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INFLUENCE OF LIGHT INTENSITY ON THE GROWTH AND PERFORMANCE OF ORNAMENTAL FOLIAGE PLANTS IN VERTICAL GARDEN SYSTEMS

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ABSTRACT

Urbanization and the consequent reduction in green spaces have necessitated innovative greening approaches such as vertical gardening to enhance ecological balance and aesthetic appeal in limited spaces. The present study was undertaken to evaluate the growth performance of ornamental foliage plants under varying light intensities in a vertical garden system. The experiment was carried out from November 2022 to March 2024 at the Floriculture Research Station, Rajendranagar, Hyderabad, employing a Factorial Completely Randomized Design (FCRD) with three ornamental foliage species—*Philodendron erubescens*, *Syngonium podophyllum*, and *Pandanus veitchii*-under four light intensity regimes: 250–500 lux (control), 500–1000 lux, 1000–1500 lux, and 1500–2000 lux. Key morphological, physiological, and quality parameters including plant height, spread, leaf number, specific leaf area, survival rate, SPAD chlorophyll content, and absolute growth rate were recorded at 90 and 180 days after planting. Results revealed that higher light intensities (particularly 1500–2000 lux) significantly enhanced growth and physiological responses across species. *Syngonium podophyllum* exhibited superior adaptability and performance under elevated light intensities, while *Pandanus veitchii* was comparatively less responsive due to its sun-loving nature. The findings underscore the critical role of light optimization in vertical garden success and indicate that strategic plant selection combined with appropriate light intensity management can significantly improve indoor plant performance. This research provides valuable insights for sustainable urban greening through vertical horticulture in resource-constrained environments.
***Keywords*:** Vertical gardening, ornamental foliage plants, light intensity, indoor greening, urban horticulture.

Introduction

Plants are autotrophic organisms capable of synthesizing their own food through photosynthesis. Their ecological roles extend beyond food production to regulating atmospheric gases, sequestering carbon dioxide, and releasing life-sustaining oxygen. Urban ecosystems, due to intense anthropogenic activity and unchecked infrastructure development, have witnessed a sharp decline in vegetative cover. This, in turn, has led to environmental challenges such as the urban heat island effect, deteriorating air quality, and loss of biodiversity (Wong *et al.*, 2003). Consequently, the integration of green infrastructure, particularly vertical gardening, has gained prominence as a sustainable and space-efficient greening strategy in urban environments.

Vertical gardening, also known as green walls or living walls, refers to the practice of growing vegetation vertically using specially designed systems attached to indoor or outdoor structures. While the idea of growing plants vertically is not new—tracing back to the Hanging Gardens of Babylon (600 BC) its systematic application in urban landscapes began only in the 20th century (Ingram *et al.*, 2003). Professor

Stanley Hart White is credited with pioneering the modern concept of the green wall through his invention "Botanical Bricks" in 1938. Later, Patrick Blanc, a French botanist, introduced the hydroponic vertical garden system that is widely used today (Blanc, 2008). The rising popularity of vertical gardens in the 21st century is attributed to their multifunctionality: they enhance urban aesthetics, insulate buildings, regulate temperature, improve air quality, and create biodiversity hotspots (Jain and Janakiram, 2016). In densely populated cities, where horizontal space is a limiting factor, vertical gardening offers a practical solution for reintroducing green cover. It transforms bare walls into vibrant ecosystems, thus helping cities shift from "grey to green."

According to studies, vegetation density has a direct impact on local air quality and thermal regulation (Peck *et al*., 1999). Plants in vertical gardens help absorb pollutants and airborne particulate matter, contributing to reduced respiratory ailments among urban residents. Indoor air pollution, often caused by volatile organic compounds (VOCs), is significantly higher than outdoor air pollution. Research has shown that certain ornamental foliage plants can reduce indoor air pollutants, thereby acting as natural air purifiers (Abbritti and Muzi, 1995; Krzyzanowski, 1999). This function becomes especially critical as studies suggest that urban populations spend 80–90% of their time indoors. In addition to their environmental and health benefits, vertical gardens also play a vital role in mitigating the urban heat island effect, a phenomenon where urban zones experience significantly higher temperatures than surrounding rural areas due to dense construction and lack of vegetation. Plants in vertical gardens reduce surface and ambient temperatures through evapotranspiration and shading. These living walls can lower indoor room temperatures by up to 5°C compared to outdoor conditions (Jain and Janakiram, 2016). Furthermore, they serve as sound barriers and improve mental well-being by enhancing the visual appeal of urban infrastructure.

As urban planning and architecture increasingly adopt green building principles, vertical gardening is now incorporated into building facades, balconies, patios, and rooftops. Real estate developers often use green infrastructure as a value addition, with evidence suggesting that vegetated landscapes can increase property values by 6–15% (Gilhooley, 2002). Additionally, the rise in vertical gardens has opened up employment opportunities for landscape designers, horticulturists, and nurserymen, thereby contributing to the green economy. Despite these benefits, vertical gardening poses certain challenges, particularly in plant selection, light management, and maintenance. The success of a vertical garden largely depends on environmental parameters, of which **light** plays a critical role. Light is a fundamental factor in photosynthesis and directly influences plant morphology, growth rate, and pigment development. However, many ornamental foliage plants used in vertical gardens are grown indoors or in shaded environments, where natural light is limited or inconsistent. In such scenarios, artificial lighting becomes essential.

Traditional artificial lighting systems, such as incandescent, fluorescent, high-pressure sodium (HPS), and metal halide lamps, emit broad-spectrum light that includes non-photosynthetically active wavelengths. These lights are energy-intensive and not optimized for plant growth (Kim *et al.,* 2004). In contrast, light-emitting diode (LED) technology has emerged as a promising alternative for artificial lighting in horticulture. LEDs offer several advantages: narrow spectral output, high energy efficiency, low heat emission, and customizable light intensity and wavelength, making them ideal for plant cultivation in constrained environments (Lin *et al.,* 2013). The response of plants to light varies significantly based on species, growth stage, and light quality. Indoor ornamental foliage plants generally require lower light intensities compared to outdoor or flowering species. Hence, standardizing the optimal light intensities for different species is imperative for maximizing plant health and aesthetic value in vertical garden systems. Insufficient light may result in etiolation, leaf chlorosis, reduced photosynthetic efficiency, and poor overall plant vigour.

Additionally, the position of plants within a vertical garden affects their exposure to light, water, and nutrients. For instance, plants located at higher elevations may receive more light but less moisture due to gravity-based irrigation systems. Therefore, it is critical to choose species with compatible growth habits, nutrient needs, and light responses. Factors such as evergreen nature, low maintenance requirement, pest resistance, and tolerance to limited root zone conditions should also be considered (Wong *et al.,* 2003). Geographical location, building orientation, and ambient air pollution levels further influence species performance. Plants selected for vertical gardens should be lightweight, possess fibrous root systems, and exhibit longevity to ensure sustainability and cost-effectiveness. The incorporation of indigenous plant species adapted to local conditions can enhance the success rate and reduce maintenance inputs.

In the Indian context, vertical gardening is a relatively nascent practice with immense potential. Initiatives like Swachh Bharat Abhiyan and Green India Mission provide a policy framework for integrating green technologies in urban development. However, scientific studies on optimal growth conditions for ornamental foliage plants under controlled light environments in vertical gardens are limited. Research is particularly lacking in areas such as light intensity optimization, plant-soil-light interactions, species compatibility, and growth media standardization.

Hence, the present study is undertaken with the objective to evaluate the performance of ornamental foliage plants under different light intensities in vertical garden systems. This research aims to bridge existing knowledge gaps and provide empirical data that can inform the design, installation, and maintenance of efficient vertical gardens suited to urban Indian settings. The outcomes are expected to contribute toward enhancing the sustainability, functionality, and visual appeal of vertical gardens while addressing challenges associated with urban greening.

Materials and Methods

Experimental Site and Climatic Conditions

The present investigation entitled " Influence of Light Intensity on the Growth and Performance of Ornamental Foliage Plants in Vertical Garden Systems" was conducted at the Floriculture Research Station, Agricultural Research Institute, Rajendranagar, affiliated with Sri Konda Laxman Telangana State Horticultural University, Hyderabad, during the period from November 2022 to March 2024.

The experimental site is situated in a semi-arid tropical climate, receiving an average annual rainfall of 615.6 mm. The location is positioned at 17.900° N latitude and 78.230° E longitude, with an altitude of 542.3 meters above mean sea level. The environmental conditions during the experimental period were conducive for growing shade-loving ornamental foliage species under controlled light environments.

Experimental Design and Layout

- **Design**: Factorial Completely Randomized Design (FCRD)
- **Number of Treatments**: 12
- **Replications**: 3
- **Frame Size**: 10' × 5'
- **Pot Size**: 5" height × 4" diameter (polypropylene)

Treatment Details

Factor I – Ornamental Foliage Plant Species

- **P_1**: *Philodendron erubescens* 'Gold' (Blushing Philodendron)
- **P_2**: *Syngonium podophyllum* (Arrowhead Vine)
- **P_3**: *Pandanus veitchii* variegata (Screw Pine)

Factor II – Light Intensities

- **L_1**: 250–500 lux (Control; natural ambient light)
- **L_2**: 500–1000 lux
- **L_3**: 1000–1500 lux
- **L_4**: 1500–2000 lux

Treatment Combinations

Treatment Code	Combination
T_1	P_1L_1 – *Philodendron* + 250–500 lux
T_2	P_1L_2 – *Philodendron* + 500–1000 lux
T_3	P_1L_3 – *Philodendron* + 1000–1500 lux
T_4	P_1L_4 – *Philodendron* + 1500–2000 lux
T_5	P_2L_1 – *Syngonium* + 250–500 lux
T_6	P_2L_2 – *Syngonium* + 500–1000 lux
T_7	P_2L_3 – *Syngonium* + 1000–1500 lux
T_8	P_2L_4 – *Syngonium* + 1500–2000 lux
T_9	P_3L_1 – *Pandanus* + 250–500 lux
T_{10}	P_3L_2 – *Pandanus* + 500–1000 lux
T_{11}	P_3L_3 – *Pandanus* + 1000–1500 lux
T_{12}	P_3L_4 – *Pandanus* + 1500–2000 lux

Each vertical structure accommodated 45 plants with 15 pots per plant species under each light intensity treatment.

Planting Material and Growing Media

Three ornamental foliage species—*Philodendron erubescens*, *Syngonium podophyllum*, and *Pandanus veitchii* were selected based on their popularity, indoor compatibility, and ornamental value. Uniform, one-month-old rooted plants were transplanted into 5-inch pots filled with a standard medium consisting of red soil, sand, and vermicompost in the ratio 1:1:2.

Vertical Garden Setup and Light Treatments

Four vertical frame structures were fabricated, each measuring 10 ft × 5 ft, to simulate vertical gardening systems. The frames were equipped with PWM (Pulse Width Modulation) controlled artificial lighting systems to ensure specific light intensities:

- **L_1 (Control)**: Natural indoor light (250–500 lux)
- **L_2**: Artificial light adjusted to 500–1000 lux
- **L_3**: Artificial light adjusted to 1000–1500 lux

- **L_4**: Artificial light adjusted to 1500–2000 lux

Light was provided for a duration of 12 hours per day for all treatments. Plates documenting the experimental setup are included in the supplementary materials.

Irrigation and Nutrient Management

Plants were fertigated every 30 days with 100 ml of nutrient solution per plant. Additionally, drip irrigation was used to maintain optimal soil moisture, with 1 L/h discharge drippers supplying water at 4–5 day intervals depending on the plant requirement.

Standard cultural practices including carbendazim (0.2%) application were adopted post-transplanting to prevent fungal diseases.

Data Collection and Observations

Observations were recorded on five randomly selected plants per replication at 90 and 180 Days After Planting (DAP) for the following parameters:

Morphological Parameters

- **Plant Height (cm)**: Measured from soil surface to plant apex.
- **Plant Spread (cm²)**: Average canopy spread measured from East–West and North–South directions.
- **Number of Leaves per Plant**: Count of fully expanded mature leaves.
- **Survival Percentage (%)**:

  = (Number of Survived Plants /Total Number of plants) x 100

Leaf Area and Associated Parameters

- **Specific Leaf Area (SLA)** (cm²/g):

$$\text{SLA} = \frac{\text{Leaf area}}{\text{Leaf dry weight}}$$

- **Leaf Area Index (LAI)** (Watson, 1952):

Leaf area index (LAI) was computed using the formulae suggested by Watson (1952).

LAI = A/P

Where, **A** = Leaf area

P = Ground area covered by pot

$= \pi \times [\text{diameter of grow bag}/2]^2$

$= 22/7 \times [25/2]^2 = 491.07 \text{ cm}^2$

Physiological Parameters

- **Chlorophyll Content (SPAD Value)**: Measured using SPAD-502 Chlorophyll Meter (Konica Minolta, Japan) on fully expanded young leaves.
- **Absolute Growth Rate (AGR)** (Redford, 1967):

$$\text{AGR (plant height)} = \frac{h_2 - h_1}{t_2 - t_1}$$

Where,

h_1 = Plant height (cm) at time T_1

h_2 = Plant height (cm) at time T_2

Statistical Analysis

All the recorded data were subjected to Analysis of Variance (ANOVA) appropriate for a Factorial Completely Randomized Design (FCRD) using statistical software. Treatment means were compared using LSD (Least Significant Difference) at 5% level of significance.

Results and Discussion

Growth Parameters

Plant height (cm)

Plant height (cm) (90 DAP)

Data recorded on plant height (90 DAP) of ornamental foliage plants influenced by light intensities and their interactions are presented in Table 1.

Pooled data at 90 DAP, the maximum plant height (12.97 cm) was recorded with L_4**:** 1500 - 2000 LUX, followed by L_3**:** 1000 - 1500 LUX (12.29 cm). Whereas, L_1**:** 250 - 500 LUX recorded significantly minimum plant height (8.80 cm).

Significant difference among different ornamental foliage plants was recorded with respect to plant height at 90 DAP. The maximum plant height (11.59 cm) was recorded with P_2- Syngonium followed by P_1- Philodendron (11.15 cm). Minimum plant height (10.67 cm) was observed with P_3- Pandanus.

In the interactions L_4P_2- 1500 - 2000 LUX + Syngonium recorded significantly maximum plant height (13.50 cm), which was followed by L_4P_1- 1500 - 2000 LUX + Philodendron (13.10 cm). While, L_1P_3- 250 - 500 LUX + Pandanus recorded minimum plant height (8.56 cm).

Plant height (180 DAP)

Data recorded on plant height (180 DAP) of ornamental foliage plants as influenced by light intensities and their interactions are presented in Table 1.

In pooled data at 180 days after planting maximum plant height (27.92 cm) was recorded in the treatment L_4**:** 1500 - 2000 LUX followed by L_3: 1000 - 1500 LUX (25.52 cm). Whereas, the L_1: 250 - 500 LUX registered significantly minimum plant height (20.12 cm).

There was significant difference among ornamental foliage plants on plant height at 180 DAP. The maximum plant height (25.63 cm) was recorded with P_2- Syngonium followed by P_1-Philodendron (24.15 cm). Whereas the minimum plant height (23.87 cm) was noticed with P_3- Pandanus.

In the interactions, L_4P_2- 1500 - 2000 LUX + Syngonium recorded significantly maximum plant height (30.11 cm) followed by L_4P_1-1500 - 2000 LUX + Philodendron (28.27 cm). Whereas, L_1P_3- 250 - 500 LUX + Pandanus noticed minimum plant height (19.50 cm).

Table 1: Effect of different light intensities on plant height (cm) at 90 and 180 days after planting in vertical garden

Treatments	**90 Days**				**180 Days**			
	P_1	**P_2**	**P_3**	**Mean**	**P_1**	**P_2**	**P_3**	**Mean**
L_1	8.80	9.03	**8.56**	**8.80**	19.81	21.03	**19.50**	**20.12**
L_2	10.11	11.04	10.37	**10.51**	23.39	25.17	25.39	**24.65**
L_3	12.60	12.80	11.46	**12.29**	25.13	26.21	25.23	**25.52**
L_4	**13.10**	**13.50**	12.31	**12.97**	**28.27**	**30.11**	25.36	**27.92**
Mean	**11.15**	**11.59**	**10.67**		**24.15**	**25.63**	**23.87**	
	S.Em ±		**CD (5%)**		**S.Em ±**		**CD (5%)**	
Ornamental foliage plants (P)	0.07		0.19		0.20		0.58	
Light intensities (L)	0.08		0.22		0.23		0.67	
PXL	0.13		0.38		0.40		1.16	

Factor I: Ornamental foliage plants (P)-
P_1- Philodendron **P_2**- Syngonium **P_3**- Pandanus
Factor II: Light intensities (L)-
L_1: 250 - 500 LUX (Control) **L_2**: 500 - 1000 LUX **L_3**: 1000 - 1500 LUX **L_4**: 1500 - 2000 LUX

Plant spread (cm)

Plant spread (N-S) (90 DAP)

Data recorded on plant spread (90 DAP) of ornamental foliage plants as influenced by different light intensities and their interactions are presented in Table 2.

In pooled data at 90 days after planting maximum plant spread (15.27 cm) was recorded in the treatment L_4**-** 1500 - 2000 LUX followed by L_3**-** 1000 - 1500 LUX (14.39 cm). Whereas, the L_1**-** 250 - 500 LUX registered significantly minimum plant spread (10.98 cm).

There was significant difference among ornamental foliage plants on plant spread at 90 DAP. The maximum plant spread (14.21 cm) was recorded with P_3- Pandanus followed by P_1-Philodendron (13.77 cm). Whereas the minimum plant spread (12.07 cm) was noticed with P_2- Syngonium.

In the interactions, L_4P_3- 1500 - 2000 LUX + Pandanus recorded significantly maximum plant spread (16.41 cm) which was at par with L_4P_1- 1500 - 2000 LUX + Philodendron (15.88 cm). Whereas, L_1P_2- 250 - 500 LUX + Syngonium noticed minimum plant spread (10.44 cm).

Plant spread (N-S) (180 DAP)

In pooled data at 180 days after planting maximum plant spread (34.75 cm) was recorded in the treatment L_4-1500 - 2000 LUX follow by L_3-1000 - 1500 LUX (32.44 cm). Whereas, the L_1-250 - 500 LUX registered significantly minimum plant spread (23.49 cm).

There was significant difference among ornamental foliage plants on plant spread at 180 DAP. The maximum plant spread (30.74 cm) was recorded with P_3- Pandanus followed by P_1-Philodendron (30.11 cm). Whereas the minimum plant spread (26.58 cm) was noticed with P_2- Syngonium.

In the interactions, L_4P_3- 1500 - 2000 LUX + Pandanus recorded significantly maximum plant spread (37.98 cm) followed by L_4P_1- 1500 - 2000 LUX + Philodendron (35.34 cm). Whereas, L_1P_2- 250 - 500 LUX + Syngonium noticed minimum plant spread (20.95 cm).

Table 2: Effect of different light intensities on plant spread (N-S) (cm) at 180 days after planting in vertical garden

Treatments	90 Days				180 Days			
	P_1	P_2	P_3	Mean	P_1	P_2	P_3	Mean
L_1	11.18	**10.44**	11.31	**10.98**	24.12	**20.95**	25.40	**23.49**
L_2	13.00	11.61	13.70	**12.77**	26.82	24.35	26.48	**25.88**
L_3	15.02	12.71	15.42	**14.39**	34.16	30.07	33.10	**32.44**
L_4	**15.88**	13.52	**16.41**	**15.27**	**35.34**	30.94	**37.98**	**34.75**
Mean	**13.77**	**12.07**	**14.21**		**30.11**	**26.58**	**30.74**	
	S.Em ±		**CD (5%)**		**S.Em ±**		**CD (5%)**	
Ornamental foliage plants (P)	0.10		0.29		0.17		0.48	
Light intensities (L)	0.12		0.34		0.19		0.56	
PXL	0.20		0.59		0.33		0.96	

Factor I: Ornamental foliage plants (P)-
P_1- Philodendron **P_2**- Syngonium **P_3**- Pandanus
Factor II: Light intensities (L)-
L_1: 250 - 500 LUX (Control) **L_2**: 500 - 1000 LUX **L_3**: 1000 - 1500 LUX **L_4**: 1500 - 2000 LUX

Plant spread (E-W) (90 DAP)

Data recorded on plant spread (90 DAP) of ornamental foliage plants as influenced by light intensities and their interactions are presented in Table 3.

In pooled data at 90 days after planting maximum plant spread (15.42 cm) was recorded in the treatment L_4: 1500 - 2000 LUX followed by L_3: 1000 - 1500 LUX (14.47 cm). Whereas, the L_1: 250 - 500 LUX registered significantly minimum plant spread (11.07 cm).

There was significant difference among ornamental foliage plants on plant spread at 90 DAP. The maximum plant spread (14.30 cm) was recorded with P_3- Pandanus which was followed by P_1- Philodendron (13.95 cm). Whereas the minimum plant spread (12.08 cm) was noticed with P_2- Syngonium.

In the interactions, L_4P_3: 1500 - 2000 LUX + Pandanus recorded significantly maximum plant spread (16.80 cm) followed by L_4P_1: 1500 - 2000 LUX + Philodendron (16.10 cm). Whereas, L_1P_2: 250 - 500 LUX + Syngonium noticed minimum plant spread (10.41 cm).

Plant spread (E-W) (180 DAP)

Data recorded on plant spread (180 DAP) of ornamental foliage plants as influenced by growing media and their interactions are presented in Table 3.

In pooled data at 180 days after planting maximum plant spread (36.79 cm) was recorded in the treatment L_4: 1500 - 2000 LUX follow by L_3: 1000 - 1500 LUX (33.80 cm). Whereas, the L_4: 250 - 500 LUX registered significantly minimum plant spread (23.18 cm).

There was significant difference among ornamental foliage plants on plant spread at 180 DAP. The maximum plant spread (32.74 cm) was recorded with P_3- Pandanus which was followed by P_1- Philodendron (31.04 cm). Whereas, the minimum plant spread (26.85 cm) was noticed with P_2- Syngonium.

In the interactions, L_4P_3: 1500 - 2000 LUX + Pandanus recorded significantly maximum plant spread (40.79 cm) followed by L_4P_1: 1500 - 2000 LUX + Philodendron (38.42 cm). Whereas, L_1P_2: 250 - 500 LUX + Syngonium noticed minimum plant spread (21.37 cm).

Table 3: Effect of different light intensities on plant spread (N-S) (cm) at 90 and 180 days after planting in vertical garden

Treatments	90 Days				180 Days			
	P_1	P_2	P_3	Mean	P_1	P_2	P_3	Mean
L_1	11.32	**10.41**	11.49	**11.07**	22.13	**21.37**	26.05	**23.18**
L_2	13.33	11.61	13.53	**12.82**	27.64	25.69	27.88	**27.07**
L_3	15.06	12.97	15.38	**14.47**	35.97	29.17	36.26	**33.80**
L_4	**16.10**	13.35	**16.80**	**15.42**	**38.42**	31.16	**40.79**	**36.79**
Mean	**13.95**	**12.08**	**14.30**		**31.04**	**26.85**	**32.74**	
	S.Em ±		**CD (5%)**		**S.Em ±**		**CD (5%)**	
Ornamental foliage plants (P)	0.11		0.32		0.19		0.56	
Light intensities (L)	0.12		0.36		0.22		0.65	
PXL	0.22		0.63		0.39		1.12	

Factor I: Ornamental foliage plants (P)-
P_1- Philodendron **P_2**- Syngonium **P_3**- Pandanus
Factor II: Light intensities (L)-
L_1: 250 - 500 LUX (Control) **L_2**: 500 - 1000 LUX **L_3**: 1000 - 1500 LUX **L_4**: 1500 - 2000 LUX

Number of leaves per plant

Number of leaves per plant (90 DAP)

Data recorded on number of leavers per plant (90 DAP) of ornamental foliage plants influenced by light intensities and their interactions are presented in Table 4.

In pooled data at 90 days after planting maximum number of leaves (9.09) was recorded in the treatment L_4: 1500 - 2000 LUX which was at par with L_3: 1000 - 1500 LUX (8.81). Whereas, the L_1: 250 - 500 LUX registered significantly minimum number of leaves per plant (5.76).

There was significant difference among ornamental foliage plants on number of leaves per plant at 90 DAP. The maximum number of leaves (9.16) was recorded with P_3- Pandanus followed by P_1-Philodendron (7.63). Whereas the minimum number of leavers per plant (7.09) was noticed with P_2-Syngonium.

In the interactions, L_4P_3: 1500 - 2000 LUX + Pandanus recorded significantly maximum number of leaves (11.18) followed by L_3P_3: 1000 - 1500 LUX + Pandanus (10.33). Whereas, L_1P_2: 250 - 500 LUX + Syngonium noticed minimum number of leaves (5.60).

Number of leaves per plant (180 DAP)

Data recorded on number of leaves (180 DAP) of ornamental foliage plants influenced by light intensities and their interactions are presented in Table 4.

In pooled data at 180 days after planting maximum number of leaves (14.85) was recorded in the treatment L_4: 1500 - 2000 LUX followed by L_3: 1000 - 1500 LUX (13.82). Whereas, the L_1: 250 - 500 LUX registered significantly minimum number of leaves (9.02).

There was significant difference among ornamental foliage plants on number of leaves per plant at 180 DAP. The maximum number of leaves (15.03) was recorded with P_3- Pandanus followed by P_1-Philodendron (11.94). Whereas the minimum number of leaves (10.48) were noticed with P_2-Syngonium.

In the interactions, L_4P_3: 1500 - 2000 LUX + Pandanus recorded significantly maximum number of leaves (18.87) followed by L_3P_3: 1000 - 1500 LUX + Pandanus (16.92). Whereas, L_1P_2: 250 - 500 LUX + Syngonium noticed minimum number of leaves (8.27).

Table 4: Effect of different light intensities on number of leaves per plant at 90 and 180 days after planting in vertical garden

Treatments	90 Days				180 Days			
	P_1	**P_2**	**P_3**	**Mean**	**P_1**	**P_2**	**P_3**	**Mean**
L_1	5.87	**5.60**	5.80	**5.76**	9.56	**8.27**	9.20	**9.02**
L_2	7.54	7.67	9.323	**8.18**	12.58	8.98	15.14	**12.24**
L_3	8.28	7.82	**10.33**	**8.81**	12.57	11.98	**16.92**	**13.82**
L_4	8.81	7.28	**11.18**	**9.09**	13.03	12.66	**18.87**	**14.85**
Mean	**7.63**	**7.09**	**9.16**		**11.94**	**10.48**	**15.03**	
	S.Em ±		**CD (5%)**		**S.Em ±**		**CD (5%)**	
Ornamental foliage plants (P)	0.10		0.29		0.13		0.38	
Light intensities (L)	0.12		0.34		0.15		0.44	
PXL	0.20		0.58		0.26		0.77	

Factor I: Ornamental foliage plants (P)-
P_1- Philodendron **P_2**- Syngonium **P_3**- Pandanus
Factor II: Light intensities (L)-
L_1: 250 - 500 LUX (Control) **L_2**: 500 - 1000 LUX **L_3**: 1000 - 1500 LUX **L_4**: 1500 - 2000 LUX

Specific leaf area (cm^2g^{-1})

Specific leaf area (cm^2g^{-1}) (90 DAP)

Data recorded on specific leaf area (cm^2g^{-1}) (90 DAP) of ornamental foliage plants as influenced by light intensities and their interactions are presented in Table 5.

In pooled data at 90 days after planting maximum specific leaf area (526.51 cm^2g^{-1}) was recorded in the treatment L_4: 1500 - 2000 LUX followed by L_3: 1000 - 1500 LUX (452.02 cm^2g^{-1}). Whereas, the L_1: 250 - 500 LUX registered significantly minimum specific leaf area (394.52 cm^2g^{-1}).

There was significant difference among ornamental foliage plants on specific leaf area at 90

DAP. The maximum specific leaf area (956.77 cm^2g^{-1}) was recorded with P_2- Syngonium followed by P_1-Philodendron (280.57 cm^2g^{-1}). Whereas the minimum specific leaf area (115.53 cm^2) was noticed with P_3-Pandanus

In the interactions, L_4P_2: 1500 - 2000 LUX + Syngonium recorded significantly maximum specific leaf area (1070.25 cm^2g^{-1}) followed by L_3P_2: 1000 - 1500 LUX + Syngonium (949.65 cm^2g^{-1}). Whereas, L_1P_3: 250 - 500 LUX + Pandanus noticed minimum specific leaf area (106.63 cm^2g^{-1}).

Specific leaf area (cm^2g^{-1}) (180 DAP)

Data recorded on specific leaf area (cm^2) (180 DAP) of ornamental foliage plants influenced by light intensities and their interactions are presented in Table 5.

In pooled data at 180 days after planting maximum specific leaf area (560.53 cm^2g^{-1}) was recorded in the treatment L_4: 1500 - 2000 LUX followed by L_3: 1000 - 1500 LUX (510.43 cm^2g^{-1}). Whereas, L_1: 250 - 500 LUX registered significantly minimum specific leaf area (304.00 cm^2g^{-1}).

There was significant difference among ornamental foliage plants on specific leaf area at 180 DAP. The maximum specific leaf area (996.72 cm^2g^{-1}) was recorded with P_2-Syngonium followed by P_2-Philodendron (269.47 cm^2g^{-1}). Whereas the minimum specific leaf area (143.63 cm^2g^{-1}) was noticed with P_3-Pandanus.

In the interactions, L_4P_2: 1500 - 2000 LUX + Syngonium recorded significantly maximum specific leaf area (1170.91 cm^2g^{-1}) followed by L_2P_2: 500 - 1000 LUX + Syngonium (1090.22 cm^2g^{-1}). Whereas, L_1P_3: 250 - 500 LUX + Pandanus noticed minimum specific leaf area (109.93 cm^2g^{-1}).

Table 5: Effect of different light intensities on specific leaf area(cm^2g^{-1}) at 90 and 180 days after planting in vertical garden

Treatments	90 Days				180 Days			
	P_1	P_2	P_3	Mean	P_1	P_2	P_3	Mean
L_1	195.64	870.09	117.83	**394.52**	154.97	647.10	109.93	**304.00**
L_2	248.62	937.10	106.63	**430.78**	275.57	**1090.22**	148.59	**504.79**
L_3	295.97	**949.65**	110.44	**452.02**	305.10	1078.64	147.56	**510.43**
L_4	382.04	**1070.25**	127.22	**526.51**	342.23	**1170.91**	168.44	**560.53**
Mean	**280.57**	**956.77**	**115.53**		**269.47**	**996.72**	**143.63**	
	S.Em ±		CD (5%)		S.Em ±		CD (5%)	
Ornamental foliage plants (P)	4.67		13.64		5.29		15.44	
Light intensities (L)	5.40		15.75		6.11		17.83	
PXL	9.35		27.28		10.58		30.88	

Factor I: Ornamental foliage plants (P)-

P_1- Philodendron **P_2**- Syngonium **P_3**- Pandanus

Factor II: Light intensities (L)-

L_1: 250 - 500 LUX (Control) **L_2**: 500 - 1000 LUX **L_3**: 1000 - 1500 LUX **L_4**: 1500 - 2000 LUX

Survival percentage (%)

Survival percentage (%) (90 DAP)

Data recorded on survival percentage (90 DAP) of ornamental foliage plants influenced by light intensities and their interactions are presented in Table 6.

In pooled data at 90 days after planting maximum survival percentage (93.33 %) was recorded in the treatment L_4: 1500 - 2000 LUX which was at par with L_3:1000 - 1500 LUX (91.67 %) and L_2: 500 - 1000 LUX (90.56 %). Whereas, the L_1:250 - 500 LUX registered significantly minimum survival percentage (87.78 %).

There was significant difference among ornamental foliage plants on survival percentage at 90 DAP. The maximum survival percentage (95.42 %) was recorded with P_2- Syngonium which was at par with P_1-Philodendron (92.50 %). Whereas the minimum survival percentage (84.58 %) was noticed with P_3- Pandanus

In the interactions, L_4P_2: 1500 - 2000 LUX + Pandanus recorded significantly maximum survival percentage (98.33 %). Whereas, L_1P_3: 250 - 500 LUX + Pandanus noticed minimum survival percentage (81.67 %).

Survival percentage (%) (180 DAP)

Data recorded on survival percentage (180 DAP) of ornamental foliage plants as influenced by light intensities and their interactions are presented in Table 6.

In pooled data at 180 days after planting maximum survival percentage (90.56 %) was recorded in the treatment L_4: 1500 - 2000 LUX which was at par with L_3 and L_2. Whereas, the L_1: 250 - 500 LUX registered significantly minimum survival percentage (83.89 %).

There was significant difference among ornamental foliage plants on survival percentage at 180 DAP. The maximum survival percentage (94.58 %) was recorded with P_2- Syngonium followed by P_1- Philodendron (87.92 %). Whereas the minimum survival percentage (80.00 %) was noticed with P_3- Pandanus

In the interactions, L_4P_2: 1500 - 2000 LUX + Syngonium and L_3P_2- 1500 - 2000 LUX + Syngonium recorded significantly maximum survival percentage (96.67 %) which was at par with L_2P_2, L_1P_2 and L_4P_1. Whereas, L_1P_3: 250 - 500 LUX + Pandanus noticed minimum survival percentage (75.00 %).

The survival percentage was higher with increasing light intensities except the lowest light intensity (L_1-250-500 LUX), which also reflected in the production of biomass under low light intensities in all the three species studied. All the three species resembled to increase light intensities, however Syngonium is highly adaptive to high light and is hardy compared to Pandanus and Philodendron under vertical gardening conditions.

Solar radiation is among the most significant environmental factors that regulate photosynthesis, and consequently, plant survival, growth, and adaptation. In any habitat, light intensity varies temporally (seasonally and diurnally) and spatially. To cope with these varying light regimes, plants develop acclimation mechanisms and exhibit plasticity (Zhang *et al.,* 2003). Most plant species possess the ability to undergo anatomical, morphological, physiological, and biochemical alterations in response to different light intensities (Czeczuga, 1987; Muraoka *et al.*, 2002; Sousa Paiva *et al.,* 2003). Comparative studies have shown that under low light conditions, the biomass of roots, stems, leaves, and the whole plant, as well as the photosynthetic rate, transpiration, and stomatal conductance, survival percentage, tend to decrease. Conversely, these parameters increase under high light conditions (Zhang *et al*., 2003; Wang *et al*., 2009).

Table 6: Effect of different light intensities on survival percentage (%) at 90 and 180 days after planting in vertical garden.

Treatments	90 Days				180 Days			
	P_1	P_2	P_3	Mean	P_1	P_2	P_3	Mean
L_1	90.00	91.67	**81.67**	**87.78**	85.00	91.67	**75.00**	**83.89**
L_2	91.67	95.00	85.00	**90.56**	86.67	93.33	80.00	**86.67**
L_3	91.67	**96.67**	86.67	**91.67**	88.33	**96.67**	81.67	**88.89**
L_4	96.67	**98.33**	85.00	**93.33**	91.67	**96.67**	83.33	**90.56**
Mean	**92.50**	**95.42**	**84.58**		**87.92**	**94.58**	**80.00**	
	S.Em ±		CD (5%)		S.Em ±		CD (5%)	
Ornamental foliage plants (P)	1.48		4.33		1.32		3.85	
Light intensities (L)	1.71		5.00		1.52		4.44	
PXL	2.97		8.66		2.64		7.69	

Factor I: Ornamental foliage plants (P)-
P_1- Philodendron **P_2**- Syngonium **P_3**- Pandanus
Factor II: Light intensities (L)-
L_1: 250 - 500 LUX (Control) **L_2**: 500 - 1000 LUX **L_3**: 1000 - 1500 LUX **L_4**: 1500 - 2000 LUX

Quality Parameters

Chlorophyll content (SPAD meter reading)

Data recorded on chlorophyll content (SPAD meter reading) of ornamental foliage plants influenced by light intensities and their interactions are presented in Table 7.

In pooled data at 180 days after planting maximum chlorophyll content (24.75) was recorded in the treatment L_4: 1500 - 2000 LUX followed by L_3: 1000 - 1500 LUX (19.84). Whereas, the L_1: 250 - 500 LUX registered significantly minimum chlorophyll content (14.17).

There was significant difference among ornamental foliage plants on chlorophyll content at 180

DAP. The maximum chlorophyll content (21.42) was recorded with P_2- Syngonium followed by P_1- Philodendron (19.27). Whereas the minimum chlorophyll content (16.61) was noticed with P_3- Pandanus.

In the interactions, L_4P_2: 1500 - 2000 LUX + Syngonium recorded significantly maximum chlorophyll content (29.62) followed by L_4P_1: 1000 - 1500 LUX + philodendron (23.39). Whereas, L_1P_3: 250 - 500 LUX +Pandanus noticed minimum chlorophyll content (11.01).

There was a significant incremental increase in chlorophyll content with increase in light intensities up to 1500-2000 LUX, which significantly correlated to the leaf morphology and production with higher photosynthetic rates. Among the species Syngonium and Philodendron exhibited higher photosynthetic rate compared to Pandanus under artificial light conditions, as it is a full sun loving plant, could not able to perform effectively under artificial light.

Hence, shade-tolerant plants efficiently capture and utilize light energy, often through increased chlorophyll content (Adamson *et al.*, 1991). Shade plants often employ acclimation strategies to adapt to low light environments, including the development of larger and thinner leaves, which can result in up to a three-fold increase in chlorophyll content (Adamson *et al.*, 1991; Taiz and Zeiger, 2002).

Table 7: Effect of different light intensities on chlorophyll content at 180 days after planting in vertical garden

Treatments	90 Days			
	P_1	P_2	P_3	Mean
L_1	16.13	15.37	**11.01**	**14.17**
L_2	17.82	19.10	16.00	**17.64**
L_3	19.73	21.60	18.19	**19.84**
L_4	**23.39**	**29.62**	21.23	**24.75**
Mean	**19.27**	**21.42**	**16.61**	
	S.Em ±		**CD (5%)**	
Ornamental foliage plants (P)	0.09		0.25	
Light intensities (L)	0.10		0.29	
PXL	0.17		0.50	

Factor I: Ornamental foliage plants (P)-
P_1- Philodendron **P_2**- Syngonium **P_3**- Pandanus
Factor II: Light intensities (L)-
L_1: 250 - 500 LUX (Control) **L_2**: 500 - 1000 LUX **L_3**: 1000 - 1500 LUX **L_4**: 1500 - 2000 LUX

Physiological Parameters

Absolute growth rate (AGR)

Data recorded on absolute growth rate (90 DAP) of ornamental foliage plants influenced by light intensities and their interactions are presented in Table 8.

Pooled data at 90 DAP, the maximum absolute growth rate (0.144) which recorded with L_4**:** 1500 - 2000 LUX, followed L_3**:** 1000 - 1500 LUX (0.137). Whereas, L_1**:** 250 - 500 LUX recorded significantly minimum absolute growth rate (0.098).

Significant difference Among different ornamental foliage plants was reported with respect to Absolute growth rate at 90 DAP. The maximum absolute growth rate (0.129) was recorded with P_2- Syngonium followed by P_1-Philodendron (0.124) Minimum Absolute growth rate (0.119) was observed with P_3- Pandanus.

In the interactions L_4P_2- 1500 - 2000 LUX + Syngonium recorded significantly maximum absolute growth rate (0.150) which was at par with L_4P_1- 1500 - 2000 LUX + Philodendron (0.146). While, L_1P_3- 250 - 500 LUX + Pandanus recorded minimum absolute growth rate (0.095).

Table 8: Effect of different light intensities on absolute growth rate (AGR) at 90 days after planting in vertical garden

Treatments	90 Days				180 Days			
	P_1	P_2	P_3	Mean	P_1	P_2	P_3	Mean
L_1	0.098	0.100	**0.095**	**0.098**	0.122	0.133	**0.120**	**0.125**
L_2	0.112	0.123	0.115	**0.117**	0.148	0.157	0.156	**0.154**
L_3	0.140	0.142	0.127	**0.137**	0.139	0.149	0.153	**0.147**
L_4	**0.146**	**0.150**	0.137	**0.144**	**0.169**	**0.185**	0.145	**0.166**
Mean	**0.124**	**0.129**	**0.119**		**0.144**	**0.156**	**0.144**	

	S.Em ±	CD (5%)	S.Em ±	CD (5%)
Ornamental foliage plants (P)	0.0007	0.0021	0.0022	0.0064
Light intensities (L)	0.0008	0.0024	0.0025	0.0073
PXL	0.0015	0.0042	0.0044	0.0127

Factor I: Ornamental foliage plants (P)-

P_1- Philodendron **P_2**- Syngonium **P_3**- Pandanus

Factor II: Light intensities (L)-

L_1: 250 - 500 LUX (Control) **L_2**: 500 - 1000 LUX **L_3**: 1000 - 1500 LUX **L_4**: 1500 - 2000 LUX

Conclusion

The study clearly demonstrates that light intensity plays a pivotal role in influencing the growth and physiological performance of ornamental foliage plants in vertical garden systems. Among the evaluated intensities, 1500–2000 lux consistently supported superior growth, higher leaf number, chlorophyll content, and survival percentage, particularly in *Syngonium podophyllum* and *Philodendron erubescens*. Conversely, *Pandanus veitchii*, being a sun-loving species, exhibited suboptimal performance under artificial lighting. The findings underscore the importance of selecting shade-tolerant species for indoor vertical gardening and tailoring light intensities to meet species-specific requirements. Additionally, the study affirms the suitability of LED lighting as an efficient and sustainable solution for indoor plant cultivation. This research contributes to developing effective strategies for urban greening, especially in space-constrained environments, by providing data-driven insights into species-light compatibility. Adopting such informed practices can significantly improve the success and sustainability of vertical gardens in modern urban settings.

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