



Photo-selective Shade Nets alters the Growth Dynamics and Physiology of *Thaumatococcus xanadu*

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ABSTRACT

Background: Photo-selective shade nets are important in protected cultivation for improving growth, physiological efficiency and foliage quality in ornamental foliage plants. *Thaumatococcus xanadu*, a tropical ornamental foliage species, responds markedly to spectral environment and shading intensity, but information on the combined influence of coloured shade nets under tropical protected conditions remains limited.

Methods: The study was conducted during 2025-2026 at SRM College of Agricultural Sciences, Chengalpattu, Tamil Nadu, India. The experiment was laid out in a completely randomized design with seven treatments and three replications, comprising open condition, green, black and red shade nets at 50% and 75% shading levels. Morphological, physiological, biochemical and microclimatic parameters were recorded and analysed using analysis of variance.

Result: The superior vegetative performance observed under the 50% red shade indicates that moderate shading combined with red-light enrichment creates a favourable microenvironment for carbon assimilation and canopy development. The 75% black photo-selective shade net (T₅) recorded the highest plant height (33.45 cm) and chlorophyll content (2.23 mg g⁻¹ FW). Open-grown plants (T₁) recorded the highest transpiration rate (3.25 mg g⁻¹ FW), indicating greater moisture stress.

Key words: Chlorophyll, Ornamental foliage, Photo-selective shade nets, *Thaumatococcus xanadu*, Transpiration rate.

INTRODUCTION

Thaumatococcus xanadu (syn. *Philodendron xanadu*) has emerged as a commercially important foliage species owing to its attractive deeply lobed leaves, compact growth habit and excellent adaptability to indoor and landscape environments. In India, commercial cultivation of cut foliage crops is gradually expanding due to its growing demand from urban landscaping, hospitality sectors and protected cultivation systems (Sujatha and Laxman, 2021). Light is one of the most important environmental factors regulating plant growth, morphogenesis and physiological performance. Variations in light intensity and spectral composition regulate photosynthetic rate, chlorophyll synthesis, stomatal behaviour, biomass accumulation and leaf anatomy. Shade-loving ornamental foliage plants are particularly sensitive to changes in light quality because their growth and foliage characteristics are closely associated with the surrounding light environment. Plants' responses to light are mediated through photoreceptors such as phytochromes, cryptochromes and phototropins, which regulate stem elongation, leaf expansion and photomorphogenesis (Quail *et al.*, 1995). It also emphasized the role of light quality in regulating photosynthetic efficiency and physiological metabolism (Taiz *et al.*, 2015).

Photo-selective coloured shade nets have recently gained importance in protected cultivation because they modify both light and spectral quality while reducing thermal stress. Pashova *et al.* (2025) also reported that photo-selective nets improve crop quality through spectral light modification and microclimate regulation under protected cultivation. These nets influence microclimatic conditions

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by lowering temperature, increasing relative humidity and regulating PAR, thereby affecting plant growth and physiological responses. Different coloured shade nets influence vegetative growth, pigment accumulation and foliage quality through modifications in spectral composition and light intensity. Red shade nets generally enhance vegetative growth and biomass accumulation, whereas green shade nets improve chlorophyll content and foliage longevity, while white shade nets were also reported to improve cut foliage quality in *Philodendron*

xanadu under Bengaluru conditions (Sujatha and Laxman, 2021). Furthermore, most previous investigations have focused either on growth responses or microclimatic modifications independently, with limited emphasis on understanding their combined physiological implications. Therefore, the present study was undertaken to evaluate the effects of different photo-selective shade nets and shading intensities on microclimate regulation, growth dynamics, physiological responses and foliage quality of *Thaumatococcus xanadu* under tropical conditions. The findings are expected to provide scientific evidence for selecting appropriate shade-net technologies for commercial production of high-quality ornamental foliage crops.

MATERIALS AND METHODS

Experimental site, plant materials and methods

The experiment was conducted during 2025-26 at the Department of Floriculture and Landscape Architecture, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Chengalpattu, Tamil Nadu, India. Uniform, healthy tissue-cultured plants of *Thaumatococcus xanadu* were used for the study. Plants were grown in polybags (measuring 28 × 28 × 50 cm) filled with red soil, farmyard manure and vermicompost (2:1:1) enriched with Azospirillum, Phosphobacteria and VAM. The study followed a completely randomized design consisting of seven treatments and three replications. Each replication comprised five plants, resulting in a total experimental population of 105 plants. The treatments included T₁- open condition (control), T₂- green shade net (50%), T₃- green shade net (75%), T₄- black shade net (50%), T₅- black shade net (75%), T₆- red shade net (50%) and T₇- red shade net (75%). Recommended cultural practices of Assam Agricultural University, Jorhat (2023) for foliage crops were followed.

Assessment of microenvironment, growth, physiological and gas exchange parameters

Microclimatic parameters under different photo-selective shade-net treatments were monitored during 2025-2026, excluding cloudy days. Air temperature and relative humidity were recorded using a digital thermo-hygrometer, while light intensity was measured with a digital lux meter (Beetech B-105; 1-4,00,000 lux) at 09:00, 12:00 and 15:00 h and mean values were calculated. Photosynthetically Active Radiation (PAR, $\mu\text{mol m}^{-2} \text{s}^{-1}$) was estimated from light intensity values using the conversion factor (1 lux = 0.0185 $\mu\text{mol m}^{-2} \text{s}^{-1}$) suggested by Thimijan and Heins, (1983). Growth parameters including plant height, number of fronds, leaf length, leaf width, petiole length were recorded at the time of planting and 90 days after planting. Chlorophyll and carotenoids contents were estimated using the 80% acetone extraction method (Arnon, 1949). Specific Leaf Weight (SLW) was calculated as dry weight per unit leaf area. Transpiration rate was determined by the gravimetric

method using excised foliage as described in the Plant Physiology Laboratory Manual, Department of Botany, University of Kashmir (2025). All physiological measurements were performed using calibrated instruments and standardized analytical procedures. Measurements were obtained from five randomly selected plants per replication to ensure data reliability and minimize sampling bias.

Statistical analysis

Experimental data were analyzed using ANOVA following Gomez and Gomez, (1984). CRAN R program (Version 4.5.3) was used to perform statistical studies. Treatment means were separated using the critical difference test at 5% significance ($p \leq 0.05$). Principal component analysis (PCA) was performed to identify the most influential growth and physiological parameters contributing to treatment variation.

RESULTS AND DISCUSSION

Microclimate modifications

Significant variations in the microclimate environment were observed under different photo-selective shade net treatments during the experimental period (Fig 1). Open conditions (T₁) recorded the highest light intensity throughout the study, with values of 28950, 27180 and 36389 lux during December 2025, January 2026 and February 2026, respectively. In contrast, the 75 per cent black shade net (T₅) consistently recorded the lowest light intensity values of 6678, 5741 and 7612 lux, confirming that shading percentage and net colour influence light penetration and spectral modification. These findings are in agreement with Josmi John (2020) and Austerman *et al.* (2023).

Air temperature varied slightly among treatments (Fig 2). The 50 per cent red shade net (T₆) recorded comparatively

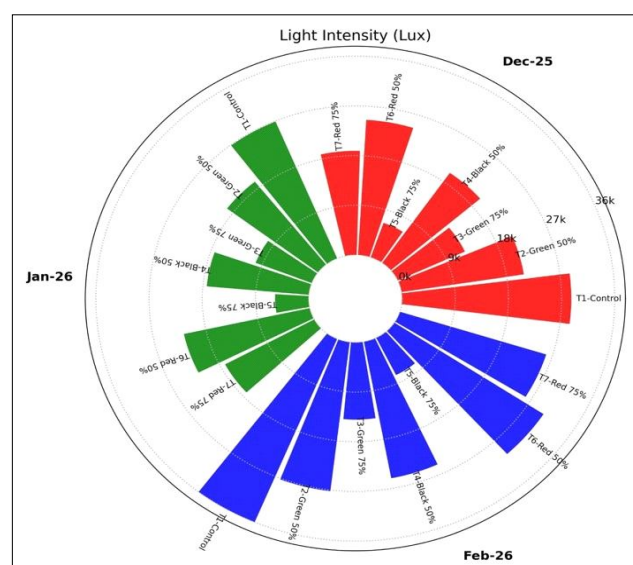


Fig 1: Effect of photo-selective shade net on light intensity (Lux).

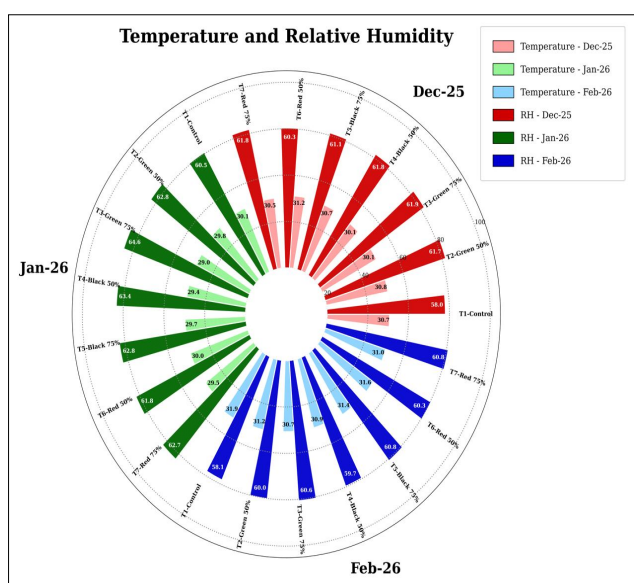


Fig 2: Influence of photo-selective net on air temperature and relative humidity under protected cultivated conditions.

higher temperatures during December 2025, while open conditions (T_1) registered warmer conditions during January and February 2026. Higher temperatures under red shade nets may be due to greater transmission of red wavelengths and higher light transmission compared to black and green nets. Shahak *et al.* (2008) and Stamps (2009) similarly reported that coloured shade nets alter spectral composition and microclimate according to their optical properties. Conversely, (T_3) consistently recorded the lowest temperature, due to reduced solar radiation and improved light diffusion under greater shading intensity. Green and black shade nets, particularly at 75 per cent shading, reduced heat accumulation by filtering more incoming solar radiation. These results corroborate the findings of Austerman *et al.* (2023), Alhelal *et al.* (2024) and Chakradhar *et al.* (2024). With reference to the relative humidity, high relative humidity was recorded invariably under all the coloured shade nets (Fig 2) compared to open conditions, whereas lower relative humidity prevailed under the (T_1) control treatment. Similar findings were reported by Chakradhar *et al.* (2024) and Sujatha and Laxman (2021) in ornamental and cut foliage species.

Incidence of photosynthetically active radiation (PAR)

PAR varied considerably among different photo-selective shade net treatments (Table 1). Open conditions (T_1) recorded the highest incidence by recording PAR values during all months, whereas the lowest PAR was consistently recorded under the 75 per cent black shade net (T_5). Among the shade net treatments, the 50 per cent red shade net (T_6) transmitted comparatively higher PAR (458.43, 407.83 and 564.45 $\mu\text{mol m}^{-2} \text{s}^{-1}$ during December 2025, January and February 2026, respectively), attributed to its higher transmittance of red wavelengths and enhanced

radiation diffusion. In contrast, black shade nets absorbed a larger proportion of solar radiation, thereby reducing PAR availability beneath the canopy. Similar microclimatic modifications under coloured shade nets have been reported in strawberry (Alhelal *et al.*, 2024), ornamental foliage crops (Chakradhar *et al.*, 2024) and apple orchards (Pashova *et al.*, 2025). These findings not only regulate light quantity but also influence the thermal and humidity regime surrounding the crop canopy, thereby affecting physiological processes and plant performance.

Growth dynamics and morphological responses

The present study revealed that photo-selective shade nets significantly influenced the growth dynamics of *Thaumatococcus xanadu* by modifying light intensity, spectral composition and microclimatic conditions (Table 2). Plants grown under the 75 per cent black shade net (T_5) recorded the highest plant height (33.45 cm), followed by 50 per cent red shade net (T_6) with 32.25 cm representing a 43.5% increase over the control. Increased plant height under higher shade intensity may be attributed to shade avoidance responses triggered by reduced red to far-red light ratio and altered light ratios, promoting assimilate allocation towards stem and petiole elongation for maximizing light interception (Taiz *et al.*, 2015; Singh *et al.*, 2023b). The elongation response under T_5 highlights the adaptation of *Thaumatococcus xanadu* to shaded environments. Similar responses have been reported in leather leaf fern and Asiatic lily grown under high shade environments (Nair *et al.*, 2020; Savita *et al.*, 2022).

In contrast, the highest frond production was observed under the 50 per cent red shade net (T_6) with 69.46 fronds, followed by T_2 (41.50) and T_4 (33.33), which produced nearly seven-fold more fronds than T_5 and substantially exceeded the control (Fig 3). Enhanced frond production under the red shade nets indicating that moderate shading combined with enhanced red-light transmission created favourable conditions for photosynthesis and vegetative development. Red wavelengths are known to stimulate phytochrome-mediated responses, increase photosynthetic efficiency

Table 1: Effect of photo-selective shade nets on PAR.

Treatments	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)		
	December 2025	January 2026	February 2026
T_1 - Control	535.37	502.83	673.19
T_2 - Green 50%	391.51	359.88	508.41
T_3 - Green 75%	233.69	190.21	261.51
T_4 - Black 50%	372.40	324.17	470.88
T_5 - Black 75%	123.54	106.20	140.82
T_6 - Red 50%	458.43	407.83	564.45
T_7 - Red 75%	352.44	320.56	485.05
S.Ed	2.013	5.588	12.391
CD ($P \leq 0.05$)	4.317*	11.986*	26.577*

*Significant at $P \leq 0.05$; NS- Non-significant at $P > 0.05$.

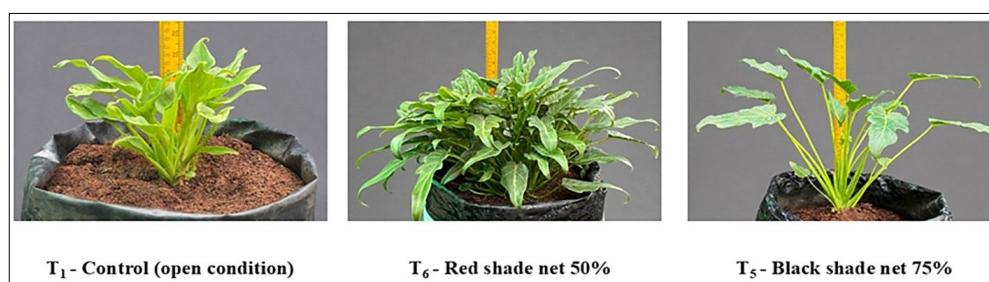


Fig 3: Influence of photo-selective net on frond production.

and promote leaf initiation, ultimately resulting in greater canopy development. Similar observations were reported by Chowdhuri *et al.* (2021) under red shade nets in *Asparagus plumosus*. Reduced frond production under T_5 despite greater height suggests a shade avoidance response, where assimilates are diverted towards elongation rather than foliage production under low-light conditions (Smith and Whitelam, 1997; Villa *et al.*, 2025). Leaf morphology characteristics further demonstrated the adaptive response of *T. xanadu* to modified light environments (Table 2). Plants grown under T_6 produced the longest leaves (11.64 cm) at 90 DAP, followed by T_3 (11.20 cm) and T_5 (10.79 cm), whereas maximum leaf width (5.87 cm) was recorded under T_5 followed by T_4 (5.26 cm). The enlargement of leaf area under shaded environments represents an adaptive strategy to maximize light interception and carbon gain under reduced irradiance. Plants grown under low-light environments generally develop broader leaves to enhance light-harvesting efficiency. Similar findings were reported by Gaurav *et al.* (2016) in *Cordyline terminalis* and Singh *et al.* (2023a) in ornamental foliage species. The findings indicate that moderate red shading favours foliage production, whereas excessive shading promotes elongation growth at the expense of canopy development.

Petiole length was significantly higher under T_5 (17.16 cm), followed by T_2 (13.64 cm), indicating shade adaptation for enhanced light interception. Increased petiole elongation under higher shade intensity is a typical shade adaptation response that enables leaves to position themselves for

improved light interception. Naveena *et al.* (2019), also reported improved foliage quality and chlorophyll accumulation in *Nephrolepis exaltata* and *Asparagus sprengeri*.

Physiological and biochemical responses

Chlorophyll accumulation was significantly enhanced under shaded treatments, with the highest chlorophyll content recorded under the 75% black shade net (2.23 mg g⁻¹ FW) (Fig 4). This was followed by the 50 per cent red shade net (T_6) with 1.97 mg g⁻¹ FW and the 50 per cent green shade

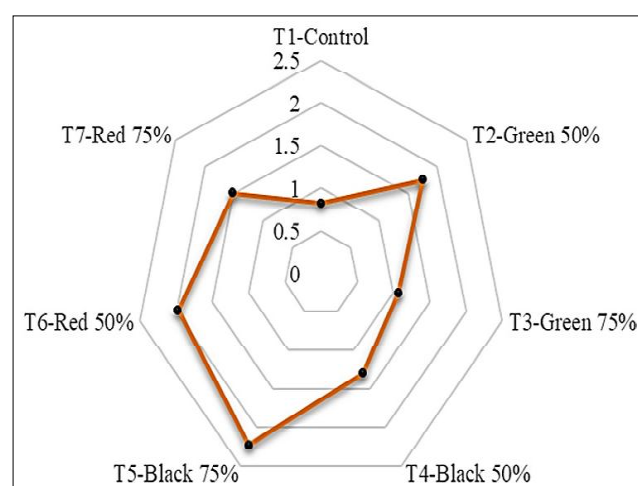


Fig 4: Effect of photo-selective shade nets on total chlorophyll content of *T. xanadu* leaves.

Table 2: Effect of photo-selective shade nets on growth and leaf morphological traits.

Treatments	Plant height (cm)		Leaf length (cm)		Leaf width (cm)		Petiole length (cm)	
	At planting	90 DAP	At planting	90 DAP	At planting	90 DAP	At planting	90 DAP
T_1 - Control	10.11	23.31 ^g	2.93	9.93 ^e	2.56	2.47 ^g	7.55	8.39 ^g
T_2 - Green 50%	13.09	26.83 ^e	4.52	10.38 ^d	3.30	3.90 ^e	8.16	13.64 ^b
T_3 - Green 75%	10.28	28.12 ^d	3.32	11.20 ^b	2.50	4.78 ^c	6.23	12.60 ^c
T_4 - Black 50%	12.07	30.14 ^c	3.54	9.48 ^f	2.79	5.26 ^b	7.24	10.42 ^e
T_5 - Black 75%	13.00	33.45 ^a	3.78	10.79 ^c	3.41	5.87 ^a	8.83	17.16 ^a
T_6 - Red 50%	12.41	32.25 ^b	3.78	11.64 ^a	3.12	4.36 ^d	7.56	11.40 ^d
T_7 - Red 75%	12.23	24.73 ^f	2.86	9.02 ^g	2.74	3.30 ^f	6.58	9.19 ^f
S.Ed	1.532	0.289	0.505	0.092	0.472	0.146	1.009	0.349
CD ($P \leq 0.05$)	NS	0.620*	NS	0.196*	NS	0.314*	NS	0.749*

*Significant at $P \leq 0.05$; NS- Non-significant at $P > 0.05$.

net (T_2) with $1.75 \text{ mg g}^{-1} \text{ FW}$, whereas the lowest value ($0.82 \text{ mg g}^{-1} \text{ FW}$) was observed under open conditions (T_1). Enhanced chlorophyll synthesis under reduced light intensity represents a physiological adaptation that improves light-harvesting efficiency and photosynthetic performance. Chowdhuri *et al.* (2021); Abbasnia Zare *et al.* (2019) and Ilić *et al.* (2017), also reported increased chlorophyll accumulation under coloured shade nets due to improved spectral quality and lower photooxidative stress. Carotenoid content of *Thaumatococcus xanadu* was also significantly influenced by shade net treatments (Table 3). The highest carotenoid content ($0.62 \text{ mg g}^{-1} \text{ FW}$) was recorded under the 75 per cent black shade-net (T_5), followed by T_6 ($0.55 \text{ mg g}^{-1} \text{ FW}$), whereas open conditions (T_1) recorded the lowest value ($0.18 \text{ mg g}^{-1} \text{ FW}$). Carotenoids play a crucial role in dissipating excess excitation energy and protecting chloroplast structures from photooxidative damage. These findings align with Chakradhar *et al.* (2023) and Jokar *et al.* (2021), who observed enhanced carotenoid content under photo-selective nets. Kannaujia *et al.* (2025) similarly reported variations in carotenoid accumulation in cherry tomatoes. Edrisi *et al.* (2026) reported that the peroxidase and photosynthetic pigment levels were improved under green and white shade nets.

Table 3: Effect of different photo-selective shade nets on gas exchange parameters.

Treatments	Carotenoid content ($\text{mg g}^{-1} \text{ FW}$)	Specific leaf weight (mg cm^{-2})	Transpiration rate ($\text{mg g}^{-1} \text{ FW}$)
T_1 - Control	0.18 ^a	3.58 ^a	3.25 ^a
T_2 - Green 50%	0.47 ^c	4.83 ^c	2.16 ^e
T_3 - Green 75%	0.25 ^f	4.22 ^e	1.34 ^g
T_4 - Black 50%	0.32 ^e	5.16 ^b	2.70 ^c
T_5 - Black 75%	0.62 ^a	3.91 ^f	1.73 ^f
T_6 - Red 50%	0.55 ^b	5.43 ^a	2.93 ^b
T_7 - Red 75%	0.40 ^d	4.51 ^d	2.45 ^d
S.Ed	0.014	0.082	0.060
CD ($P \leq 0.05$)	0.029*	0.176*	0.129*

*Significant at $P \leq 0.05$; NS- Non-significant at $P > 0.05$.

Plant gas exchange characteristics and leaf productivity

Specific leaf weight (SLW) was highest under the 50% red shade net T_6 (5.43 mg cm^{-2}), followed by T_4 (5.16 mg cm^{-2}), indicating greater dry matter accumulation and superior foliage quality. Lowest value (3.58 mg cm^{-2}) was observed under T_1 (Table 3). The increased specific leaf weight under moderate red-light enrichment reflects improved carbon assimilation and biomass partitioning. The superior SLW under T_6 confirms that moderate shading combined with favourable red-light enrichment enhanced assimilate production and foliage quality. Similar results were reported by Gaurav *et al.* (2016) and Singh *et al.* (2023a), who suggested that increased SLW reflects greater photosynthetic productivity and leaf tissue density.

Transpiration rate varied significantly among photo-selective shade net treatments (Table 3). The highest transpiration rate ($3.25 \text{ mg g}^{-1} \text{ FW}$) was recorded under T_1 , followed by T_6 ($2.93 \text{ mg g}^{-1} \text{ FW}$), while the lowest value ($1.34 \text{ mg g}^{-1} \text{ FW}$) was observed under T_3 . Reduced transpiration under higher shade intensities may be attributed to lower air temperature, reduced radiation load and higher relative humidity. Such conditions reduce vapour pressure deficit and water loss through stomata, thereby improving plant water-use efficiency. Similar results were reported by Alhelal *et al.* (2024) and Abbasnia Zare *et al.* (2019).

Multivariate analysis

Principal component analysis revealed significant variability among growth and physiological parameters under different shade-net treatments (Table 4). PC1 was strongly influenced by plant height (PH) (0.495), chlorophyll content (CC) (0.432), leaf width (LW) (0.431) and petiole length (PL) (0.410), indicating major contribution towards to total variability. In PC2, petiole length (PL) (0.389) showed positive loading, whereas number of fronds (-0.660) and specific leaf weight (SLW) (-0.600) showed strong negative effects. Leaf length (LL) negatively influenced PC3 (-0.848), while chlorophyll content (CC) (-0.731) contributed negatively to PC4. Petiole length (PL) (0.649) and specific leaf weight (SLW) (0.557) contributed positively to PC5 and PC7, respectively. The PCA results support the conclusion that photo-selective shade nets influence multiple growth and physiological processes simultaneously through modifications in light quality and microclimatic conditions.

Table 4: PCA between growth and physiological parameters.

Treatments	PC1	PC2	PC3	PC4	PC5	PC6	PC7
PH	0.495	0.047	0.089	0.254	-0.596	-0.529	0.213
Number of fronds	0.199	-0.66	-0.17	-0.114	0.042	-0.261	-0.643
LL	0.343	-0.022	-0.848	0.14	0.002	0.322	0.198
LW	0.431	0.223	0.315	0.528	0.115	0.425	-0.438
PL	0.41	0.389	-0.05	-0.251	0.649	-0.441	0.006
CC	0.432	0.008	0.211	-0.731	-0.271	0.402	0.018
SLW	0.238	-0.6	0.313	0.165	0.367	0.112	0.557

Note: PH- Plant height, LL- Leaf length, LW- Leaf width, PL- Petiole length, CC- Chlorophyll content, SLW- Specific leaf weight.

CONCLUSION

From a commercial perspective, the results clearly demonstrate that shade-net colour and shading intensity must be selected according to the production objective. The 50% red shade net provided an optimum balance between light transmission and spectral modification, resulting in superior frond production, leaf expansion and specific leaf weight and foliage quality. In contrast, 75% black shade net promoted chlorophyll accumulation, carotenoid synthesis and elongation growth as adaptive responses to reduced irradiance. conditions. Therefore, the adoption of 50% red photo-selective shade nets can improve the productivity, aesthetic quality and market value of *Thaumatococcus xanadu* under tropical protected cultivation systems. Furthermore, the enhanced water-use efficiency and favourable microclimatic regulation observed under shade-net environments indicate their potential role in climate-resilient ornamental crop production. Future studies integrating photosynthetic gas exchange, chlorophyll fluorescence and economic analysis would further strengthen recommendations for commercial adoption.

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Disclaimers

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Informed consent

None.

Conflict of interest

The authors declare that there are no conflicts of interest.

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