO₂ application increased the activity of the salicylic acid pathway, potentially leading to increased resistance to this pathogen (El-Shetehy et al., 2021). Stem rot is caused by a necrotropic pathogen, whose resistance is generally mediated by the jasmonate pathway (Davidsson et al., 2013). There is negative crosstalk between salicylic acid and

jasmonate, suggesting that SiO₂ application does not increase resistance to the pathogen that causes stem rot (Caarls et al., 2015).

Although an overall reduction in disease incidence and severity was observed with increasing nanosilica concentration, the response was not entirely consistent. Notably, anthracnose incidence and severity increased at 0.6 g L⁻¹ compared with 0.3 g L⁻¹. Such variability is likely due to the uneven pathogen distribution and infection pressure among treatments under field conditions. Consequently, controlled inoculation experiments using standardized pathogen inoculum are needed to clarify the contribution of silica to disease resistance and to validate its protective effects under uniform infection conditions.

Table 7. Severity of anthracnose disease in SiO₂ treatments at 12 WAT

Nanosilica concentration (g L ⁻¹)	Anthracnose	
	Disease severity (%)	Resistance class
0	43.75	Moderately susceptible
0.3	22.92	Moderately resistant
0.6	62.50	Susceptible
0.9	12.50	Moderately resistant

Note: Resistance class based on (Mounika et al., 2017).

Correlation analysis

Based on Pearson's correlation analysis, there is a significant correlation between *Aglaonema* variables after SiO₂ application (Fig. 5). Leaf length, leaf width, and plant height are significantly positively correlated. Longer, wider leaves increase photosynthetic area, thereby boosting photosynthetic production. Photosynthetic products are then used as a source of energy and carbon for stem elongation and the formation of other organs (Akram et al., 2024). Stomatal density has a significant positive correlation with plant height and leaf length. High stomatal density increases CO₂ diffusion for photosynthesis and increases transpiration rate, thereby increasing nutrient mass flow from roots to leaves.

Leaf chlorophyll content (chl *a*, chl *b*, and t chl) correlates positively with plant height and leaf length. Increased chlorophyll levels enhance photosynthetic capacity, thereby increasing the photosynthates needed to support vegetative growth (Wang et al., 2025). Leaf water content shows a negative correlation with leaf length and stomatal density. Leaves with longer leaves and more stomata tend to experience higher transpiration, resulting in increased water loss and decreased leaf tissue water content. Leaf water content also correlates negatively with photosynthetic pigments

(chl *a*, chl *b*, t chl, and car). Decreased water content inhibits synthesis and accelerates chlorophyll degradation, thereby reducing photosynthetic pigment content (Ulya et al., 2020). The chlorophyll ratio is negatively correlated with carotenoid content. An increase in carotenoids as a photoprotective response tends to decrease the proportion of chlorophyll *a* or *b*, thereby decreasing the chlorophyll *a/b* ratio.

The incidence and severity of anthracnose have a significant positive correlation with chlorophyll *a*, chlorophyll *b*, and total chlorophyll content. This indicates that the incidence and severity of anthracnose are higher when chlorophyll content is higher. The fungi that cause anthracnose, *Gloeosporium graffi* and *Colletotrichum*, prefer new tissues or leaves with high chlorophyll content because these tissues are rich in nutrients such as nitrogen and carbohydrates (Won et al., 2023). High nitrogen availability can reduce the formation of phenolic compounds through the shikimate pathway and increase the accumulation of amino acids and amides in the apoplast, thereby creating conditions that support fungal disease development (Marschner, 2012). This pathogen is opportunistic, targeting the most nutrient-rich parts of the plant with relatively weaker defenses to maximize growth and reproduction (Zakaria, 2021).

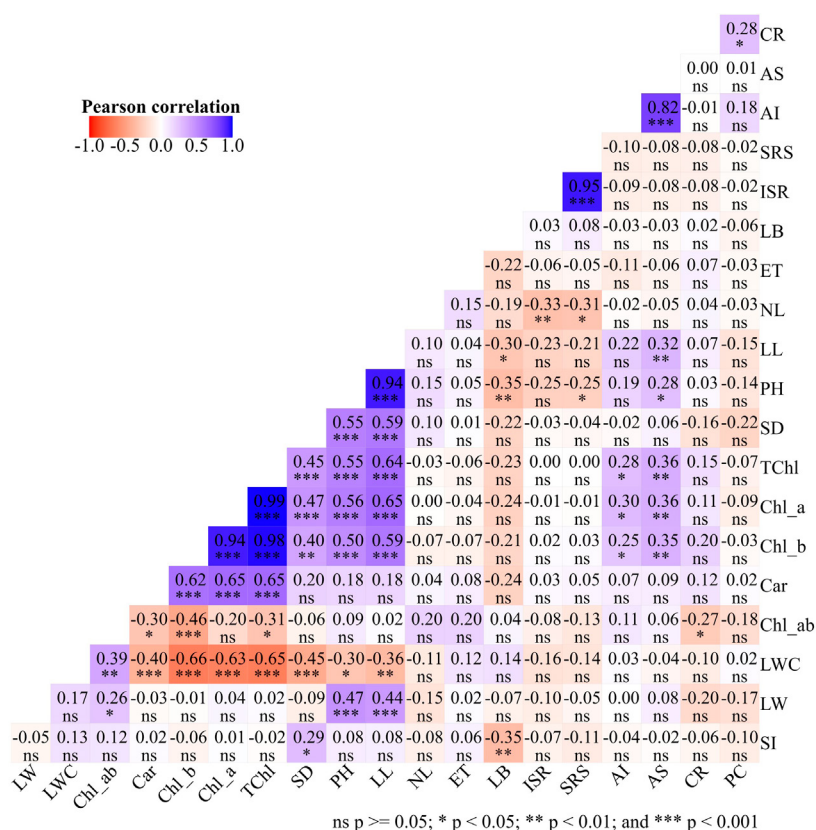


Fig. 5. Pearson's correlation of all variables in *Aglaonema* after 24 weeks of SiO₂ application. PH: plant height, NL: number of leaves, LL: leaf length, LW: leaf width, LWC: leaf water content, ET: epidermis thickness, SI: stomatal index, SD: stomatal density, Chl *a*: chlorophyll *a*, Chl *b*: chlorophyll *b*, Chl *ab*: chlorophyll *a/b* ratio, TChl: total chlorophyll, Car: carotenoid, ISR: incidence of soft rot, SRS: soft rot severity, AI: anthracnose incidence, AS: anthracnose severity, LB: *Lepidosaphes beckii*, CR: *Ceroptastes rubens*, PC: *Pseudococcidae*.

Conclusions

The application of SiO₂ foliar spray had a significant effect on the growth of *Aglaonema*, namely, plant height and leaf width, increased leaf epidermis thickness, stomatal index, stomatal density, and reduced incidence and severity of anthracnose, stem rot diseases, *Lepidosaphes beckii*, *Ceroptastes rubens*, and *Pseudococcidae*. There are differences in response among *Aglaonema* cultivars to SiO₂ application for all variables, indicating that plant genetic and anatomical factors may influence the effectiveness of SiO₂ application. Based on consumer aesthetic criteria that favor *Aglaonema* with relatively low height, broad, long leaves, and resistance to pests and diseases, a SiO₂ concentration of 0.9 g L⁻¹ is the optimal treatment.

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Author Contribution

RS: Conceptualization, Data Curation, Investigation, Methodology, Project Administration, Visualization, Resources & Writing – Original Draft. **S:** Formal Analysis, Investigation, Resources, Methodology, Writing – Review & Editing. **DS:** Supervision, Validation, Writing – Review & Editing. **RK:** Supervision, Validation, Writing – Review & Editing. **MSR:** Funding Acquisition, Resources, Supervision, Validation, Writing – Review & Editing.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

Data will be made available upon request to the authors.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that the use of AI and AI-assisted technologies was not applied in the writing process.

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