Effects of Light Quality and Photoperiod on Growth and Physiology of Michelia maudiae Seedlings (Postprint)

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Abstract

To screen for suitable light environments during the seedling cultivation of *Paramichelia baillonii*, one-year-old *P. baillonii* seedlings were used as experimental materials. Two photoperiods of 12 h $\cdot$ d^{-1} and 16 h $\cdot$ d^{-1} were established, combined with four light qualities of red-blue composite light (8R1B, 6R1B) and red-blue-purple-green composite light (8R1B1P1G, 6R1B1P1G), along with a white light (W) control. Using a two-factor randomized block experimental design and membership function method, the response patterns of *P. baillonii* seedling growth, photosynthetic pigments, and endogenous hormone contents to different light quality and photoperiod treatments were investigated. The results showed that: (1) Light quality, photoperiod, and their interaction had significant effects ($P < 0.05$) on seedling height increment, leaf area, chlorophyll a, zeatin (ZR), abscisic acid (ABA) contents, and endogenous hormone ratios (IAA/ABA, (IAA+GA_3+ZR)/ABA). (2) The 16 h $\cdot$ d^{-1} photoperiod was beneficial for increasing seedling height increment, leaf area, seedling quality index, biomass, chlorophyll a, indole-3-acetic acid (IAA), ZR contents, and endogenous hormone ratios. (3) When the photoperiod was 16 h $\cdot$ d^{-1}, the seedling height increment, leaf area, and seedling quality index were maximal under the 8R1B treatment, reaching 21.84 cm, 158.39 cm^2, and 2.43, respectively; the chlorophyll a/b ratio and ZR content under the 8R1B treatment were higher than those under the 6R1B treatment; and the chlorophyll a, carotenoid, IAA, gibberellin (GA_3) contents, chlorophyll a/b ratio, and endogenous hormone ratios under the 8R1B1P1G treatment were greater than those under the 6R1B1P1G treatment. In summary, red-blue composite light with a higher proportion of red light and appropriately extended photoperiod were beneficial for improving *P. baillonii* seedling quality, whereas the addition of purple and green light did not promote its growth. The 16 h $\cdot$ d^{-1}\$×\$8R1B treatment was the most suitable lighting condition for *P. baillonii* seedling growth.

Full Text

Effects of Light Quality and Photoperiod on the Growth and Physiology of *Paramichelia baillonii* Seedlings

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Abstract

To identify optimal light conditions for cultivating *Paramichelia baillonii* seedlings, one-year-old seedlings were subjected to two photoperiods ($12\ h \cdot d^{-1}$ and $16\ h \cdot d^{-1}$) combined with four light quality treatments: red-blue composite light (8R1B, 6R1B), red-blue-purple-green composite light (8R1B1P1G, 6R1B1P1G), and white light (W) as a control. Using a two-factor randomized block design and subordinate function analysis, we investigated how different light qualities and photoperiods affect seedling growth, photosynthetic pigments, and endogenous hormone content. The results showed that: (1) Light quality, photoperiod, and their interaction significantly affected height growth, leaf area, chlorophyll *a*, zeatin (ZR), abscisic acid (ABA) content, and endogenous hormone ratios (IAA/ABA, (IAA+GA_3+ZR)/ABA) ($P < 0.05$). (2) The $16\ h \cdot d^{-1}$ photoperiod promoted increases in height growth, leaf area, seedling quality index, biomass, chlorophyll *a*, auxin (IAA), ZR content, and endogenous hormone ratios. (3) Under the $16\ h \cdot d^{-1}$ photoperiod, the 8R1B treatment produced maximum values for height growth (21.84 cm), leaf area (158.39 cm^2), and seedling quality index (2.43). The 8R1B treatment also yielded higher chlorophyll a/b ratios and ZR content compared to 6R1B, while 8R1B1P1G showed greater chlorophyll *a*, carotenoid, IAA, gibberellin (GA_3) content, chlorophyll a/b ratios, and endogenous hormone ratios than 6R1B1P1G. In conclusion, red-blue composite light with a higher red light proportion combined with extended photoperiod improves *P. baillonii* seedling quality, while purple and green light additions showed no promotional effects. The $16\ h \cdot d^{-1} \times$ 8R1B treatment represents the most suitable light condition for *P. baillonii* seedling growth.

Keywords: *Paramichelia baillonii*, LED, light quality, photoperiod, growth, photosynthetic pigments, endogenous hormones

Introduction

Light is the most critical environmental factor for plant growth, playing a vital role throughout the entire life cycle. Due to their unique spectral absorption characteristics, plants require different optimal photoperiods at various growth stages, and different light qualities exert differential effects. Extensive research has investigated the effects of red-blue light combinations and other composite spectra on plant growth and physiology. For example, red-blue light combinations have positively promoted growth, photosynthetic pigment synthesis, and biomass accumulation in *Hippeastrum* (Qie, 2020) and *Lycoris radiata* seedlings (Li et al., 2019). However, adding green light to red-blue combinations has been found to hinder chlorophyll synthesis in eggplant seedlings (Yang et al., 2018) and *Solanum muricatum* tissue culture plantlets (Wang et al., 2020), while purple light treatment significantly reduced plant height, biomass, and photosynthetic pigments in yellow sweet pepper seedlings compared to white light (Bai et al., 2017). Conversely, adding 25% green light (2R1B1G) to red-blue combinations significantly promoted leaf growth and chlorophyll content in *Bletilla striata* (Wang et al., 2021), and appropriate purple light supplementation improved yield and quality in hydroponic celery (Liu et al., 2020). A 16 $h \cdot d^{-1}$ photoperiod with purple-green light supplementation also had positive effects on the growth and physiological characteristics of *Cunninghamia lanceolata* tissue culture seedlings (Xu, 2017). These findings indicate that while red-blue light is the most commonly used composite spectrum in protected cultivation and generally promotes plant growth, the effects of other light qualities remain inconsistent and require further investigation, particularly for forest trees and precious species.

Paramichelia baillonii (also known as *Michelia baillonii*), belonging to the Magnoliaceae family and the genus *Paramichelia*, is a rare, evergreen, broad-leaved tree species naturally distributed in Yunnan Province, China, and recently introduced to Guangxi and Fujian. With its straight trunk, decay-resistant wood, and attractive grain, *P. baillonii* represents an excellent timber and landscape tree species for southern China. However, low seed germination rates and poor natural regeneration, combined with habitat disturbance and environmental changes, have led to declining natural populations, necessitating improved artificial propagation techniques to expand population numbers. Current research on *P. baillonii* seedlings has focused on growth characteristics (Liu et al., 2019), fertilization effects (Huang, 2015), and container types (Qiu et al., 2018). Previous studies have shown that *P. baillonii* seedlings have limited adaptability to high light intensity, with growth favored by natural sunlight or light shading (72.3% transmittance) (Ma and Jiao, 2008; Liu et al., 2020), though the effects of different light qualities remain unclear.

Light quality influences plant morphogenesis, photosynthetic physiology, and substance metabolism. Compared to other spectral regions, red and blue light are more effectively absorbed by photosynthetic pigments. Red light promotes stem elongation, increases leaf area, enhances aboveground biomass, and stimulates carbohydrate synthesis, while blue light promotes stomatal opening and root growth and regulates chlorophyll synthesis. Green light can induce shade-avoidance responses through petiole elongation and activate PEPC gene expression, while purple light can delay senescence, enhance nitrogen metabolism-related enzyme activity, and promote nitrogen absorption.

To investigate the response of *P. baillonii* to light quality and photoperiod, this study used one-year-old seedlings exposed to LED light sources with red-blue composite light (8R1B, 6R1B), red-blue-purple-green composite light (8R1B1P1G, 6R1B1P1G), and two photoperiods (12 $h \cdot d^{-1}$, 16 $h \cdot d^{-1}$). We analyzed seedling growth characteristics, photosynthetic pigments, and endogenous hormone changes to explore responses to different light qualities and photoperiods. These findings provide a basis for optimizing container seedling cultivation and tissue culture techniques using artificial light sources and offer valuable insights for studying light environment adaptability and regeneration mechanisms in *P. baillonii*.

Materials and Methods

1.1 Experimental Materials Healthy, uniform one-year-old *P. baillonii* seedlings [average height (20.16 ± 1.86) cm, average ground diameter (7.05 ± 0.23) mm] were obtained from Guangxi Liangfengjiang National Forest Park (108°21 E, 22°40 N). Seedlings were transplanted into nursery cups (10 cm diameter × 15 cm height), one plant per cup, and cultivated in a nursery greenhouse. The substrate consisted of 70% forest soil, 20% coconut coir, and 10% perlite. LED tubes (T5 2835L, Shenzhen Weixinli Optoelectronics Co., Ltd.) measured 1,200 mm × 24 mm with 16 W power per tube; light quality ratios were determined by the number of LED chips.

1.2 Experimental Design The experiment was conducted at the Nursery Demonstration Base of Guangxi University College of Forestry (108°22 E, 22°48 N) from April 10 to September 10, 2017. Given that 610–720 nm and 400–510 nm are the primary absorption bands for plants, with less absorption in the 510–610 nm range (Zhou et al., 2013), light treatments included white light (W) as control, red-blue composite light (8R1B, 6R1B), and red-blue-purple-green composite light (8R1B1P1G, 6R1B1P1G) combined with two photoperiods (12 $h \cdot d^{-1}$ and 16 $h \cdot d^{-1}$; light/dark periods of 12 h/12 h and 16 h/8 h, respectively). Light quality ratios were based on Xu et al. (2020), resulting in ten treatment combinations (Table 1). Each treatment had three replicates with ten seedlings per replicate. The artificial cultivation greenhouse featured adjustable light sources, with two LED tubes per treatment positioned at 75–85 cm vertical height (adjustable to maintain equal light intensity). Light intensity was maintained at 350 ± 10 $\mathrm{mol} \cdot \mathrm{m}^{-2} \cdot \mathrm{s}^{-1}$ (measured with an MQ-500 handheld quantum meter, Apogee Instruments, USA), with shading materials between treatments to prevent light interference. Photoperiods were controlled by timers: 7:00–19:00 for 12 $h \cdot d^{-1}$ and 5:00–21:00 for 16 $h \cdot d^{-1}$. Routine seedling management included ventilation every two days (20:00–23:00).

1.3.1 Growth and Biomass Measurements Plant height was measured with a 0.1 cm precision ruler, and ground diameter with a 0.02 mm precision vernier caliper. Height and diameter increments were calculated as differences between final (September 10) and initial (April 10) measurements. Leaf area was measured using a YMJ-B portable leaf area meter (Henan Yunfei Technology Co., Ltd., China) on fully expanded leaves of moderate size. In September, three average-sized plants per replicate were selected for total fresh weight measurement, then oven-dried to constant weight for determination of root, stem, and leaf dry weights and total dry weight. The seedling quality index (SQI) was calculated as: SQI = total seedling dry weight / [(final height/final ground diameter) + (stem dry weight/root dry weight)].

1.3.2 Chlorophyll and Endogenous Hormone Measurements Two seedlings per replicate were randomly selected, and leaves of different maturity levels were collected from various plant parts and mixed for physiological measurements. Chlorophyll *a*, chlorophyll *b*, and carotenoid contents were determined following Qiu et al. (2016). One gram of sample was extracted with 80% acetone:ethanol (2:1) solution in darkness for 24 h, and absorbance was measured at 470, 649, and 665 nm using a spectrophotometer for pigment content calculation.

For endogenous hormones, 0.5 g of mixed sample was ground in liquid nitrogen, then extracted with 2 mL of 80% methanol containing 50 mg polyvinylpyrrolidone (PVP) under weak light and ice bath. The mixture was transferred to a 10 mL centrifuge tube, extracted at 4 °C for 12 h, then centrifuged (8,000 r/min, 20 min). After C-18 extraction, enzyme-linked immunosorbent assay (ELISA) was used to determine indoleacetic acid (IAA), gibberellin (GA_3), zeatin riboside (ZR), and abscisic acid (ABA) contents and calculate relevant hormone ratios. Kits were purchased from Nanjing Jiancheng Bioengineering Institute.

1.3.3 Data Analysis Since both light quality and photoperiod individually and interactively affect seedling quality, fuzzy mathematics membership function analysis was used for comprehensive evaluation of different treatment effects. The membership value formula was: U(Xi) = (Xi - Ximin) / (Ximax - Ximin), where Xi is the measured value, and Ximax and Ximin are the maximum and minimum values of an indicator across all treatments. For indicators negatively correlated with seedling growth, the inverse membership function was used: U(Xi) = 1 - (Xi - Ximin) / (Ximax - Ximin). Higher average membership values indicated better seedling cultivation effects (Zhang et al., 2014).

Data were organized using Microsoft Excel 2016. Statistical analysis (two-way ANOVA, significance tests, and Pearson correlation analysis) was performed using IBM SPSS Statistics 26.0. Figures were prepared using Origin 2021. Data are presented as mean ± standard deviation.

Results

2.1 Effects of Light Quality and Photoperiod on Seedling Growth Light quality, photoperiod, and their interaction significantly affected height growth, leaf area, and total fresh weight ($P < 0.01$), while photoperiod and its interaction did not significantly affect ground diameter growth (Table 2). As

shown in Figure 1 [Figure 1: see original paper], under the same light quality, the 16 h · d^{-1} photoperiod produced greater total dry weight and seedling quality index than the 12 h · d^{-1} photoperiod. Under the 16 h · d^{-1} photoperiod, the 8R1B treatment showed significantly greater height growth than other light quality treatments, with leaf area and plant weight comparable to the 6R1B treatment and significantly greater than W and 6R1B1P1G treatments. The 8R1B1P1G treatment showed higher values for height growth, diameter growth, leaf area, plant weight, and seedling quality index than 6R1B1P1G. Specifically, the 16$×8R1Btreatmentproducedmaximumvaluesforheightgrowth(21.84cm), leafarea(158.39cm^{2}), andseed
treatment.

2.2 Effects of Light Quality and Photoperiod on Photosynthetic Pigments Light quality and its interaction significantly affected chlorophyll *a*, *b*, *a*/*b* ratio, and carotenoid content ($P < 0.05$), while photoperiod had a highly significant effect on chlorophyll *a* content ($P < 0.01$) (Table 3). As shown in Figure 2 [Figure 2: see original paper], under the same light quality, the 16 h · d^{-1} photoperiod generally produced higher chlorophyll *a* content than the 12 h · d^{-1} photoperiod. Under the 16 h · d^{-1} photoperiod, 8R1B and 6R1B were more conducive to chlorophyll *a* and carotenoid synthesis, with 8R1B showing significantly higher chlorophyll *a*/*b* ratios than W, 6R1B1P1G, and 8R1B1P1G treatments. The 8R1B1P1G treatment showed higher chlorophyll *a*, carotenoid content, and chlorophyll *a*/*b* ratios than 6R1B1P1G. Specifically, the 16$×8R1Btreatmentproducedmaximumvaluesforchlorophyll*a*(3.88mg· g^{-1}), carotenoids(0.48mg · g{-1}), andchlorophyll*a*/*b*(2.32), whilechlorophyll* b * content(3.23mg · g^{-1})peakedunderthe16×$6R1B1P1G treatment.

2.3 Effects of Light Quality and Photoperiod on Endogenous Hormones Light quality, photoperiod, and their interaction all highly significantly affected ZR and ABA content and the (IAA+GA_3+ZR)/ABA ratio ($P < 0.01$). Light quality significantly affected GA_3 content and the IAA/ABA ratio ($P < 0.05$), while photoperiod highly significantly affected IAA content and the IAA/ABA ratio ($P < 0.01$) (Table 4). As shown in Figure 3 [Figure 3: see original paper], under the same light quality, the 16 h · d^{-1} photoperiod produced higher IAA and ZR contents, higher endogenous hormone ratios, and lower ABA content than the 12 h · d^{-1} photoperiod. Under the 16 h · d^{-1} photoperiod, the 8R1B1P1G treatment showed improvements in all endogenous hormone indicators compared to 6R1B1P1G, while 8R1B produced significantly higher ZR content than 6R1B. Specifically, the 16$×6R1BtreatmentproducedmaximumvaluesforIAA(67.19ng · g^{-1}), IAA/ABA(1.43), and(IAA+GA{3}+ZR)/ABA(1.75).The16×8R1B1P1GtreatmentshowedthehighestG
content (10.95 ng · g^{-1}), while ZR content (6.94 ng · g^{-1}) and ABA content (45.07 ng · g^{-1}) reached maximum and minimum values, respectively, under the 16$×$8R1B treatment.

2.4 Correlation Analysis and Comprehensive Evaluation Pearson correlation analysis revealed that height growth, leaf area, and plant weight were significantly correlated with all physiological indicators except chlorophyll $a+b$ content, while ground diameter growth showed weak correlations with photosynthetic pigments and endogenous hormones. Height growth showed strong correlations with ZR content, IAA/ABA, and (IAA+GA_3+ZR)/ABA ratios ($r > 0.80$). Leaf area and plant weight also showed strong correlations with IAA/ABA and (IAA+GA_3+ZR)/ABA ratios ($r > 0.75$). Plant weight was strongly correlated with chlorophyll b content ($|r| > 0.75$), while height growth and leaf area showed significant negative correlations with ABA content ($|r| > 0.82$).

Since single indicators cannot comprehensively reflect seedling performance, we used membership values to evaluate the coordination and balance among seedling components (Zhang et al., 2014; Yao et al., 2019). From 16 indicators, we selected 11—including height and diameter growth, leaf area, total dry weight, photosynthetic pigment content, and endogenous hormone content—to comprehensively evaluate cultivation effects under different light environments. As shown in Table 5 , the 16$×$8R1B treatment had the highest membership value (0.908), indicating balanced physiological indicators and superior growth compared to the control. This demonstrates that high red light proportion and extended photoperiod promote *P. baillonii* seedling development, while purple and green light additions had no significant effects.

Discussion

3.1 Seedling Growth and Biomass Responses to Light Quality and Photoperiod Plants perceive light signals primarily through red/far-red receptors, blue/near-UV receptors, and UV receptors, which regulate growth, development, and physiological metabolism (Su et al., 2014; Ouzounis et al., 2015; Manivannan et al., 2015). Under the 16 $h \cdot d^{-1}$ photoperiod, the 8R1B treatment produced significantly greater height growth, leaf area, and seedling quality index than 8R1B1P1G. Compared to 6R1B1P1G, the 6R1B treatment showed greater height growth, leaf area, plant weight, and seedling quality index. These results indicate that red-blue composite light better promotes *P. baillonii* seedling growth, likely because seedlings have minimal requirements for purple and green light. Red light wavelengths (640–663 nm) align closely with the maximum absorption peaks of chlorophyll and phytochrome, participating in the regulation of photosynthetic apparatus operation and assimilate transport (Appelgren, 1991; Baroli et al., 2008), while blue light regulates stomatal opening (Christie, 2007; Gruszecki et al., 2010). Moreover, higher red light proportions favor height growth and biomass accumulation in *P. baillonii*, while increased blue light proportions reduce height growth and leaf area, similar to responses observed in mulberry seedlings (Hu et al., 2018), red raspberry (Guo et al., 2016), and *Emmenopterys henryi* (Xiao et al., 2020). The addition of purple and green light to red-blue combinations had minimal impact on *P. baillonii* growth, possibly due to species-specific responses to light quality, as similarly observed in *Magnolia hypolampra* seedlings (Wu et al., 2021). Photoperiod can induce and regulate the expression of genes related to vegetative growth. Previous studies have shown that extended photoperiod increases relative growth rates in *Quercus* species (Yao et al., 2022). Our results demonstrate that, under constant light quality, extending the photoperiod to 16 $h \cdot d^{-1}$ increased height growth, leaf area, and total dry weight in *P. baillonii*. This occurs because photoperiod affects the duration of photosynthetic assimilate synthesis and allocation (Dong et al., 2016). Longer photoperiods increase photosynthesis duration, enabling sufficient organic synthesis and accelerating growth and biomass accumulation. However, ground diameter growth showed no significant response to photoperiod, suggesting that photosynthetic assimilates in *P. baillonii* seedlings are largely allocated to height and leaf growth during the seedling stage.

3.2 Photosynthetic Pigment Responses to Light Quality and Photoperiod Photosynthetic pigments, including chlorophyll and carotenoids, absorb and transfer light energy to promote plant development, and their synthesis is significantly affected by light environment (Xing et al., 2018). The chlorophyll a/b ratio reflects light energy utilization efficiency. Under the 16 $h \cdot d^{-1}$ photoperiod, 8R1B and 6R1B treatments showed higher chlorophyll a/b ratios than 8R1B1P1G and 6R1B1P1G, respectively, indicating more efficient light energy utilization under red-blue light. Higher red light proportions promoted chlorophyll *a* and carotenoid content in *P. baillonii*, while increased blue light proportions enhanced chlorophyll *b* content. This contrasts with *Liquidambar formosana* seedlings, which showed opposite trends (Wang et al., 2019), likely reflecting species-specific differences in spectral adaptation. The mechanism of composite light effects is not simply additive. The 12×8R1B1P1G and 16×6R1B1P1G treatments showed significantly higher chlorophyll *b* content than 12×8R1B and 16×6R1B, respectively, demonstrating additive effects of light quality that become more pronounced with increased spectral diversity. Purple-green light delayed chlorophyll *b* degradation in *P. baillonii* leaves, increasing its content, similar to additive effects observed in transgenic poplar leaves (Zhang et al., 2016). Additionally, extended photoperiod under constant light quality promoted chlorophyll *a* content, indicating that appropriate photoperiods enhance photosynthetic pigment content and light utilization capacity in *P. baillonii*.

3.3 Endogenous Hormone Responses to Light Quality and Photoperiod Light environments regulate plant growth and development by affecting endogenous hormone content and balance (Han et al., 2021; Wang et al., 2017). ABA promotes senescence, while IAA, GA_3, and ZR delay it (Jibran et al., 2013). Changes in IAA/ABA and (IAA+GA_3+ZR)/ABA ratios serve as important physiological signals regulating senescence processes (Ohashi-Kaneko et al., 2007). Under the 16 $h \cdot d^{-1}$ photoperiod, the 8R1B1P1G treatment showed significantly higher IAA, GA_3 content, IAA/ABA, and (IAA+GA_3+ZR)/ABA ratios than 6R1B1P1G, while 8R1B produced significantly higher ZR content than 6R1B. These results indicate that, under constant photoperiod, composite light with higher red light proportions better promotes synthesis of growth-promoting hormones in *P. baillonii* leaves. This occurs because red light utilizes phytochrome to regulate the activity of enzymes involved in growth-promoting hormone synthesis, while blue light promotes IAA oxidase activity, as similarly observed in *Tsoongiodendron odorum* (Liu et al., 2022) and mulberry (Hu et al., 2018). Under constant light quality, the 16 $h \cdot d^{-1}$ photoperiod significantly increased IAA and ZR contents and IAA/ABA and (IAA+GA_3+ZR)/ABA ratios compared to 12 $h \cdot d^{-1}$, suggesting that extended photoperiod promotes growth-promoting hormone content, possibly through the main photoreceptor PHYB regulating endogenous hormone synthesis and balance via photoperiod (Fan et al., 2014).

3.4 Comprehensive Evaluation of Light Environment Responses

Plant adaptability to environmental conditions cannot be evaluated through single indicators, prompting the use of membership values for comprehensive assessment (Wang et al., 2022). In this study, the 16$×8R1Btreatmentproducedthehighestmembershipvalue(0.908)andseedlingqualityindex(2.43),withmaxim
1}),andlowestABAcontent(45.07ng·g^{-1}).Theseresultsdemonstratethatappropriatephotoperiodandlightqu
P.baillonii*.Furthermore,significantpositivecorrelationsbetweenheightgrowth,leafarea,plantweightandch
a*,carotenoids,IAA,GA{3},ZRcontent,chlorophyll*a*/*b*ratio,IAA/ABA,and(IAA+
GA{3}$+ZR)/ABA ratios indicate close relationships between photosynthetic pigments, endogenous hormones, and seedling growth. Light period and quality can directly affect photosynthetic pigments and endogenous hormones, thereby regulating seedling growth, though the specific mechanisms require further investigation.

Different light qualities and photoperiods regulate *P. baillonii* seedling growth by affecting photosynthetic pigments and endogenous hormones, with significant positive correlations between growth indicators and chlorophyll *a*, carotenoids, IAA, GA_3, ZR content, chlorophyll *a*/*b* ratio, IAA/ABA, and (IAA+GA_3+ZR)/ABA ratios. Red-blue composite light with high red light proportion and extended photoperiod promote *P. baillonii* growth and development, while red-blue-purple-green composite light shows no significant promotional effect. Therefore, the 16 $h \cdot d^{-1} \times$ 8R1B treatment represents a suitable light environment for *P. baillonii* seedling cultivation, maintaining high levels of photosynthetic pigments and endogenous hormones that improve seedling quality.

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Note: Figure translations are in progress. See original paper for figures.