



Response of Syngonium Species to Plant Growth Regulators on Leaf Characteristics in Vertical Gardening

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Vertical gardening is useful for growing ornamental foliage plants under limited space conditions, where leaf morphology is important for quality and visual appeal. Balanced leaf development under restricted space and limited growing media remains challenging. The present study evaluated the effect of growth regulators on

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leaf characteristics of *Syngonium* species under vertical gardening conditions. The investigation was conducted at the Floricultural Research Station, ARI, Rajendranagar, Hyderabad, Sri Konda Laxman Telangana Horticultural University, during 2023–2024 and 2024–2025. The experiment was laid out in a factorial randomised block design with three replications. Treatments comprised Cycocel at 500 ppm, Cycocel at 1000 ppm, Benzyl Adenine at 100 ppm and Benzyl Adenine at 200 ppm, with three *Syngonium* types: *Syngonium reticulata*, *Syngonium podophyllum* ‘Neon’ and *Syngonium podophyllum* ‘Bronze’. Observations were recorded 125 days after planting for leaf length, leaf width, leaf area, dry weight of leaf, specific leaf area, specific leaf weight and leaf thickness. Significant variation was observed among treatments, species and their interactions. Benzyl Adenine at 200 ppm recorded the highest leaf length (16.26 cm), leaf width (8.69 cm), leaf area (132.20 cm²) and dry weight of leaf (0.385 g). Benzyl Adenine at 100 ppm recorded the highest specific leaf area (356.8 cm² g⁻¹), whereas Cycocel at 1000 ppm recorded the highest specific leaf weight (4.41 mg cm⁻²) and leaf thickness (0.88 mm). Among the species, *Syngonium reticulata* recorded higher values for most leaf characters. The findings indicate that Benzyl Adenine may improve leaf expansion, while Cycocel may support compact foliage development.

Keywords: Vertical gardening; *syngonium reticulata*; *syngonium podophyllum*; cycocel; benzyl adenine; leaf area; leaf thickness; specific leaf area; specific leaf weight; ornamental foliage plants.

1. Introduction

Vertical gardening has gained importance as a suitable approach for urban greening by utilising vertical spaces for plant cultivation. In such systems, ornamental plants with attractive foliage and desirable growth habits play an important role in enhancing aesthetic value and environmental quality. Vertical landscapes provide ecological and aesthetic benefits by improving the quality of urban environments (Dunnett & Kingsbury, 2008). Among ornamental foliage plants, *Syngonium spp.*, belonging to the family Araceae, is widely used in interior landscaping due to its attractive foliage, varied leaf shapes, rapid growth and adaptability under different environmental conditions (Chen et al., 2005). The ornamental value of *Syngonium* largely depends on leaf characteristics such as leaf size, shape, area, thickness and biomass accumulation, which influence overall plant quality (Poole & Conover, 1993).

Recent living wall research indicates that plant selection and species performance are central to the success and maintenance of living walls because plants are exposed to restricted root space and variable wall microclimates (Stollberg & von Birgelen, 2023).

Recent ornamental plant literature also emphasises that visual quality traits are important components of ornamental value, supporting the need to manage plant traits that determine appearance (Kumar et al., 2026).

In vertical gardening, maintaining desirable leaf morphology is particularly important because of limited growing space. Therefore, regulation of leaf development and architecture is essential to achieve well-balanced plants suitable for vertical gardening. Plant growth regulators have a significant role in modifying leaf development, expansion and biomass production by regulating physiological processes. Growth regulators such as Cycocel (chlormequat chloride) and Benzyl Adenine are widely used plant growth regulators that significantly influence the growth and ornamental quality of foliage plants by altering hormonal balance and developmental pathways (Gholampour et al., 2012; Kumar et al., 2021). Khetarpal and Shaikh (2015) reported that the application of BAP improved leaf morphology in *Syngonium podophyllum*. Kasem and Helaly (2021) observed that BAP application increased leaf area, foliage fresh weight and dry weight in *Syngonium podophyllum*. Similarly, Sardoei and Shahbazi (2021) reported that BA application in *Ficus benjamina* influenced growth characteristics, demonstrating the role of cytokinins in improving leaf attributes in *Syngonium spp.* Berova and Zlatev (2000) observed that growth retardants influenced leaf growth characteristics by regulating biomass allocation and plant structure. Cathey (1964) reported that CCC application resulted in changes in leaf characteristics, including reduced leaf expansion and improved compact plant form in ornamental crops.

Recent studies on potted *Syngonium*, *Syngonium podophyllum* ‘White Butterfly’ and dwarf schefflera further support that plant growth regulator treatments can alter leaf-related physiological and quality traits, including

leaf area index, specific leaf area, specific leaf weight, leaf area, leaf number and photosynthetic pigments (Sardoei et al., 2018; Sardoei et al., 2024; Supriya et al., 2025).

However, information remains limited on the comparative response of multiple *Syngonium species* to Cycocel and Benzyl Adenine under vertical gardening conditions, particularly in relation to leaf morphology, dry matter accumulation, specific leaf area, specific leaf weight and leaf thickness.

1.1 Objective

Considering the importance of leaf quality and plant architecture in vertical gardening, the present investigation, titled “Response of *Syngonium species* to plant growth regulators on leaf characteristics in vertical gardening”, was undertaken to evaluate the influence of different plant growth regulators and *Syngonium species* on leaf morphological characteristics, biomass accumulation and overall foliage quality under vertical gardening conditions.

2. Material and Methods

2.1 Location

The present investigation was carried out at the Floricultural Research Station, ARI, Rajendranagar, Hyderabad, Sri Konda Laxman Telangana Horticultural University, during 2023–2024 and 2024–2025.

2.2 Experiment Details

In this experiment, plant growth regulators were studied in *Syngonium* plants and consisted of two factors. Factor one (plant growth regulators) consisted of four levels, viz., G1- Cycocel at 500 ppm, G2- Cycocel at 1000 ppm, G3- Benzyl Adenine at 100 ppm and G4- Benzyl Adenine at 200 ppm, and factor two (different species of *Syngonium*) consisted of three levels, viz., S1- *Syngonium reticulata*, S2- *Syngonium podophyllum* (Neon) and S3- *Syngonium podophyllum* (Bronze). The treatments were replicated three times, with 10 plants maintained per replication.

2.3 Experiment Material

A vertical gardening structure was designed and established to study the influence of different treatments on the growth and quality of ornamental foliage plants. The framework consisted of an iron stand supporting a metallic mesh measuring 10 feet in length and 5 feet in height. Each stand was fabricated to accommodate six treatments, each comprising 15 pots with a 5-inch length, 4-inch width and 500 g capacity. The potting mixture consisted of red soil + cocopeat + sand + vermicompost in a ratio of 0.5:1:0.5:2, as recommended by Sunil et al. (2024). The pots were provided with a hook-like structure to facilitate easy hanging on the vertical gardening frame.

The vertical frame was divided into six stands (vertical columns), each consisting of six rows of pots. Each pot was planted with one of three *Syngonium species*. The arrangement followed the treatment combinations based on plant growth regulator levels (Factor 1). The growth regulators were prepared according to the required concentration and sprayed at 60 and 90 DAP. The plants were maintained under a controlled light intensity of 1500–2000 Lux for 8 hours per day.

2.4 Observations Recorded

All observations were recorded 125 days after planting.

2.4.1 Leaf Length (cm)

Leaf length was defined as the distance from the end of the petiole to the tip of the upper leaf lobe. Leaf length was measured using a leaf area meter on randomly selected leaves and expressed in centimetres (cm)

2.4.2 Leaf Width (cm)

Leaf width was recorded using a leaf area meter from five fully matured leaves and expressed in centimetres (cm).

2.4.3 Leaf Area (cm²)

Leaf area was calculated using a leaf area meter from five fully matured leaves, and the mean value was expressed in square centimetres (cm²).

2.4.4 Dry Weight of Leaf (g)

Fully grown leaves were collected in zip-lock bags and promptly transported to the laboratory. The leaves were placed on a metal tray and dried in a hot-air oven at 70°C until a constant weight was obtained. Their dry weights were recorded using an electronic weighing balance, and the averages were calculated and expressed in grams (g).

2.4.5 Specific Leaf Area (cm² g⁻¹)

Specific leaf area was determined as the ratio of leaf area to leaf dry weight and was expressed in cm² g⁻¹, as described by Kvet et al. (1971).

$$SLA = \frac{\text{leaf area}}{\text{dry leaf weight}} \text{ cm}^2 \text{ g}^{-1}$$

2.4.6 Specific Leaf Weight (mg cm⁻²)

Specific leaf weight is a measure of leaf weight per unit area. It was measured by taking the ratio of leaf weight to leaf area and expressed in mg cm⁻², as suggested by Pearce et al. (1968).

$$SLW = \frac{\text{leaf weight}}{\text{leaf area}} \text{ mg cm}^{-2}$$

2.4.7 Leaf Thickness (mm)

Leaf thickness was measured using Vernier callipers from five fully matured leaves and expressed in millimetres (mm).

2.5 Statistical Analysis

The data were analysed using R Studio software version 2021.09.1 Build 372. The observations recorded for various parameters were subjected to analysis of variance using FCRD. Statistical significance was tested using the 'F' value at the 5% level of probability, and whenever the F value was significant, the critical difference was worked out at the 5% level of probability.

3. Results and Discussion

3.1 Leaf Length (cm)

The leaf length was significantly influenced by plant growth regulators, species and their interaction during both seasons as well as in the pooled analysis (Table 1).

Among the plant growth regulators, G4 (Benzyl Adenine at 200 ppm) recorded the maximum leaf length (16.26 cm), whereas G2 (Cycocel at 1000 ppm) resulted in the minimum leaf length (7.67 cm). Among the species, S1 recorded the maximum leaf length (13.08 cm), followed by S3 (11.63 cm). In contrast, S2 consistently recorded the minimum leaf length (11.16 cm). Among the interaction effects between the growth regulators and *Syngonium species*, G4S1 recorded the maximum leaf length (18.00 cm), and G2S2 recorded the minimum leaf length (7.30 cm).

Table 1. Effect of plant growth regulators on leaf length (cm)

Treatments	2023-24				2024-25				POOLED DATA			
	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean
G ₁	8.66 ^f	7.62 ^h	7.83 ^{gh}	8.04 ^c	8.57 ^f	7.53 ^h	7.74 ^g	7.95 ^c	8.61 ^c	7.58 ^{gh}	7.78 ^g	7.99 ^c
G ₂	8.24 ^{fg}	7.36 ^h	7.44 ^h	7.68 ^d	8.34 ^f	7.25 ^h	7.38 ^{hi}	7.66 ^d	8.29 ^f	7.30 ^h	7.41 ^h	7.67 ^d
G ₃	17.40 ^b	14.76 ^c	15.51 ^{cd}	15.89 ^b	17.44 ^b	14.85 ^e	15.48 ^d	15.92 ^b	17.42 ^b	14.80 ^d	15.50 ^c	15.90 ^b
G ₄	18.08 ^a	14.95	15.78 ^c	16.27 ^a	17.93 ^a	14.98 ^e	15.85 ^c	16.25 ^a	18.00 ^a	14.97 ^d	15.81 ^c	16.26 ^a
Mean	13.10 ^a	11.18 ^c	11.64 ^b		13.07 ^a	11.16 ^e	11.62 ^b		13.08 ^a	11.16 ^e	11.63 ^b	
	S.Em (±)			CD at (5%)	S.Em (±)			CD at (5%)	S.Em (±)			CD at (5%)
G	0.12			0.34	0.05			0.14	0.07			0.20
S	0.10			0.30	0.04			0.12	0.06			0.17
G X S	0.20			0.60	0.08			0.24	0.12			0.34

Note: G₁: Cycocel at 500ppm, G₂: Cycocel at 1000 ppm, G₃: Benzyl Adenine at 100 ppm, G₄: Benzyl Adenine at 200 ppm, S₁: Syngonium reticulata, S₂: Syngonium podophyllum (Neon), S₃: Syngonium podophyllum (Bronze), S.Em (±)- Standard Error of Mean; CD at (5%) – Critical Difference at 5% level of significance

Table 2. Effect of plant growth regulators on leaf width (cm) of different Syngonium species in vertical gardening

Treatments	2023-24				2024-25				POOLED DATA			
	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean
G ₁	5.82 ^f	5.04 ⁱ	5.38 ^{gh}	5.41 ^c	5.91 ^f	5.00 ⁱ	5.40 ^{gh}	5.44 ^c	5.87 ^f	5.02 ⁱ	5.39 ^h	5.42 ^c
G ₂	5.6 ^{fg}	4.53 ^j	5.20 ^{hi}	5.11 ^d	5.57 ^g	4.63 ^j	5.23 ^{hi}	5.14 ^d	5.59 ^g	4.58 ^j	5.22 ^h	5.13 ^d
G ₃	9.01 ^b	7.49 ^c	8.25 ^d	8.25 ^b	8.97 ^b	7.60 ^e	8.31 ^d	8.29 ^b	8.99 ^b	7.54 ^c	8.28 ^d	8.27 ^b
G ₄	9.32 ^a	8.15 ^d	8.60 ^c	8.69 ^a	9.40 ^a	8.08 ^d	8.62 ^c	8.70 ^a	9.36 ^a	8.11 ^d	8.61 ^c	8.69 ^a
Mean	7.44^a	6.30^c	6.86^b		7.46^a	6.33^c	6.89^b		7.45^a	6.31^c	6.87^b	
	c			CD at (5%)	S.Em (±)			CD at (5%)	S.Em (±)			CD at (5%)
G	0.060			0.170	0.050			0.140	0.040			0.110
S	0.050			0.150	0.040			0.120	0.030			0.090
G X S	0.100			0.300	0.080			0.240	0.070			0.190

Note: G₁: Cycocel at 500ppm, G₂: Cycocel at 1000 ppm, G₃: Benzyl Adenine at 100 ppm, G₄: Benzyl Adenine at 200 ppm, S₁: Syngonium reticulata, S₂: Syngonium podophyllum (Neon), S₃: Syngonium podophyllum (Bronze), S.Em (±)- Standard Error of Mean; CD at (5%) – Critical Difference at 5% level of significance

Table 3. Effect of plant growth regulators on leaf area (cm²) of different Syngonium species in vertical gardening

Treatments	2023-24				2024-25				POOLED DATA			
	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean
G ₁	64.62 ^f	45.57 ⁱ	54.31 ^{gh}	54.83 ^c	65.11 ^c	46.34 ^h	55.04 ^f	65.11 ^c	64.87 ^f	45.95 ^j	54.67 ^g	55.16 ^c
G ₂	54.93 ^g	42.04 ^j	51.12 ^h	49.36 ^d	53.39 ^{fg}	44.58 ⁱ	50.09 ^g	53.39 ^d	54.16 ^g	43.31 ^k	50.61 ^h	49.36 ^d
G ₃	130.54 ^b	121.05 ^e	128.81 ^c	126.80 ^b	132.84 ^b	122.54 ^d	129.11 ^c	132.84 ^b	131.69 ^b	121.8 ^e	128.96 ^c	127.48 ^b
G ₄	139.22 ^a	125.25 ^d	132.43 ^b	132.30 ^a	138.75 ^a	124.33 ^d	133.22 ^b	138.75 ^a	138.98 ^a	124.79 ^d	132.82 ^b	132.20 ^a
Mean	97.33^a	83.48^c	91.67^b		97.52^a	84.45^c	91.86^b		97.42^a	83.96^c	91.77^b	
	S.Em (±)		CD at (5%)		S.Em (±)		CD at (5%)		S.Em (±)		CD at (5%)	
G	0.67		1.96		0.65		1.91		0.42		1.22	
S	0.58		1.69		0.57		1.65		0.36		1.05	
G X S	1.16		3.39		1.13		3.3		0.72		2.11	

Note: G₁: Cycocel at 500ppm, G₂: Cycocel at 1000 ppm, G₃: Benzyl Adenine at 100 ppm, G₄: Benzyl Adenine at 200 ppm, S₁: Syngonium reticulata, S₂: Syngonium podophyllum (Neon), S₃: Syngonium podophyllum (Bronze), S.Em (±)- Standard Error of Mean; CD at (5%) – Critical Difference at 5% level of significance

Table 4. Effect of plant growth regulators on leaf thickness (mm)

Treatments	2023-24				2024-25				POOLED DATA			
	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean
G ₁	0.89 ^b	0.76 ^c	0.85 ^c	0.83 ^b	0.88 ^b	0.75 ^d	0.86 ^b	0.83 ^b	0.88 ^b	0.75 ^c	0.85 ^c	0.83 ^b
G ₂	0.97 ^a	0.79 ^d	0.85 ^{bc}	0.87 ^a	0.98 ^a	0.80 ^c	0.86 ^b	0.88 ^a	0.97 ^a	0.79 ^d	0.86 ^c	0.88 ^a
G ₃	0.37 ^f	0.25 ^{gh}	0.26 ^g	0.29 ^e	0.38 ^e	0.25 ^g	0.26 ^g	0.29 ^e	0.37 ^f	0.25 ^h	0.26 ^h	0.29 ^e
G ₄	0.35 ^f	0.23 ^h	0.24 ^{gh}	0.28 ^d	0.34 ^f	0.22 ^h	0.23 ^{gh}	0.27 ^d	0.35 ^g	0.22 ⁱ	0.24 ^{hi}	0.27 ^d
Mean	0.64^a	0.51^c	0.55^b		0.64^a	0.50^c	0.55^b		0.64^a	0.51^c	0.55^b	
	S.Em (±)		CD at (5%)		S.Em (±)		CD at (5%)		S.Em (±)		CD at (5%)	
G	0.006		0.017		0.006		0.016		0.005		0.014	
S	0.005		0.015		0.005		0.014		0.004		0.012	
G X S	0.010		0.029		0.010		0.028		0.008		0.024	

Note: G₁: Cycocel at 500ppm, G₂: Cycocel at 1000 ppm, G₃: Benzyl Adenine at 100 ppm, G₄: Benzyl Adenine at 200 ppm, S₁: Syngonium reticulata, S₂: Syngonium podophyllum (Neon), S₃: Syngonium podophyllum (Bronze), S.Em (±)- Standard Error of Mean; CD at (5%) – Critical Difference at 5% level of significance

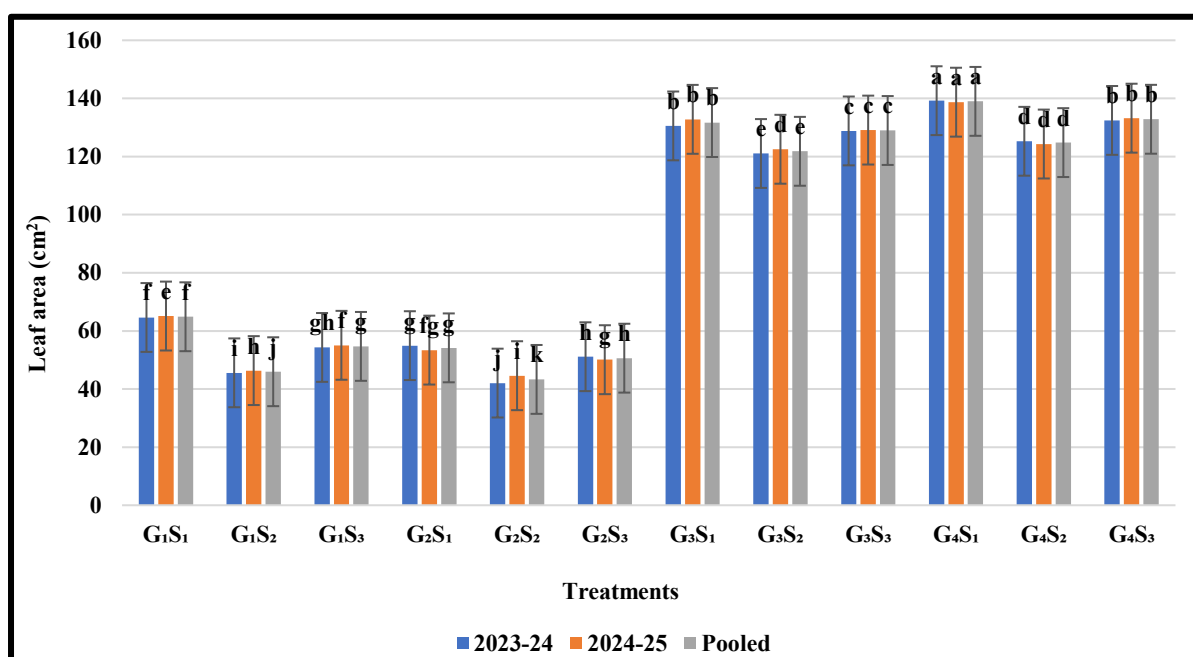


Fig. 1. Effect of plant growth regulators on leaf area (cm²) of different *Syngonium* species

Note: G₁: Cycocel at 500ppm, G₂: Cycocel at 1000 ppm, G₃: Benzyl Adenine at 100 ppm, G₄: Benzyl Adenine at 200 ppm, S₁: *Syngonium reticulata*, S₂: *Syngonium podophyllum* (Neon), S₃: *Syngonium podophyllum* (Bronze)

3.2 Leaf Width (cm)

The data presented in Table 2 revealed significant variation in leaf width among the treatments during both seasons as well as in the pooled analysis.

Among the plant growth regulators, the maximum leaf width (8.69 cm) was recorded with G4 (Benzyl Adenine at 200 ppm), whereas the minimum leaf width (5.13 cm) was observed with G2 (Cycocel at 1000 ppm). Among the species, S1 recorded the maximum leaf width (7.45 cm), followed by S3 (6.87 cm). In contrast, S2 consistently recorded the minimum leaf width (6.31 cm). For the interaction between the growth regulators and *Syngonium species*, G4S1 recorded the maximum leaf width (9.36 cm), and G2S2 recorded the minimum leaf width (4.58 cm).

3.3 Leaf Area (cm²)

Significant differences were observed among the treatments for leaf area, as presented in Table 3 and Fig. 1. Among the plant growth regulators, G4 (Benzyl Adenine at 200 ppm) recorded the maximum leaf area (132.20 cm²), whereas G2 (Cycocel at 1000 ppm) resulted in the minimum leaf area (49.36 cm²). Among the species, S1 recorded the maximum leaf area (97.42 cm²), followed by S3 (91.77 cm²). In contrast, S2 consistently recorded the minimum leaf area (83.96 cm²). The interaction effect revealed that G4S1 recorded the maximum leaf area (131.98 cm²), and G2S2 recorded the minimum leaf area (43.31 cm²).

Benzyl Adenine increased leaf length, width and area in *Syngonium species* due to its ability to stimulate cell division and expansion in leaf tissues, resulting in larger leaves and greater leaf area (Bhattacharjee, 1981; Salem et al., 2016). These changes may enhance photosynthetic capacity and overall plant vigour. Similar findings have been reported in chrysanthemum (Singh et al., 2020), *Ficus benjamina* (Sardoei & Shahbazi, 2021), hybrid tea rose (Mondal & Sarkar, 2018) and Asiatic lilies (Kapri et al., 2018), where Benzyl Adenine application led to a significant increase in leaf size and area.

In contrast, Cycocel reduces leaf length, width and area by inhibiting gibberellin biosynthesis, which limits cell elongation and expansion. This results in smaller, thicker leaves and a more compact plant form (Jing et al., 2023; Soliman et al., 2022).

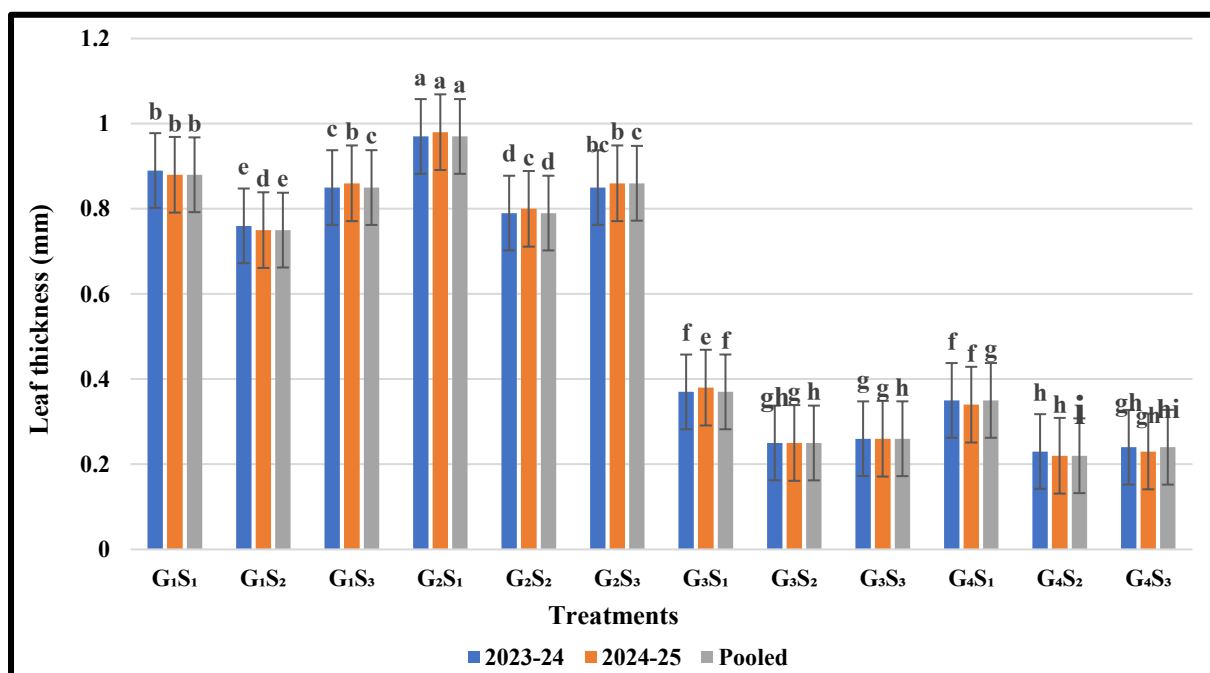


Fig. 2. Effect of plant growth regulators on leaf thickness (mm) of different *Syngonium* species

Note: G₁: Cycocel at 500ppm, G₂: Cycocel at 1000 ppm, G₃: Benzyl Adenine at 100 ppm, G₄: Benzyl Adenine at 200 ppm, S₁: *Syngonium reticulata*, S₂: *Syngonium podophyllum* (Neon), S₃: *Syngonium podophyllum* (Bronze)

3.4 Leaf Thickness (mm)

The data presented in Table 4 and Fig. 2 revealed significant variation in leaf thickness among the treatments. Among the plant growth regulators, the maximum leaf thickness (0.88 mm) was recorded with G₂ (Cycocel at 1000 ppm), whereas the minimum leaf thickness (0.27 mm) was observed with G₄ (Benzyl Adenine at 200 ppm). Among the species, S₁ recorded the maximum leaf thickness (0.64 mm), followed by S₃ (0.55 mm). In contrast, S₂ consistently recorded the minimum leaf thickness (0.51 mm). For the interaction between the growth regulators and *Syngonium species*, G₂S₁ recorded the maximum leaf thickness (0.97 mm), and G₄S₂ recorded the minimum leaf thickness (0.22 mm).

Cycocel increases leaf thickness primarily by inhibiting gibberellin biosynthesis, which restricts cell elongation and expansion, leading to the development of smaller, thicker leaves. According to Shah and Shah (1991) and Allen et al. (1970), this effect is attributed to increased cell division in the palisade and spongy mesophyll layers, resulting in more densely packed cells and greater leaf thickness. In contrast, Benzyl Adenine generally promotes cell division and expansion, resulting in thinner, larger leaves (Fuadi & Syamsuardi, 2014).

A similar increase in leaf thickness due to CCC has also been reported in *Gardenia jasminoides* (Soliman et al., 2022), ornamental cabbage and kale (Gholampour et al., 2012) and *Chrysanthemum frutescens* (Ghatas, 2016).

3.5 Dry Weight of Leaf (g)

Significant differences were observed among the treatments for dry weight of leaf, as presented in Table 5. Among the plant growth regulators, G₄ (Benzyl Adenine at 200 ppm) recorded the maximum dry weight of leaf (0.385 g), whereas G₂ (Cycocel at 1000 ppm) resulted in the minimum dry weight of leaf (0.217 g).

Among the species, S₁ recorded the maximum dry weight of leaf (0.331 g), followed by S₃ (0.293 g). In contrast, S₂ consistently recorded the minimum dry weight of leaf (0.269 g). The interaction effect revealed that G₄S₁ recorded the maximum dry weight of leaf (0.428 g), and G₂S₂ recorded the minimum dry weight of leaf (0.204 g).

Table 5. Effect of plant growth regulators on dry weight of leaf (g)

Treatments	2023-24				2024-25				POOLED DATA			
	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean
G ₁	0.242 ^f	0.210 ⁱ	0.224 ^h	0.225 ^c	0.247 ^g	0.212 ^j	0.221 ⁱ	0.227 ^c	0.245 ^g	0.211 ^j	0.223 ⁱ	0.226 ^c
G ₂	0.232 ^g	0.201 ^j	0.213 ⁱ	0.216 ^d	0.234 ^h	0.207 ^k	0.217 ^{ij}	0.219 ^d	0.233 ^h	0.204 ^k	0.215 ^j	0.217 ^d
G ₃	0.414 ^b	0.320 ^e	0.355 ^d	0.363 ^b	0.42 ^b	0.317 ^f	0.348 ^d	0.362 ^b	0.417 ^b	0.318 ^f	0.352 ^d	0.363 ^b
G ₄	0.427 ^a	0.348 ^d	0.384 ^c	0.386 ^a	0.429 ^a	0.337 ^e	0.384 ^c	0.383 ^a	0.428 ^a	0.343 ^c	0.384 ^c	0.385 ^a
Mean	0.329^a	0.270^c	0.294^b		0.333^a	0.268^c	0.293^b		0.331^a	0.269^c	0.293^b	
	S.Em (±)			CD at (5%)	S.Em (±)			CD at (5%)	S.Em (±)			CD at (5%)
G	0.001			0.004	0.002			0.005	0.001			0.004
S	0.001			0.004	0.001			0.004	0.001			0.003
G X S	0.002			0.007	0.003			0.008	0.002			0.006

Note: G₁: Cycocel at 500ppm, G₂: Cycocel at 1000 ppm, G₃: Benzyl Adenine at 100 ppm, G₄: Benzyl Adenine at 200 ppm, S₁: Syngonium reticulata, S₂: Syngonium podophyllum (Neon), S₃: Syngonium podophyllum (Bronze), S.Em (±)- Standard Error of Mean; CD at (5%) – Critical Difference at 5% level of significance

Table 6. Effect of plant growth regulators on specific leaf area (cm² g⁻¹)

Treatments	2023-24				2024-25				POOLED DATA			
	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean
G ₁	269.06 ^c	222.41 ^h	245.80 ^f	245.09 ^c	263.27 ^c	218.95 ^{gh}	248.74 ^f	243.65 ^c	266.16 ^c	219.68 ^h	247.27 ^f	244.37 ^c
G ₂	229.78 ^{gh}	221.79 ^h	234.86 ^{fg}	228.81 ^d	228.51 ^{gh}	215.82 ^h	230.88 ^g	225.07 ^d	229.15 ^g	218.80 ^h	232.87 ^g	226.94 ^d
G ₃	320.64 ^d	382.94 ^a	363.34 ^b	355.64 ^a	316.08 ^d	387.08 ^a	370.70 ^b	357.90 ^a	318.36 ^d	385.01 ^a	367.02 ^b	356.8 ^a
G ₄	325.21 ^d	356.93 ^c	347.28 ^c	343.14 ^b	323.66 ^d	368.60 ^b	347.25 ^c	346.50 ^b	324.44 ^d	362.76 ^b	347.27 ^c	344.82 ^b
Mean	286.17^b	295.52^a	297.82^a		282.88^b	297.61^a	299.39^a		284.53^b	296.56^a	298.61^a	
	S.Em (±)			CD at (5%)	S.Em (±)			CD at (5%)	S.Em (±)			CD at (5%)
G	2.21			6.46	2.75			8.03	2.30			6.71
S	1.92			5.59	2.38			6.96	1.99			5.81
G X S	3.83			11.18	4.77			13.92	3.98			11.62

Note: G₁: Cycocel at 500ppm, G₂: Cycocel at 1000 ppm, G₃: Benzyl Adenine at 100 ppm, G₄: Benzyl Adenine at 200 ppm, S₁: Syngonium reticulata, S₂: Syngonium podophyllum (Neon), S₃: Syngonium podophyllum (Bronze), S.Em (±)- Standard Error of Mean; CD at (5%) – Critical Difference at 5% level of significance

Table 7. Effect of plant growth regulators on specific leaf weight (mg cm⁻²)

Treatments	2023-24				2024-25				POOLED DATA			
	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean	S ₁	S ₂	S ₃	Mean
G ₁	3.72 ^d	4.51 ^a	4.07 ^c	4.11 ^b	3.80 ^c	4.57 ^{ab}	4.02 ^d	4.13 ^b	3.76 ^d	4.55 ^a	4.05 ^c	4.12 ^b
G ₂	4.35 ^b	4.54 ^a	4.26 ^b	4.38 ^a	4.38 ^{bc}	4.64 ^a	4.33 ^c	4.45 ^a	4.37 ^b	4.58 ^a	4.30 ^b	4.41 ^a
G ₃	3.12 ^e	2.61 ^g	2.75 ^{fg}	2.83 ^d	3.16 ^f	2.58 ^h	2.70 ^{gh}	2.82 ^c	3.14 ^e	2.60 ^h	2.73 ^g	2.82 ^d
G ₄	3.08 ^e	2.80 ^f	2.88 ^f	2.92 ^c	3.09 ^f	2.71 ^{gh}	2.88 ^g	2.89 ^c	3.08 ^e	2.76 ^g	2.88 ^f	2.91 ^c
Mean	3.57^a	3.62^{ab}	3.49^b		3.61^a	3.63^a	3.48^b		3.59^a	3.62^a	3.49^b	
	S.Em (±)		CD at (5%)		S.Em (±)		CD at (5%)		S.Em (±)		CD at (5%)	
G	0.03		0.09		0.04		0.11		0.03		0.09	
S	0.03		0.08		0.03		0.05		0.03		0.08	
G X S	0.05		0.16		0.07		0.19		0.05		0.16	

Note: G₁: Cycocel at 500ppm, G₂: Cycocel at 1000 ppm, G₃: Benzyl Adenine at 100 ppm, G₄: Benzyl Adenine at 200 ppm, S₁: Syngonium reticulata, S₂: Syngonium podophyllum (Neon), S₃: Syngonium podophyllum (Bronze), S.Em (±)- Standard Error of Mean; CD at (5%) – Critical Difference at 5% level of significance

Among all treatments, Benzyl Adenine at the higher concentration recorded the maximum dry weight of leaves, which can be attributed to its role in promoting mitotic activity in leaf tissues, leading to increased cell number and size, which directly contributed to higher leaf dry weight. This cytokinin effect enhances chlorophyll content and photosynthetic efficiency, supporting greater biomass production and accumulation in leaves (Aminifard et al., 2020).

Furthermore, the highest leaf area resulting from BA treatment in all species resulted in a larger photosynthetic surface and increased dry matter accumulation (Bhattacharjee, 1981; Salem et al., 2016). Additionally, Benzyl Adenine delays leaf senescence, allowing leaves to remain physiologically active for longer periods and further increasing dry weight (Sorour et al., 2016). Similar results have been reported in *Ficus benjamina* by Sardoei and Shahbazi (2021) and in calla lily by Kasem & Helaly (2021).

Due to reduced leaf number and leaf area in Cycocel-treated *Syngonium species*, the dry weight was recorded as the minimum. Cycocel reduces leaf dry weight by inhibiting gibberellin biosynthesis, which limits cell elongation and expansion. This results in smaller, thicker leaves with less dry matter accumulation, as Cycocel restricts both cell growth and leaf expansion (Jing et al., 2023; Soliman et al., 2022).

3.6 Specific Leaf Area ($\text{cm}^2 \text{g}^{-1}$)

Significant differences were observed among the treatments for specific leaf area (SLA), as presented in Table 6. Among the plant growth regulators, G3 (Benzyl Adenine at 100 ppm) recorded the maximum SLA ($356.8 \text{ cm}^2 \text{ g}^{-1}$), whereas G2 (Cycocel at 1000 ppm) resulted in the minimum SLA ($226.94 \text{ cm}^2 \text{ g}^{-1}$). Among the species, S3 recorded the maximum SLA ($298.61 \text{ cm}^2 \text{ g}^{-1}$) and was on par with S2 ($296.56 \text{ cm}^2 \text{ g}^{-1}$). In contrast, S1 consistently recorded the minimum SLA ($284.53 \text{ cm}^2 \text{ g}^{-1}$). The interaction effect revealed that G3S2 recorded the maximum SLA ($385.01 \text{ cm}^2 \text{ g}^{-1}$), and G2S2 recorded the minimum SLA ($218.80 \text{ cm}^2 \text{ g}^{-1}$).

3.7 Specific Leaf Weight (mg cm^{-2})

The results presented in Table 7 revealed significant variation in specific leaf weight (SLW) among the treatments. Among the plant growth regulators, the maximum SLW (4.41 mg cm^{-2}) was recorded with G2 (Cycocel at 1000 ppm), whereas the minimum SLW (2.82 mg cm^{-2}) was observed with G3 (Benzyl Adenine at 100 ppm).

Among the species, S2 recorded the maximum SLW (3.62 mg cm^{-2}), followed by S1 (3.59 mg cm^{-2}). In contrast, S3 consistently recorded the minimum SLW (3.49 mg cm^{-2}). For the interaction between the growth regulators and *Syngonium species*, G2S2 recorded the maximum SLW (4.58 mg cm^{-2}), and G3S2 recorded the minimum SLW (2.73 mg cm^{-2}).

Specific leaf weight is the ratio of leaf dry weight to leaf area and is the reciprocal of specific leaf area. Although Benzyl Adenine recorded the maximum leaf area, leaf dry weight and SLA, Cycocel exhibited the maximum specific leaf weight. Cycocel restricts cell elongation and leaf expansion, resulting in smaller, thicker leaves with higher dry matter accumulation per unit leaf area. In contrast, Benzyl Adenine promotes cell division and leaf expansion, producing larger and relatively thinner leaves, which leads to higher leaf area and specific leaf area but comparatively lower specific leaf weight.

Similar trends were reported in marigold and petunia, where Cycocel reduced cell elongation but increased leaf thickness, tissue density and SLW (Latimer, 1991). Likewise, in chrysanthemum, Cycocel produced compact plants with thicker leaves and increased SLW (Sajid et al., 2016). Increased leaf thickness due to Cycocel was also reported in *Gardenia jasminoides* by Soliman et al. (2022).

4. Conclusions

The study showed that plant growth regulators influenced the leaf characteristics of selected *Syngonium species* under vertical gardening conditions. Benzyl Adenine at 200 ppm recorded higher values for leaf length, leaf width, leaf area and dry weight of leaf, indicating its role in improving leaf expansion and foliage development. Benzyl Adenine at 100 ppm recorded the highest specific leaf area, suggesting the development of broader leaf area in relation to leaf dry weight. Cycocel at 1000 ppm recorded higher specific leaf weight and leaf thickness,

indicating its effect in producing comparatively compact and thicker leaves. Among the species evaluated, *Syngonium reticulata* showed better performance for most recorded leaf characters, including leaf length, leaf width, leaf area, dry weight of leaf and leaf thickness. Based on the results, Benzyl Adenine may be useful where improved foliage growth is desired, while Cycocel may be considered for maintaining compact foliage in space-limited vertical gardening systems. Further validation is required before broad recommendation under different growing environments.

5. Limitations

The study was conducted at one location under a specific vertical gardening system during two experimental years, which may limit wider generalisation of the findings. Only three *Syngonium* types and four plant growth regulator treatments were evaluated, and an untreated control was not included. The study focused mainly on leaf characteristics and did not include detailed physiological, biochemical, root growth, post-establishment or long-term performance parameters. Future studies should include untreated controls, additional concentrations, more species or cultivars, different vertical gardening conditions and longer observation periods to confirm the practical usefulness of these treatments.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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