Journal of Research in Science and Engineering (JRSE)
ISSN: 1656-1996 Volume-8, Issue-10, Octobery 2026
DOI: 10.66069/ojspub.16561011

Species-Specific Coloration Responses of Colored-Leaf Plants to High and Low Light: A Case Study of Seven Common Garden Plants in South China

Jingen Peng, Xuejun Liu*

School of Construction Engineering, Shenzhen Polytechnic University, Shenzhen 518055, Guangdong, China
*Correspondence Author, liuxuejun@szpu.edu.cn

Abstract: ***Leaf coloration in colored-leaf plants is regulated by light intensity, but the response modes differ among species, directly affecting light-environment design in garden configuration. In this study, seven common colored-leaf plants from the subtropical region of South China, Excoecaria cochinchinensis, Tradescantia spathacea, Coleus scutellarioides, Celosia cristata, Jacobaea maritima, Loropetalum chinense var. rubrum, and Cordyline fruticosa 'Aichiaka', were used as materials. Four treatments were established: full light (100% light transmittance), 60% light transmittance, 40% light transmittance, and 20% light transmittance. After 6 weeks of treatment, leaf RHSCC (Royal Horticultural Society Colour Chart) color codes, anthocyanin content, and the maximum photochemical efficiency of PSII (Fv/Fm) were measured. The results showed that the coloration responses of the seven colored-leaf plants could be divided into three types: high-light-coloration type, low-light-coloration type, and light-intensity-insensitive type. Among them, the high-light-coloration type included C. scutellarioides, C. cristata, and T. spathacea; their anthocyanin contents under full light and 60% light transmittance were higher than under low-light treatments, and their RHSCC color codes tended toward purple-red under high light and purple-red-green under low light. The low-light-coloration type included Loropetalum chinense var. rubrum and C. fruticosa 'Aichiaka'; their anthocyanin contents were highest under 60% or lower light transmittance, and their RHSCC color codes tended toward purple-red under low light and cyan-green under high light. The light-intensity-insensitive type included J. maritima and E. cochinchinensis; their RHSCC color codes and anthocyanin contents differed little among different light intensities, and the silvery white color of Jacobaea maritima was mainly determined by epidermal trichome structure. Fv/Fm decreased under high light or full light in species mostly belonging to the high-light-coloration type, whereas species whose Fv/Fm remained stable near 0.8 under all light intensities mostly belonged to the low-light-coloration type or the light-intensity-insensitive type. The study indicates that garden configuration of colored-leaf plants should design light environments according to coloration response type rather than the unified label of "colored-leaf plants."***

Keywords: Colored-leaf plants, Light intensity, Leaf coloration, Anthocyanin, RHSCC, Species specificity.

1. Introduction

Colored-leaf plants are important elements in urban garden landscapes, and their leaf color directly determines the visual effect of the landscape. Light is one of the most critical environmental factors affecting leaf coloration in colored-leaf plants. It regulates the activities of key enzymes in anthocyanin biosynthesis and affects the ratio of chlorophyll to anthocyanin, thereby changing leaf color [1–3]. Previous studies have shown that the direction of coloration responses to light intensity differs among colored-leaf plants: woody colored-leaf plants differ markedly in their adaptation to light intensity, and light intensity, light quality, and photoperiod can all affect chloroplast development and chlorophyll biosynthesis in higher plants. Environmental factors regulate chlorophyll and anthocyanin metabolism through transcription factors such as PIFs, HY5, MYBs, and ERFs, leading to changes in pigment content and ratios and consequently in leaf color [4]. Some other species perform better in leaf color under moderate shading; for example, the colored-leaf plant Ardisia mamillata displays its best leaf color under 55% shading, and its coloration occurs in specialized epidermal cells, i.e., trichomes, while full light is instead unfavorable for its leaf coloration [5]. The responses of leaf pigment contents to light intensity differ among golden-leaf plants; some species show obvious differences at 80% light intensity, whereas others are relatively insensitive [6]. Such differences in response direction mean that a unified light-environment management strategy cannot be applied to all colored-leaf plants in garden configuration.

The subtropical region of South China has a warm and humid climate and is rich in understory colored-leaf plant resources, many of which have red leaf surfaces or leaf abaxial sides. At present, comparative studies on the direction of coloration responses of common colored-leaf plants in South China under the same experimental conditions are still lacking. Existing studies have mostly focused on single species, such as yellow-leaf *Forsythia* under different light gradients [7] and *Caladium bicolor* under different light quality treatments [8]. However, there is a lack of systematic comparison of the coloration response direction of multiple species under the same experimental conditions, and no classification according to "coloration response direction" has been made. This leads to a lack of operational classification basis in garden practice: which colored-leaf plants are suitable for full-light configuration, which are suitable for understory or semi-shaded environments, and which are insensitive to light intensity and can be flexibly configured still have no clear answers.

This study took seven common colored-leaf plants in South China as objects, set four light intensity treatments, and measured leaf RHSCC (Royal Horticultural Society Colour

Chart) color codes, anthocyanin content, and the maximum photochemical efficiency of photosystem II (Fv/Fm) to answer a core question: Is the response direction of leaf coloration to light intensity species-specific among different colored-leaf plants? Can coloration response types be classified accordingly? The results can provide a theoretical basis for the garden light-environment configuration of colored-leaf plants in South China.

2. Materials and Methods

2.1 Plant Materials

The test materials were seven common colored-leaf plants in South China: *Excoecaria cochinchinensis, Tradescantia spathacea, Coleus scutellarioides, Celosia cristata, Jacobaea maritima, Loropetalum chinense* var. rubrum, and *Cordyline fruticosa* 'Aichiaka' (Fig. 1). They were purchased on October 18, 2022 from the Lingnan Flower Market in Guangzhou, Guangdong Province. Forty pots of each species were purchased, with similar specifications and uniform leaf color performance. After repotting, ten pots of each species were randomly assigned to each of four groups and placed in four flat plots in the Horticultural Practice Field of the North Campus of Shenzhen Polytechnic University (22°35′ N, 113°56′ E). Routine watering management was applied.

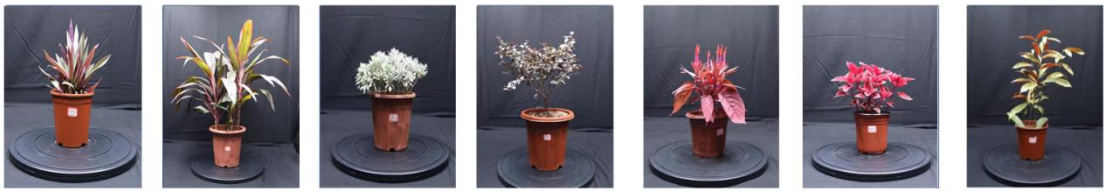


Figure 1: Seven tested colored-leaf plant species (From left to right:*Tradescantia spathacea, Cordyline fruticosa* 'Aichiaka' ,*Jacobaea maritima, Loropetalum chinense* var. Rubrum, *Celosia cristata, Coleus scutellarioides, Excoecaria cochinchinensis*).

2.2 Shading Treatment

October 28, 2022 was taken as the starting point of measurement (0 w), after which shading treatment was carried out. Galvanized steel pipe frames were set up in three groups of plant planting areas and covered with three types of shade nets with different light transmittances. The measured light transmittances were 60%, 40%, and 20%, respectively (Fig. 2). The remaining group was used as the full-light control (100% light transmittance). One week, two weeks, four weeks, and six weeks after treatment were recorded as 1 w, 2 w, 4 w, and 6 w, respectively, for follow-up observations.

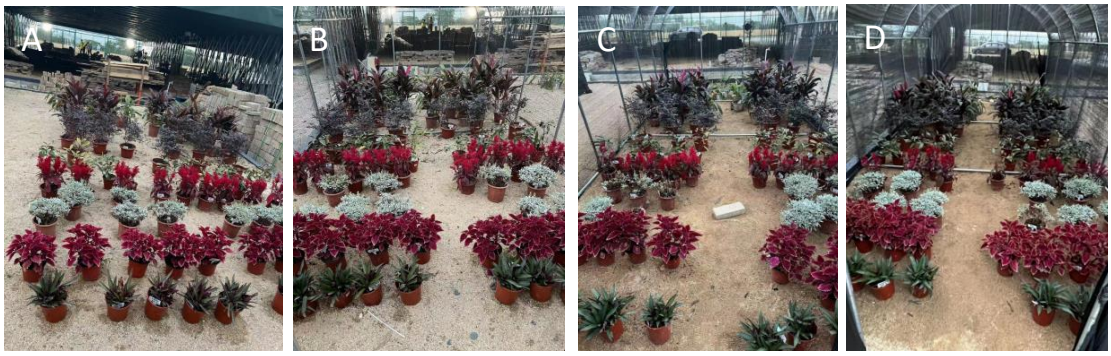


Figure 2: Photographs of seven tested colored-leaf plants under four light intensity treatments (A: full light, 100% light transmittance, B: 60% light transmittance, C: 40% light transmittance, D: 20% light transmittance).

2.3 Measurement Indicators and Methods

Leaf color was compared using the RHSCC. For *C. scutellarioides, C.cristata, L. chinense* var. rubrum, *C. fruticosa* 'Aichiaka', and *J. maritima*, the adaxial side (front) of leaves was measured; for *T. spathacea* and *E. cochinchinensis*, the abaxial side (back) of leaves was measured. Four replicates were used for each treatment.

Determination of anthocyanin content: Fresh leaves were taken, cut into pieces and mixed, and about 0.1 g was weighed. Then 2 mL of methanol solution containing 1% HCl was added, and extraction was performed with shaking under low light for 4 h. The absorbance was measured at 530 nm and 653 nm with a spectrophotometer. Anthocyanin content was calculated according to the method of Murray and Hackett [9]. Three replicates were used for each treatment.

Chlorophyll fluorescence measurement: A PAM-2500 portable modulated fluorometer was used, and four typical leaves of each plant were selected for in vivo measurement. The measurement position was consistent with that for RHSCC (the leaf abaxial side for *E. cochinchinensis* and *T. spathacea*, and the leaf adaxial side for the others). After dark adaptation for 15 min, Fv/Fm was measured.

2.4 Data Analysis

Excel was used for data organization, and Origin 2019 was used to draw graphs. Due to the limited sample size, the data distribution did not satisfy normality; therefore, this study mainly used descriptive statistics and judged trends based on the consistency among replicates of each treatment. For key indicators such as anthocyanin content and Fv/Fm, when the direction of differences among treatments was consistent and the coefficient of variation among replicates was less than 15%, the trend was considered reliable.

3. Results

3.1 High-light-coloration type: *C. Scutellarioides, C. Cristata, T. Spathacea*

The common characteristics of these three species are: anthocyanin content under full light and 60% light transmittance was significantly higher than under 40% and 20% light transmittance, and RHSCC color codes tended toward purple-red under high light and shifted toward purple-red-green or green under low light.

C. scutellarioides: Anthocyanin content was highest under full light and 60% light transmittance. At 6 w, the anthocyanin content under 20% light transmittance was about 50%–60% of that under full light. RHSCC color codes under full light and 60% light transmittance were mostly 45A–61A (purple-red), while under 40% and 20% light transmittance they were mostly N34A–N45A (purple-red-green to green). Hand sections showed that the red pigment was mainly distributed in the upper epidermis, and the distribution range of red pigment narrowed after shading. Fv/Fm decreased to some extent under full light at 6 w, indicating a certain degree of photoinhibition under high light, but coloration was still optimal.

C. cristata: Anthocyanin content under full light and 60% light transmittance was significantly higher than under 40% and 20% light transmittance. RHSCC color codes under full light and 60% light transmittance were mostly N79A–187A (purple-red), while under 40% and 20% light transmittance they were mostly N77A–187A (purple-red-green). At 6 w, the anthocyanin content under 20% light transmittance was about 40%–50% of that under full light. Fv/Fm was mostly close to 0.8 under all treatments, but decreased slightly under full light and 60% light transmittance at 6 w.

T. spathacea: Anthocyanin content was highest under 60% light transmittance, followed by full light, and lowest under 20% light transmittance. RHSCC color codes under all treatments were mainly N79A–N79C (purple-red), but the color was darker and more vivid under 60% light transmittance and full light. The distribution of red pigment on the leaf abaxial side showed no obvious difference among light intensities, but pigment content differed markedly. Fv/Fm decreased considerably under full light at 6 w.

Summary: *C. scutellarioides, C. cristata*, and *T. spathacea* accumulated more anthocyanin and showed more vivid leaf coloration under high light; under low light, anthocyanin content decreased and leaves shifted toward green. Although high light had some effect on Fv/Fm, it did not change the overall trend of "better coloration under high light."

3.2 Low-light-coloration Type: *L. Chinense* var. Rubrum, *C. Fruticosa* 'Aichiaka'

The common characteristics of these two species are: anthocyanin content was highest under 60% or lower light transmittance, and RHSCC color codes tended toward purple-red under low light and shifted toward cyan-green under high light.

L. chinense var. rubrum: Anthocyanin content was highest under 60% light transmittance and relatively low under full light. RHSCC color codes under all treatments were mostly N79B–N1187A (purple), but the color was darker and more uniform under 60% and 40% light transmittance. At 6 w, the anthocyanin content under full light was about 60%–70% of that under 60% light transmittance. Fv/Fm remained stable at about 0.8 under all light intensities, indicating that its light energy utilization efficiency was insensitive to changes in light intensity. Plant height and crown width differed little among light intensities, further indicating strong shade tolerance.

C. fruticosa 'Aichiaka': Anthocyanin content under 40% and 20% light transmittance was significantly higher than under full light and 60% light transmittance. RHSCC color codes under low light transmittance were mostly 59A–71A (purple-red), while under high light transmittance they were mostly 146A–148A (cyan-green with purple-red). Hand sections showed that shading treatment affected red pigment synthesis; the decrease in red pigment content under low light was smaller than the increase in chlorophyll under high light, so red was relatively more obvious. Fv/Fm changed smoothly under all light intensities and was most stable under 40% light transmittance at 6 w.

Summary: *L. chinense* var. rubrum and *C. fruticosa* 'Aichiaka' showed better coloration under low light. Under high light, anthocyanin content decreased or chlorophyll content increased, causing leaves to shift toward cyan-green. The Fv/Fm of these two species was relatively stable under all light intensities, indicating good photosynthetic adaptability to changes in light intensity.

3.3 Light-intensity-insensitive Type: *J. Maritima, E. Cochinchinensis*

The common characteristics of these two species are: RHSCC color codes and anthocyanin content differed little among different light intensities, and coloration was insensitive to changes in light intensity.

J. maritima: RHSCC color codes under all light intensities were 108D–191D (silvery white), and the overall appearance was silvery white, with no obvious differences among treatments. Hand sections showed that green pigments in Jacobaea maritima were distributed in both the upper and lower epidermis, but the silvery white appearance of leaves was mainly determined by epidermal trichome structure rather than pigments. Anthocyanin content fluctuated greatly among different light intensities but showed no obvious preference for high or low light. Fv/Fm remained stable at about 0.8 under all light intensities.

E. cochinchinensis: The RHSCC color codes of the leaf abaxial side under all light intensities were stable at 183A, 183B, and 185A (dark red in the Grey-Red Group to medium red in the Grey-Purple Group), and the overall color was dark red. Anthocyanin content did not differ significantly among different light intensities, and at 6 w the values among treatments tended to be similar. Hand sections showed that the upper epidermis of Excoecaria cochinchinensis leaves contained green pigment, and red pigment was distributed in all parts except the upper epidermis; there was no obvious

difference in pigment distribution among different light intensities. Fv/Fm decreased to some extent under all light intensities at 6 w, but the differences among treatments were not large.

Summary: The silvery white color of *J. maritima* is determined by epidermal trichome structure and does not depend on anthocyanin biosynthesis; therefore, light intensity has little effect on its RHSCC color code. The red pigment content on the leaf abaxial side of *E. cochinchinensis* remained relatively stable under different light intensities, and its coloration was insensitive to light intensity.

3.4 Comparison of the Three Response Types

Figure 3 and 4 show the seven plants were classified by coloration response direction, and the results were as follows: high-light-coloration type: *C. scutellarioides, C. cristata, T. spathacea*. Under high light, anthocyanin content was high and RHSCC tended toward purple-red; under low light, anthocyanin content decreased and RHSCC shifted toward green. Low-light-coloration type: *L. chinense* var. rubrum, *C. fruticosa* 'Aichiaka'. Under low light, anthocyanin content was high and RHSCC tended toward purple-red; under high light, anthocyanin content decreased or chlorophyll content increased, and RHSCC shifted toward cyan-green. Light-intensity-insensitive type: *J. maritima, E. cochinchinensis*. RHSCC color codes and anthocyanin content differed little among different light intensities. The silvery white color of *J. maritima* is structurally determined, and the red pigment content of *E. cochinchinensis* is stable.

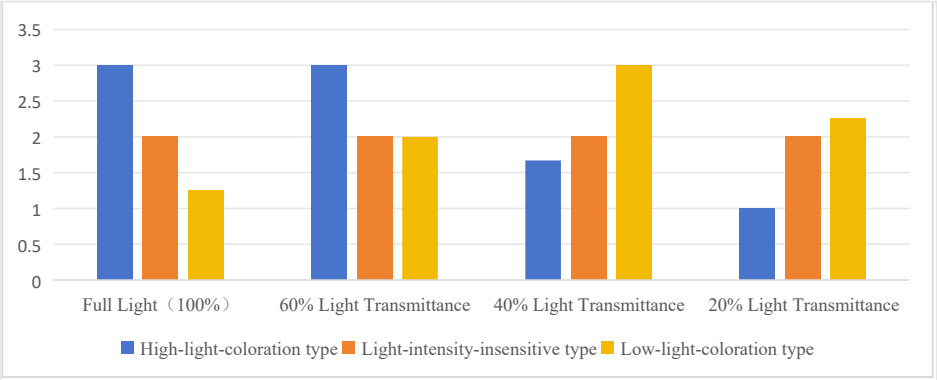


Figure 3: Conceptual diagram of the trends in anthocyanin content of the three coloration response types.
Note: Values were assigned according to the trends in the original pigment content bar charts (high = 3, medium = 2, low = 1) and averaged by response type.

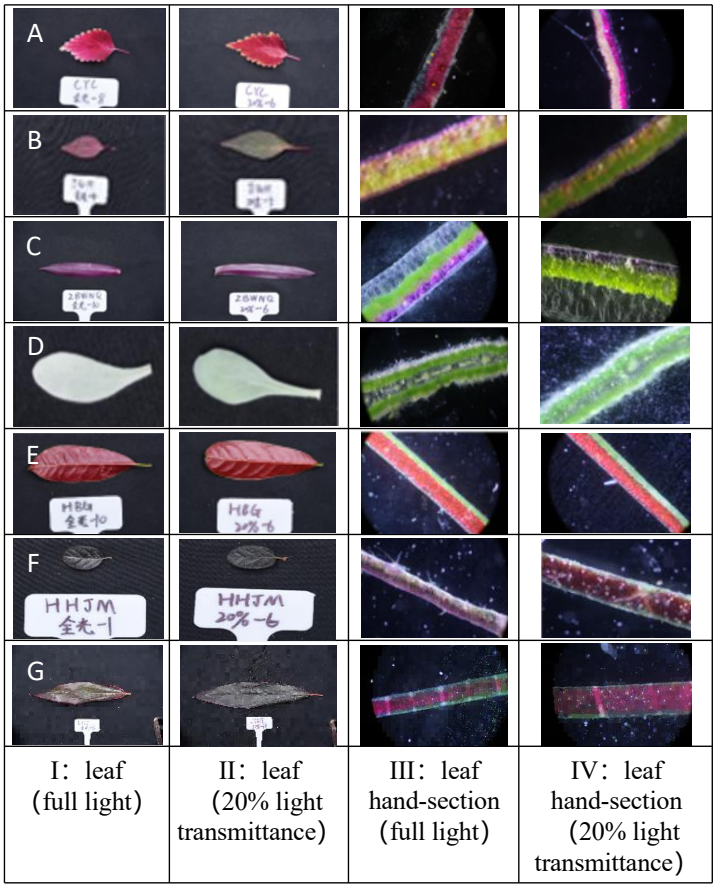


Figure 4: Leaf coloration and hand sections of seven colored-leaf plants under full light and 20% light transmittance (high-light-coloration type: A. *Coleus scutellarioides*, B. *Celosia cristata*, C. *Tradescantia spathacea*; light-intensity-insensitive type: D. *Jacobaea maritima*, E. *Excoecaria cochinchinensis*; low-light-coloration type: F. *Loropetalum chinense* var. rubrum, G. *Cordyline fruticosa* 'Aichiaka').

Table 1: Summary of anthocyanin content and RHSCC color codes of the three coloration response types

Response type	Species	High-light treatment (full light/60% light transmittance)	Low-light treatment (40%/20% light transmittance)
High-light-coloration type	*C. scutellarioides*	Anthocyanin content high; RHSCC 45A–61A, purple-red	Anthocyanin content low; RHSCC N34A–N45A, purple-red-green to green
High-light-coloration type	*C. cristata*	Anthocyanin content high; RHSCC N79A–187A, purple-red	Anthocyanin content low; RHSCC N77A–187A, purple-red-green
High-light-coloration type	*T. spathacea*	Anthocyanin content high; RHSCC N79A–N79C, purple-red (dark)	Anthocyanin content low; RHSCC N79A–N79C, purple-red (light)
Low-light-coloration type	*L. chinense* var. rubrum	Anthocyanin content relatively low; RHSCC N79B–N187A, purple (light)	Anthocyanin content high; RHSCC N79B–N187A, purple (dark)
Low-light-coloration type	*C. fruticosa* 'Aichiaka'	Anthocyanin content low; RHSCC N146A–148A, cyan-green with purple-red	Anthocyanin content high; RHSCC N59A–71A, purple-red
Light-intensity-insensitive type	*J. maritima*	Anthocyanin content showed no consistent trend among light intensities; RHSCC color code stable; RHSCC 108D–191D, silvery white	Anthocyanin content showed no consistent trend among light intensities; RHSCC color code stable; RHSCC 108D–191D, silvery white
Light-intensity-insensitive type	*E. cochinchinensis*	Anthocyanin difference not significant; RHSCC 183A/183B/185A, dark red	Anthocyanin difference not significant; RHSCC 183A/183B/185A, dark red

Note: RHSCC, Royal Horticultural Society Colour Chart.

4. Discussion

4.1 Differences in the Light-intensity Dependence of Anthocyanin Biosynthesis are the Main Reason for Species Specificity in Coloration Responses

In this study, high-light-coloration species (*C. scutellarioides, C. cristata, T. spathacea*) had higher anthocyanin content under high light, which is consistent with the known mechanism that key enzymes in anthocyanin biosynthesis (such as PAL and CHS) are activated under strong light [1–3]. Light signals can regulate the expression of anthocyanin structural genes through transcription factors such as HY5, thereby affecting anthocyanin accumulation [10–11]. Under strong light, chlorophyll content decreases, and the relative proportion of anthocyanin increases, making leaves appear more vividly purple-red. Under low light, chlorophyll content increases, green masks red, and leaves show re-greening.

Low-light-coloration species (*L. chinense* var. rubrum, *C. fruticosa* 'Aichiaka') showed the opposite response direction. In *L. chinense* var. rubrum, anthocyanin content was highest under 60% light transmittance and decreased under full light. This may be related to photo-oxidative degradation of anthocyanin under high light [12], or to increased chlorophyll synthesis under high light leading to a decrease in the relative proportion of red. The more obvious red color of *C. fruticosa* 'Aichiaka' under low light may be related to decreased chlorophyll content under low light and an increased relative proportion of red pigment.

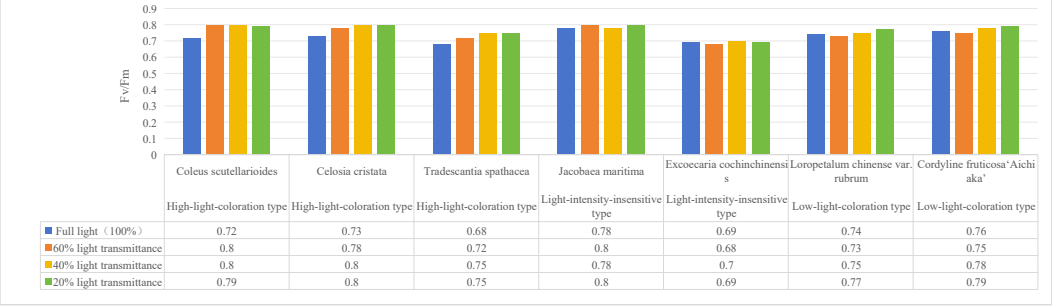
4.2 The Distinction between Structural Color and Pigment color is the Reason for Stable Coloration in Light-intensity-insensitive Species

The silvery white color of *J. maritima* comes from the structural color of epidermal trichomes rather than pigments such as anthocyanin. Structural color is determined by the physical structure of trichomes and does not depend on pigment biosynthesis pathways; therefore, changes in light intensity have little effect on its RHSCC color code. The red pigment content on the leaf abaxial side of *E. cochinchinensis* remained relatively stable under different light intensities, indicating that its anthocyanin biosynthesis is less sensitive to changes in light intensity, or that other regulatory mechanisms maintain stable pigment content.

This result has important garden application significance: not all "colored-leaf plants" have coloration regulated by light intensity. For structural-color plants (such as *J. maritima*) and plants with stable pigment content (such as *E. cochinchinensis*), the main goal of light intensity management should be growth rather than coloration.

4.3 Relationship between Fv/Fm and Coloration Response Type

In this study, the Fv/Fm of low-light-coloration species (*L. chinense* var. rubrum, *C. fruticosa* 'Aichiaka') and light-intensity-insensitive species (*J. maritima, E. cochinchinensis*) remained stable at about 0.8 under all light intensities, indicating that their light energy utilization efficiency was insensitive to changes in light intensity. In contrast, high-light-coloration species (*C. scutellarioides, C. cristata, T. spathacea*) showed decreased Fv/Fm under full light or low light at 6 w, indicating that their light energy utilization efficiency was more sensitive to changes in light intensity.



	Coleus scutellarioides	Celosia cristata	Tradescantia spathacea	Jacobaea maritima	Excoecaria cochinchinensis	Loropetalum chinense var. rubrum	Cordyline fruticosa'Aichiaka'
	High-light-coloration type	High-light-coloration type	High-light-coloration type	Light-intensity-insensitive type	Light-intensity-insensitive type	Low-light-coloration type	Low-light-coloration type
Full light（100%）	0.72	0.73	0.68	0.78	0.69	0.74	0.76
60% light transmittance	0.8	0.78	0.72	0.8	0.68	0.73	0.75
40% light transmittance	0.8	0.8	0.75	0.78	0.7	0.75	0.78
20% light transmittance	0.79	0.8	0.75	0.8	0.69	0.77	0.79

Figure 5: Comparison of Fv/Fm among the three response types.

Anthocyanins in leaves not only perform a coloration function but also have important photoprotective effects. Studies have shown that anthocyanins can alleviate photoinhibition of PSII under high light by shielding excess light energy and scavenging reactive oxygen species [12–14]. In this study, high-light-coloration species (*C. scutellarioides, C. cristata, T. spathacea*) accumulated more anthocyanin under high light, and Fv/Fm decreased only slightly, possibly precisely because the photoprotective effect of anthocyanin reduced high-light damage to PSII. In contrast, low-light-coloration species (*L. chinense* var. rubrum, *C. fruticosa* 'Aichiaka') showed better coloration under low light, and their photosynthetic apparatus was insensitive to changes in light intensity, indicating stronger shade tolerance.

The above phenomena indicate that there is a certain association between coloration response type and photosynthetic adaptability. High-light-coloration species show better coloration under high light, but high light also causes some stress to their photosynthetic apparatus; low-light-coloration species show better coloration under low light, and their photosynthetic apparatus is insensitive to changes in light intensity, indicating stronger shade tolerance. In garden configuration, high-light-coloration species are suitable for full-light or high-light environments, but attention should be paid to possible photoinhibition caused by strong summer light; low-light-coloration species are suitable for understory or semi-shaded environments and have strong adaptability to changes in light intensity.

4.4 Garden Application Recommendations

Based on the results of this study, garden configuration of colored-leaf plants in South China can follow the following principles: high-light-coloration type is recommended to be configured in full-light or high-light environments to fully exert its coloration potential. Appropriate shading in summer under high temperature and strong light can reduce photoinhibition; low-light-coloration type is recommended to be configured in understory, north side of buildings, or semi-shaded environments, where coloration is better under low light. *L. chinense* var. rubrum has strong shade tolerance and can also grow under full light, but its coloration effect is slightly inferior; light-intensity-insensitive type has flexible light environment configuration and can arrange light according to growth requirements rather than coloration requirements. *J. maritima* is afraid of strong light and needs appropriate shading in summer; *E. cochinchinensis* is suitable for semi-shaded environments.

5. Conclusions

This study took seven common colored-leaf plants in South China as objects and compared the effects of different light intensities on leaf coloration under the same experimental conditions. The following conclusions were drawn:

1) The response direction of leaf coloration to light intensity in colored-leaf plants has obvious species specificity and can be divided into three types: high-light-coloration type, low-light-coloration type, and light-intensity-insensitive type.

2) The high-light-coloration type includes *C. scutellarioides, C. cristata*, and *T. spathacea*; their anthocyanin content is higher under high light, and their RHSCC color codes tend toward purple-red. The low-light-coloration type includes *L. chinense* var. rubrum and *C. fruticosa* 'Aichiaka'; their anthocyanin content is higher or chlorophyll content is lower under low light, and their RHSCC color codes tend toward purple-red. The light-intensity-insensitive type includes *J. maritima* and *E. cochinchinensis*; their RHSCC color codes and anthocyanin content differ little among different light intensities.

3) Fv/Fm remained stable at about 0.8 in low-light-coloration and light-intensity-insensitive species, and decreased at 6 w in high-light-coloration species, indicating a certain association between coloration response type and photosynthetic adaptability.

4) In garden configuration, the light environment should be designed according to the coloration response type of colored-leaf plants rather than the unified label of "colored-leaf plants." The high-light-coloration type is suitable for full-light or high-light configuration, the low-light-coloration type is suitable for understory or semi-shaded configuration, and the light-intensity-insensitive type can be flexibly configured.

This study has the following limitations: the number of replicates for some indicators was limited, and strict analysis of variance was not performed; the experimental period was 6 weeks, and long-term light intensity effects still need further verification; the structural color mechanism of *J. maritima* was not deeply characterized. Future studies can increase the number of replicates, extend the observation period, and combine measurements of key enzyme activities in anthocyanin biosynthesis to further reveal the molecular mechanism of species specificity in coloration responses.

Funding

1) 2023 Shenzhen Polytechnic University Research Project: Exploring the physiological and ecological adaptive significance of red leaf abaxial side—taking understory plants in the subtropical region of South China as an example (Project No.: 6023310015K).

2) 2026 Shenzhen Polytechnic University University-Enterprise Joint R&D Center Project, Shenzhen Polytechnic University–Lvyuanfang Urban Garden Plant Health Management Technology R&D Center (Project No.: 602631009PQ).

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Author Profile

Jingen Peng (1987–), male, associate professor, doctoral degree, research direction: application of garden plants and garden ecology.

Xuejun Liu (1968–), male, associate professor, master's degree, research direction: application of garden plants.