



Article

Effect on the Growth and Photosynthetic Characteristics of *Anthurium andreaeanum* ('Pink Champion', 'Alabama') under Hydroponic Culture by Different LED Light Spectra

Yinglong Song^{1,†}, Wenqian Shang^{1,†}, Dandan Ma^{2,†}, Zheng Wang^{1,*} , Songlin He^{1,3,*}, Liyun Shi¹, Yuxiao Shen¹, Dan He¹, Erqiang Wang⁴ and Xiaohui Wang⁴

¹ College of Landscape Architecture and Art, Henan Agricultural University, Zhengzhou 450002, China; edward_song1989@163.com (Y.S.); qianqian656@163.com (W.S.); sisyrin@henau.edu.cn (L.S.); yxshen@henau.edu.cn (Y.S.); dandan990111@163.com (D.H.)

² Jiyang College, Zhejiang Agriculture & Forestry University, Shaoxing 311800, China; adan1178@126.com

³ School of Horticulture Landscape Architecture, Henan Institute of Science and Technology, Xinxiang 453003, China

⁴ Peony Research Institute, Luoyang Academy of Agriculture and Forestry Sciences, Luoyang 471023, China; lnhhzx@126.com (E.W.); wxhny@126.com (X.W.)

* Correspondence: wzhengt@163.com (Z.W.); hsl213@yeah.net (S.H.); Tel.: +86-136-4384-6891 (Z.W.); +86-037-3304-0569 (S.H.)

† These authors contributed equally to this work.



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Abstract: *Anthurium andreaeanum* was one of the best indoor ornamental plants. Two cultivars of *Anthurium andreaeanum* (Pink Champion, Alabama) were used to investigate the effects of light quality on physiological and biochemical indexes. There were six different light quality treatments: Fluorescent Daylight Lamp (CK), and RB (100% Blue, 60% R + 40% B, 70% R + 30% B, 80% R + 20% B, 100% Red) provided by light emitting diodes (LED). The results showed that blue light was beneficial to shoot growth and dry matter accumulation, photosynthetic rate, soluble sugar, and POD activities. Red light was beneficial for the synthesis and accumulation of soluble protein, and could promote root growth. 'Pink Champion' and 'Alabama' obtained the relatively better morphological parameters, chlorophyll contents, photosynthetic parameters, and antioxidant enzyme activities in 7:3 and 6:4 treatments. The antioxidant enzyme (POD, SOD) activities under composite light of red and blue treatments were better than that of monochromatic red, blue light treatments and CK on the whole. Comprehensive evaluation showed that the treatment of 7:3 was a suitable light environment indoors and could be used as the preferred light quality ratio in the production and application of *Anthurium andreaeanum*.

Keywords: light quality; light emitting diode; anthurium; indoor ornamental plant; secondary metabolite; antioxidant enzyme

1. Introduction

Anthurium andreaeanum was a perennial herb of the genus *Anthurium* in *Araceae*. It was one of the most important cut flowers and indoor ornamental plants [1,2], and had broad market application prospects [3,4]. *Anthurium andreaeanum* could grow in a low-light environment, and exploring its adaptability to a low-light environment could provide a reference for low-energy-consumption plant factory, thereby saving energy consumption and improving economic benefits. Current studies on *Anthurium andreaeanum* mainly focused on tissue culture [5–7], variety breeding [8–10], disease control [11–13], and stress physiology [14–17]. The research on the light quality environment physiology of *Anthurium andreaeanum* was mainly focused on the plantlets growth in tissue culture [18,19] and vase life [20,21]. However, there were few reports on the light environment regulation and light quality ratio by transplantation plantlets of *Anthurium andreaeanum*.

Light was an important and indispensable factor in the course of plant growth, and the light quality was particularly important [22–24]. It reported that different light wavelengths could regulate photosynthesis, germination, flowering, biomass accumulation and phytochemical synthesis [25–28]. Many studies show that red light played the most important role in the development of photosynthetic apparatus and influences morphogenesis by light-induced transformations of the phytochrome system [29,30]. Blue light could influence chlorophyll biosynthesis, stomata opening and photomorphogenesis [29,31,32]. As the main absorption peaks of photosynthetic pigment in plant leaves were red and blue light, they were obvious effects on photosynthesis in plants. However, a single red or blue light was not sufficient for the normal growth of plants [33]. Many studies had shown that a certain proportion of red and blue light was beneficial to the growth of plants [34–37]. LED had small mass/volume ratio, long life, low energy consumption, and various monochromatic spectra in visible light, which could adapt to plant photoreceptors to provide more optimal light conditions for different plant growth needs by adjusting the light quality ratio, and influenced the morphology and metabolism of plants, so it had been used as the ideal plant lighting [38–41]. At present, many scholars had used an LED light source to study on *Oncidium*, *Chrysanthemum*, *Cucumber*, *Tomato*, and had achieved preliminary results [42–45]. However, there was no report about the effect of LED on the growth of hydroponic plant seedlings, especially indoor ornamental plants under low light conditions.

In this experiment, the transplantation plantlets of *Anthurium andreaeanum* ('Pink Champion' and 'Alabama') were used as indoor ornamental plant materials to study the effects of different LED light qualities on growth, photosynthetic characteristics, and antioxidant enzyme activities under low light conditions—in order to select the optimal light proportions using red and blue LEDs for improving commodity plantlet qualities and indoor ornamental plant growth, and expand the theoretical and technical basis of *Anthurium andreaeanum* production.

2. Materials and Methods

2.1. Plant Materials, Treatments, and Culture Conditions

The *Anthurium andreaeanum* tissue cultured plantlets ('Pink Champion' and 'Alabama', purchased from Dezhou Shijifeng Horticulture Scientific and Innovation Co., Ltd., Dezhou, China) were used as test materials. The plantlets roots were washed with distilled water, and transplanted in the nutrition bowl (Bottom diameter/calibre/height: 7 cm/9 cm/8 cm) with substrate (perlite:vermiculite = 1:1). Hydroponic Cultured the plantlets with Japanese-style Garden Nutrient Solution (Main elements concentrations: N 243.9 mg·L⁻¹, P 41.8 mg·L⁻¹, K 312.8 mg·L⁻¹, Ca 161.0 mg·L⁻¹). The plantlets were irrigated by a nutrient solution every three days. There were 20 plantlets in each treatment, and each treatment was repeated three times.

Plantlets were cultured under six different light quality treatments (Figure 1): Fluorescent Daylight Lamp (TLD-type PGFLs, Philips Co., Shanghai, China) was used as control (CK), and different light spectra ratios provided by light-emitting diodes (LEDs, lamp belt, designed by our research team and tailor-made by Xiamen Hualian Electronics Co., Ltd., Xiamen, China) [100% blue (B); 60% red + 40% blue (6:4); 70% red + 30% blue (7:3); 80% red + 20% blue (8:2); 100% red (R)]. All the light-sources were installed on top of the plant culture rack and controlled separately by a central processor (layer number/layer height/layer length/layer width: 6/40 cm/1200 cm/600 cm, designed by our research team and tailor-made by Sheng Yuan Instrument Co., Ltd., Zhengzhou, China).

Plantlets in each treatment were cultured on the plant culture rack in the culture room (Laboratory of Ornamental Plants, Henan Agricultural University, Zhengzhou, China) after being transplanted. Throughout the culture period (60 days), the air temperature and relative humidity in the culture room were respectively maintained at 25 ± 1 °C and 70 ± 5%. The photoperiod was 14 h·d⁻¹, and the photosynthetically active radiation at the canopy level was set at 40 ± 2 μmol·m⁻²·s⁻¹ (Simulate an indoor low-light growth environment, measured by a Hansatech QRT1 PAR sensor, Hansatech Instruments Ltd., Norfolk, UK).

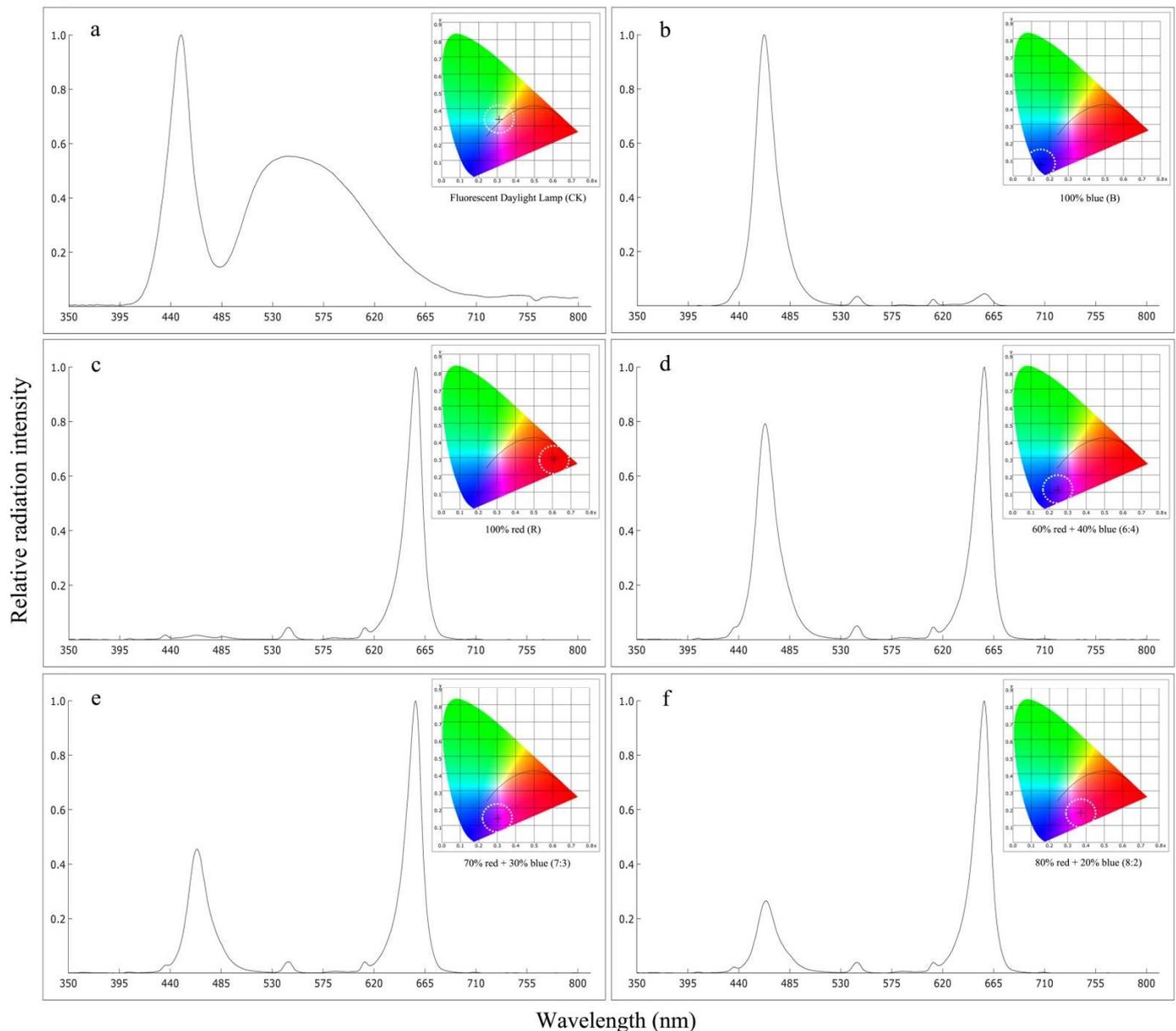


Figure 1. Relative spectral distribution of the fluorescent daylight lamp and LEDs. (a) Fluorescent Daylight Lamp as control (CK), (b) 100% blue (B), (c) 100% red (R), (d) 60% red + 40% blue (6:4), (e) 70% red + 30% blue (7:3), (f) 80% red + 20% blue (8:2). The white circle shows the center of the spectral component marker.

2.2. Morphological Indicators and Root Activity Analysis

All the plantlets in each treatment were cultured for 60 days, and the following parameters were assessed: plant height, leaf number, maximum leaf length, leaf width (i.e., leaf expanded surface of the third leaf from the apex), root number, maximum root length, root activity, and shoot and root fresh/dry weight (FW/DW) (total and separately). Root length was measured from the base of attachment of the root to the stem of the root tip of the longest root harvested from the plantlets. To measure DW, shoots and roots were dried separately at 105 °C for 30 min then at 60 °C for 48 h in a thermostat, or until constant weight. The root activity of plantlet *in vitro* was detected by the triphenyl tetrazolium chloride (TTC) reduction methods described by Ryssov-Nielson and Trevors [46,47].

2.3. Chlorophyll, Chlorophyll Fluorescence, and Photosynthetic Parameters Analysis

The chlorophyll (Chl) content of the third leaf from the apex was assessed by extracting in acetone with absolute ethyl alcohol [48]. In brief, leaves of each treatment were washed with sterile distilled water and any moisture was absorbed with blotting paper. In addition, 0.2 g of chopped leaves were placed in 20 mL of a 1:1 (*v/v*) mixture of 80% acetone and absolute ethyl alcohol in a 25 mL stoppered test tube in the dark for 24 h. Using 80% acetone as the blank, the absorbance (OD) was measured at $\lambda = 663, 645$ and 470 nm using a UV spectrophotometer (Shimadzu, Tokyo, Japan).

Chlorophyll fluorescence was measured by a Fluorescence Monitoring System (FMS, Hansathech Instruments, King's Lynn, UK). Leaves were dark adapted for 20 min prior determination of minimum (F_o) and maximum (F_m) fluorescence. The maximum quantum yield of PSII photochemistry (F_v/F_m) was determined as Equation (1). Then, leaves were adapted to PPFD of $500 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and a saturating pulse of 0.8 s with $> 6000 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ was applied in order to determine the maximum (F_m') and the steady-state (F_s) fluorescence in light adapted conditions. The quantum yield of PSII (Φ_{PSII}) was calculated according to Equation (2) [49]. The non-photochemical quenching (NPQ) due to dissipation of excess light energy was calculated as Equation (3) [50]:

$$F_v/F_m = (F_m - F_o)/F_m \quad (1)$$

$$\Phi_{\text{PSII}} = (F_m' - F_s)/F_m' \quad (2)$$

$$\text{NPQ} = (F_m - F_m')/F_m' \quad (3)$$

The second fully expanded leaf was used for determination of CO_2 assimilation rate (P_n), stomatal conductance (g_s), intercellular carbon dioxide concentration (C_i), and transpiration rate (E) using an infrared gas analyzer (LI-6400, Li-COR, Lincoln, OR, USA) in a growth chamber with a constant temperature of 25 °C, saturated CO_2 concentration and 70% relative humidity.

2.4. Soluble Sugars and Soluble Proteins Analysis

The content of soluble sugars was measured by the method of Clegg [51]. Samples (0.05 g shoot DW) were put into a test tube, to which 5 mL of distilled water was added and mixed. After 30 min in a water bath at 85 °C, the supernatant was collected. This step was repeated twice, and then distilled water was added to a volume of 10 mL. The soluble sugar content was determined with the sulfuric acid anthrone method at a wavelength of 620 nm.

Soluble proteins were measured by the Bradford method [52]. Samples (0.05 g shoot DW) were ground up in a mortar with liquid nitrogen, to which 3 mL of a phosphate-buffered solution (pH 7.0) was added. The extract was centrifuged at $13,000 \times g$ for 15 min at 4 °C, and 0.1 mL of the supernatant was combined with 4.9 mL of a Coomassie brilliant blue G-250 solution ($0.1 \text{ g}\cdot\text{L}^{-1}$). After 2 min, the soluble protein content was determined at a wavelength of 595 nm.

2.5. Antioxidant Enzymes Activity Analysis

Superoxide dismutase (SOD) activity and peroxidase (POD) activity were assessed based on the photochemical method and the rate of oxidation method described by Zhao [53].

2.6. Statistical Analysis

Analysis of variance (ANOVA) was performed with SPSS 18.0 software (SPSS Inc., Chicago, IL, USA) and significant differences between means were determined by Duncan's multiple range test (DMRT) at $p \leq 0.05$.

3. Results

3.1. Plant Growth and Morphology

The effect of light quality on the growth under hydroponics were summarized in Tables 1 and 2, and the morphological parameters of 'Pink Champion' were better than 'Alabama' on the whole. 'Pink Champion' showed the biggest values of root and total fresh weight under 7:3 treatment, and were significantly higher than other treatments. The plant height, leaf number, root number, root length, shoot fresh weight, root and total dry weight of 'Pink Champion' all had the maximum values in 7:3 treatment, and were significantly higher than CK. 'Alabama' had the largest values of plant height, leaf width, root length, root, and total fresh weight at 7:3 treatment, and was significantly higher than other treatments. The leaf length, root number, shoot fresh weight and total dry weight of 'Alabama' were the biggest under 7:3 treatment, and were significantly higher than CK. However, there were no significant differences during all the treatments on leaf number, shoot and root dry weight, and dry mass rate of 'Alabama'. The leaf width of 'Pink Champion' and 'Alabama' under B were significantly higher than that of R treatment. 'Pink Champion' also showed the bigger plant height, leaf length, shoot and total dry weight, and dry mass rate in B than R.

Table 1. Effects of different light qualities on the growth of *Anthurium* 'Pink Champion, Alabama'.

Cultivar	Treatment	Plant Height (cm)	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Root Number	Root Length (cm)
Pink Champion	CK	20.72 bc ± 0.39	8.20 b ± 0.58	6.90 ab ± 0.27	3.50 ab ± 0.11	9.60 c ± 0.82	8.46 b ± 0.56
	B	22.06 ab ± 1.56	8.00 b ± 0.55	7.42 a ± 0.44	3.59 a ± 0.19	11.20 bc ± 0.93	8.78 b ± 0.55
	6:4	22.32 ab ± 0.54	9.00 ab ± 0.63	7.26 ab ± 0.57	4.02 a ± 0.30	13.60 ab ± 0.24	9.98 ab ± 0.29
	7:3	24.68 a ± 1.14	10.60 a ± 0.75	7.04 ab ± 0.24	3.62 a ± 0.10	16.60 a ± 0.75	11.28 a ± 0.48
	8:2	23.72 ab ± 0.96	9.40 ab ± 0.98	6.96 ab ± 0.43	3.72 a ± 0.17	13.80 ab ± 0.86	8.94 b ± 0.56
	R	18.76 c ± 1.01	8.00 b ± 0.84	6.02 b ± 0.26	2.98 b ± 0.18	13.20 b ± 0.66	8.88 b ± 0.66
Alabama	CK	18.14 bc ± 1.35	6.80 a ± 0.58	6.18 b ± 0.29	3.86 bc ± 0.19	8.40 bc ± 0.51	9.16 b ± 0.65
	B	16.22 c ± 0.89	7.20 a ± 0.73	6.50 ab ± 0.24	4.08 b ± 0.12	8.00 c ± 0.32	8.82 b ± 0.92
	6:4	20.48 b ± 0.67	7.80 a ± 0.49	6.60 ab ± 0.43	3.90 bc ± 0.15	11.00 ab ± 0.89	11.00 b ± 0.71
	7:3	24.06 a ± 0.57	7.40 a ± 0.24	7.32 a ± 0.44	4.72 a ± 0.24	11.80 a ± 0.21	14.28 a ± 0.61
	8:2	19.70 b ± 1.04	8.20 a ± 0.50	6.78 ab ± 0.28	4.16 b ± 0.24	9.00 abc ± 0.44	10.58 b ± 0.51
	R	18.40 bc ± 0.63	7.00 a ± 0.32	6.22 b ± 0.21	3.42 c ± 0.14	10.00 abc ± 0.52	10.72 b ± 0.40

The statistical analysis has been carried out separately for each cultivar. Different letters indicate significant differences using the Duncan's Multiple Range Test ($p < 0.05$; $n = 10$).

Table 2. Effects of different light qualities on fresh and dry weight of *Anthurium* 'Pink Champion, Alabama'.

Cultivar	Treatment	Fresh Weight (g)			Dry Weight (g)			Dry Mass Rate (%)
		Shoot	Root	Total	Shoot	Root	Total	
Pink Champion	CK	5.85 bc ± 0.43	2.02 c ± 0.21	7.87 c ± 0.62	0.83 a ± 0.07	0.13 b ± 0.01	0.96 b ± 0.08	11.68 ab ± 0.83
	B	6.23 bc ± 0.47	2.27 c ± 0.31	8.50 bc ± 0.67	0.84 a ± 0.06	0.20 ab ± 0.03	1.05 ab ± 0.07	12.40 a ± 0.69
	6:4	6.70 b ± 0.56	3.15 bc ± 0.45	9.85 bc ± 0.59	0.87 a ± 0.07	0.24 ab ± 0.04	1.11 ab ± 0.09	11.48 ab ± 0.59
	7:3	8.60 a ± 0.64	5.00 a ± 0.51	13.60 a ± 0.91	1.02 a ± 0.09	0.31 a ± 0.02	1.33 a ± 0.10	9.73 ab ± 0.24
	8:2	7.07 ab ± 0.46	3.56 b ± 0.32	10.64 b ± 0.71	0.97 a ± 0.07	0.26 a ± 0.04	1.23 ab ± 0.05	11.71 ab ± 0.68
	R	4.89 c ± 0.64	2.76 bc ± 0.35	7.65 c ± 0.37	0.39 b ± 0.08	0.22 ab ± 0.03	0.62 c ± 0.03	8.57 b ± 0.65
Alabama	CK	3.85 b ± 0.16	1.72 b ± 0.28	5.58 b ± 0.30	0.47 a ± 0.05	0.13 a ± 0.04	0.60 b ± 0.04	11.10 a ± 0.82
	B	3.98 b ± 0.38	1.42 b ± 0.36	5.40 b ± 0.35	0.56 a ± 0.09	0.16 a ± 0.02	0.72 ab ± 0.04	14.64 a ± 0.57
	6:4	4.98 ab ± 0.31	2.23 b ± 0.33	7.21 b ± 0.54	0.63 a ± 0.05	0.23 a ± 0.03	0.86 ab ± 0.05	12.12 a ± 0.72
	7:3	5.69 a ± 0.25	3.26 a ± 0.39	8.95 a ± 0.38	0.68 a ± 0.09	0.28 a ± 0.03	0.96 a ± 0.05	10.81 a ± 0.65
	8:2	4.33 b ± 0.19	2.19 b ± 0.26	6.52 b ± 0.50	0.55 a ± 0.07	0.18 a ± 0.02	0.73 ab ± 0.06	11.68 a ± 0.13
	R	3.96 b ± 0.16	1.83 b ± 0.32	5.79 b ± 0.36	0.47 a ± 0.03	0.17 a ± 0.02	0.64 b ± 0.05	11.57 a ± 0.66

The statistical analysis has been carried out separately for each cultivar. Different letters indicate significant differences using the Duncan's Multiple Range Test ($p < 0.05$; $n = 10$).

3.2. Root Activity

The root activity of 'Pink Champion' and 'Alabama' showed the trend of rising first and then going downward with the increase of the red light content (Figure 2), and 'Pink Champion' was higher than 'Alabama' on a whole, except the 7:3 treatment. 'Pink Champion' and 'Alabama' all obtained the largest value of root activity in 7:3 treatment, and were

significantly higher than CK. The root activity of 'Pink Champion' and 'Alabama' under B were higher than R, and the difference was not significant.

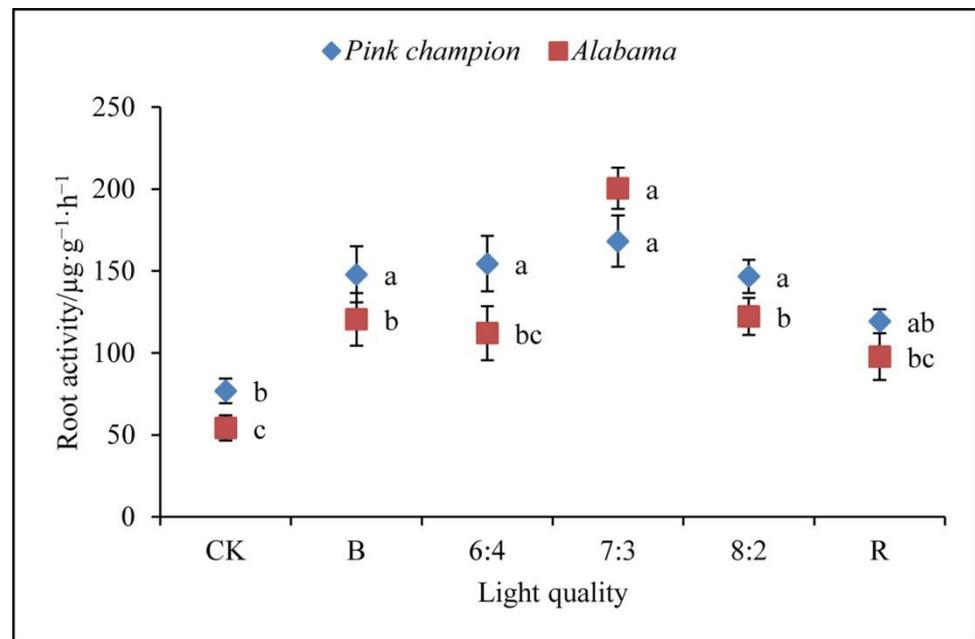


Figure 2. Effects of different light qualities on root activity of *Anthurium* 'Pink Champion, Alabama'. The statistical analysis has been carried out separately for each cultivar. Vertical bars indicate standard error ($n = 5$). Different letters represent significant difference at $p < 0.05$ among treatments by the Duncan's multiple range test.

3.3. Pigment Contents

The leaf chlorophyll content of 'Pink Champion' and 'Alabama' were focused on in Figure 3, 'Alabama' had higher Chl a and Chl b contents than 'Pink Champion' in all the treatments, but the Cars contents were the opposite. The pigment contents Chl a, Chl b, and Cars of 'Pink Champion' and 'Alabama' were rising first and then going downward with the increase of the red light ratio as a whole. 'Pink Champion' had the biggest Chl a and Cars at 8:2 and the largest Chl b in 7:3, and both were significantly higher than CK, B, and R. 'Alabama' showed maximum Chl a, Chl b, and Cars contents under 6:4, and were significantly higher than CK, B, and R. The change trend of Chl a + b was the same as that of Chl a and Chl b, but the change trend of the Chl a/b was the opposite. 'Pink Champion' and 'Alabama' obtained the minimum values of Chl a/b in 7:3 and 6:4, respectively, which were significantly lower than CK, B, and R. In addition, the Chl a/b values of 'Pink Champion' were higher than that of 'Alabama' as a whole.

3.4. Chlorophyll Fluorescence

As showed in Figure 4, the chlorophyll fluorescence parameters Φ PSII and qP of 'Pink Champion' and 'Alabama' showed the trend of rising first and then going downward with the increase of the red light ratio, but Fv/Fm and NPQ were increased, decreased and then increased again in response to increases in the red light ratio on the whole. 'Pink Champion' had the biggest Fv/Fm, Φ PSII, qP and NPQ under 7:3 treatment, the Φ PSII, qP, and NPQ in 7:3 treatment were significantly lower than CK, but the Fv/Fm had no significant difference during all the treatments. 'Alabama' showed the largest Fv/Fm, qP, and NPQ under 7:3 as well, significantly higher than CK, and maximum Φ PSII in 6:4 treatment, significantly higher than R. The Fv/Fm, Φ PSII, and qP of 'Pink Champion' were better than 'Alabama' as a whole. In addition, Φ PSII and qP values under B were better than R treatment, but the difference was not significant.

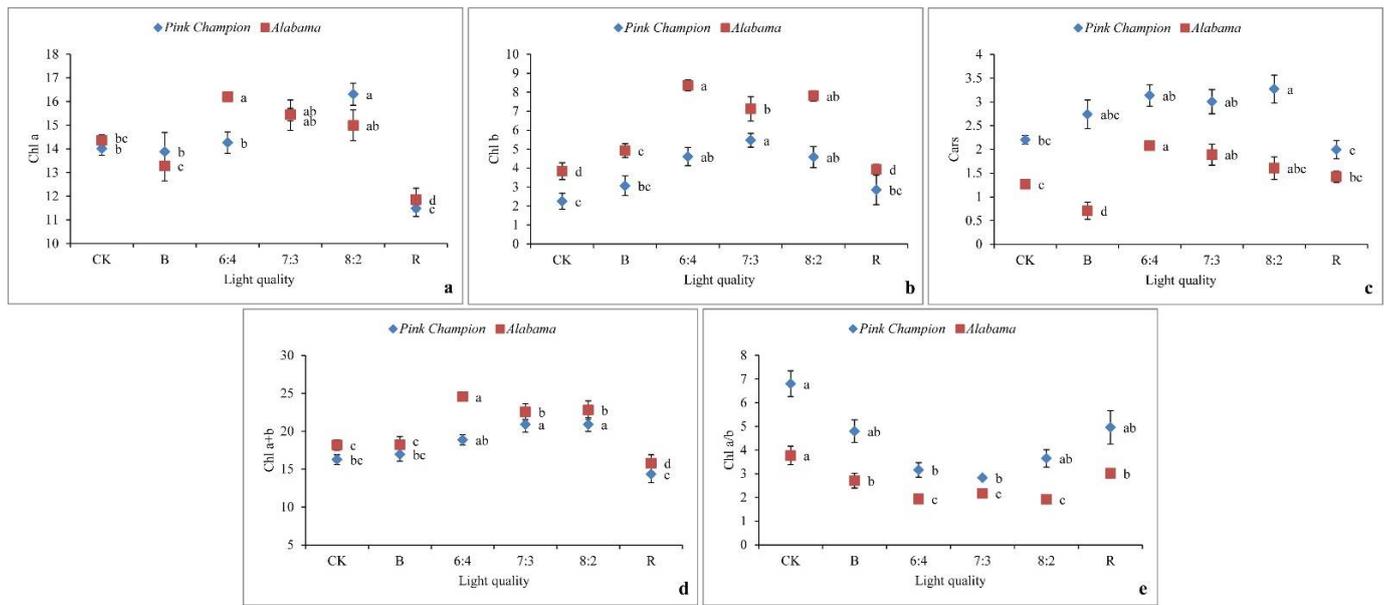


Figure 3. Effects of different light qualities on leaf chlorophyll content of *Anthurium* 'Pink Champion, Alabama' ((a) Chl a, (b) Chl b, (c) Carotenoid, (d) Chl a + b, (e) Chl a/b.). The statistical analysis has been carried out separately for each cultivar. Vertical bars indicate standard error ($n = 5$). Different letters represent a significant difference at $p < 0.05$ among treatments by the Duncan's multiple range test.

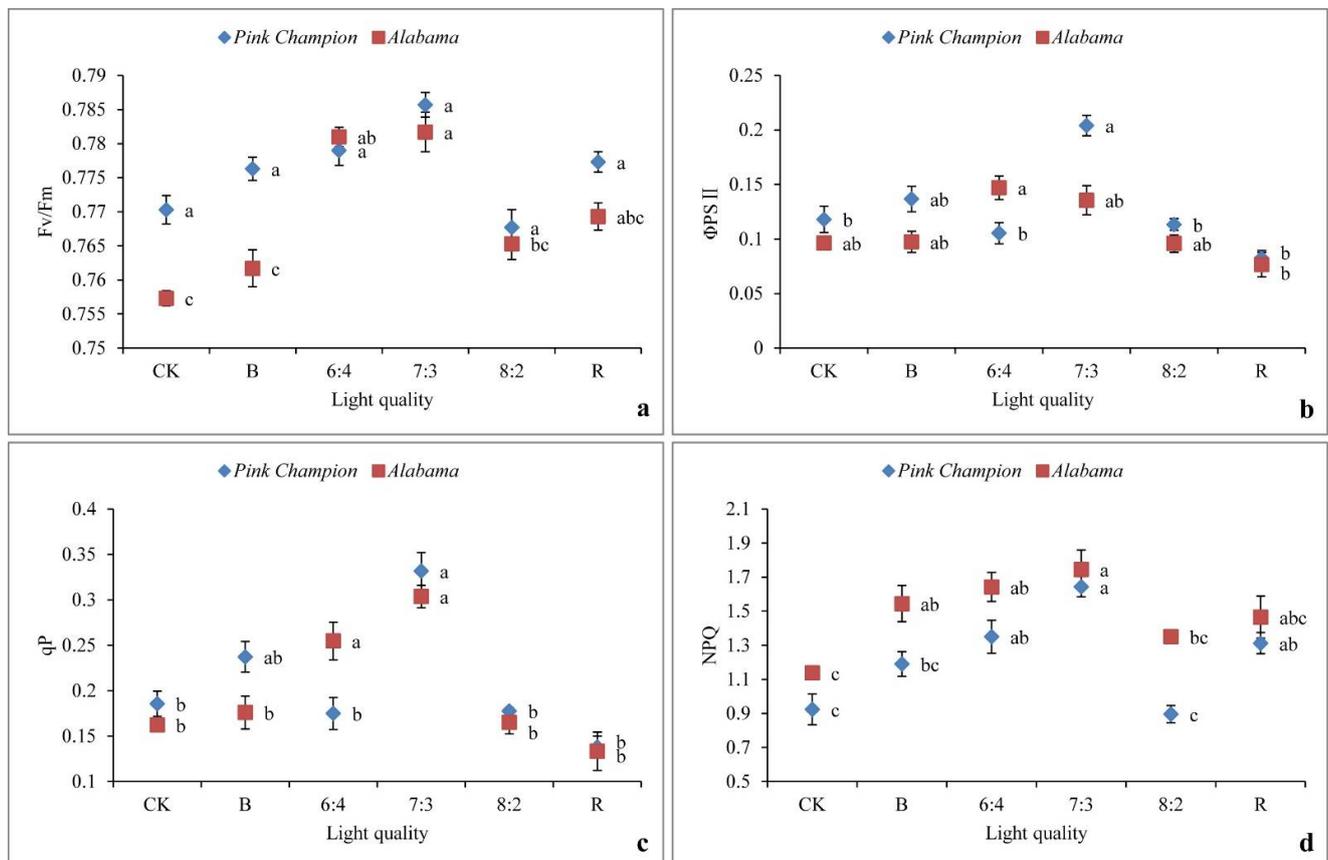


Figure 4. Effects of different light qualities on chlorophyll fluorescence parameters of *Spathiphyllum* *Anthurium* 'Pink Champion, Alabama' ((a) Fv/Fm, (b) Φ PSII, (c) qP, (d) NPQ.). The statistical analysis has been carried out separately for each cultivar. Vertical bars indicate standard error ($n = 5$). Different letters represent a significant difference at $p < 0.05$ among treatments by the Duncan's multiple range test.

3.5. Photosynthesis

The photosynthetic parameters of ‘Pink Champion’ and ‘Alabama’ showed the trend of rising first, then going downward, and then rising again with the increase of the red light ratio on the whole, and the photosynthetic parameters of ‘Pink Champion’ were better than ‘Alabama’ (Figure 5).

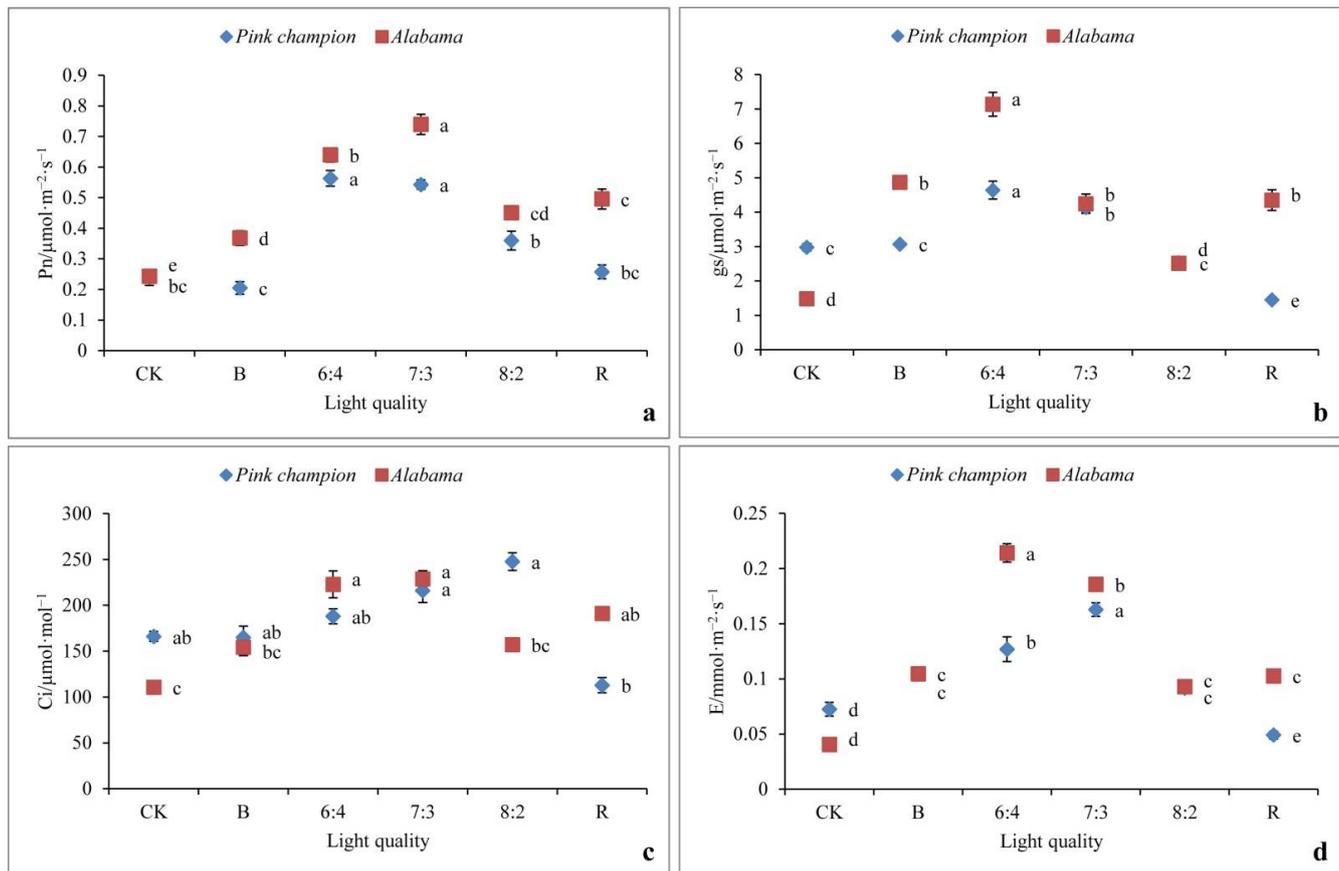


Figure 5. Effects of different light qualities on photosynthetic parameters of *Anthurium* ‘Pink Champion, Alabama’ ((a) Pn, (b) gs, (c) Ci, (d) E). The statistical analysis has been carried out separately for each cultivar. Vertical bars indicate standard error ($n = 5$). Different letters represent a significant difference at $p < 0.05$ among treatments by the Duncan’s multiple range test.

‘Pink Champion’ and ‘Alabama’ all had the biggest values of gs at 6:4 treatment, and were significantly higher than other treatments, but the largest values of Pn, E, and Ci were showed in different treatments between ‘Pink Champion’ and ‘Alabama’. ‘Pink Champion’ obtained the maximum values of Pn, E, and Ci under 6:4, 7:3 and 8:2, respectively, and showed the minimum E, gs and Ci at R, least Pn at B. ‘Alabama’ had the largest Pn, E, and Ci in 7:3, 6:4, and 7:3, respectively, and had the minimum photosynthetic parameters under CK. The gs and E of ‘Pink Champion’ were significantly higher in B than R. The Pn and Ci of ‘Alabama’ were significantly higher in R than B.

3.6. Soluble Sugars, Soluble Proteins

With the increase of the red light ratio, the soluble sugars content of ‘Pink Champion’ and ‘Alabama’ were rising first and then going downward (Figure 6a). ‘Pink Champion’ obtained the largest soluble sugars content in B, followed by 6:4, and the lowest value in CK. ‘Alabama’ obtained the largest soluble sugars content under 7:3 treatment, and the minimum value under R treatment. The soluble sugars content of ‘Pink Champion’ and ‘Alabama’ in B were higher than R treatment as a whole.

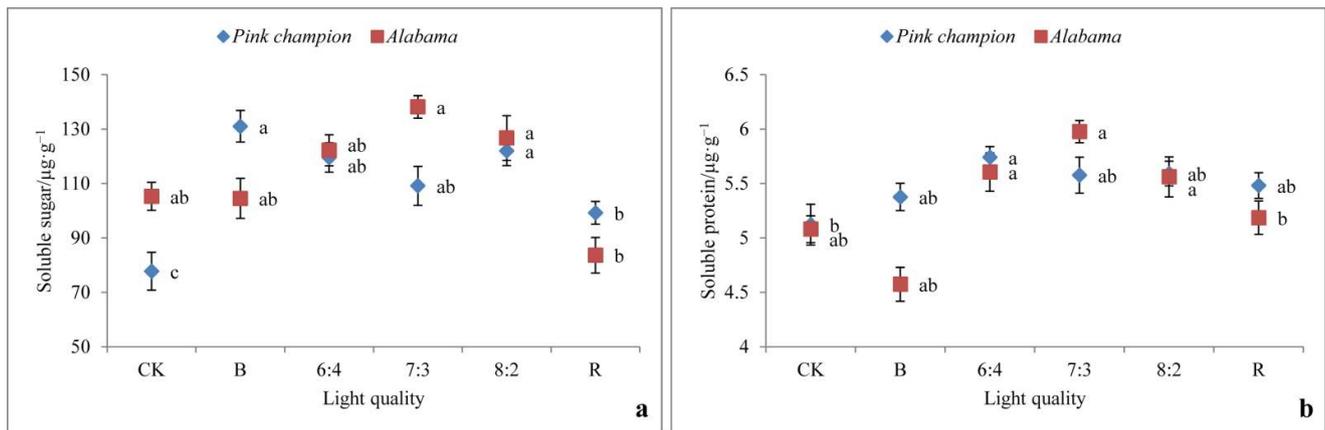


Figure 6. Effects of different light qualities on soluble sugar (a) and protein (b) of *Anthurium* 'Pink Champion, Alabama'. The statistical analysis has been carried out separately for each cultivar. Vertical bars indicate standard error ($n = 5$). Different letters represent a significant difference at $p < 0.05$ among treatments by the Duncan's multiple range test.

The soluble proteins content of 'Alabama' showed the trend of declining first and rising slightly, but it still went down at last (Figure 6b); it showed the biggest soluble proteins content at 7:3, and had the lowest value under B, but there was no significant difference between them. 'Pink Champion' showed the trend of rising first and then going downward, it obtained the maximum value at 6:4, and was significantly higher than that of CK.

3.7. Antioxidant Enzyme Activity (POD, SOD)

The POD and SOD activities of 'Pink Champion' and 'Alabama' showed the same trend of rising first and then going downward with the increase of the red light ratio (Figure 7). 'Pink Champion' and 'Alabama' all obtained the maximum POD activities under 6:4, and the largest SOD activities at 7:3 treatment. They all showed the minimum POD activities at CK, and the POD activities were higher in B than R, which had no significant difference between them. The POD activities of 'Pink Champion' were overall higher than 'Alabama', and it as a whole was one time higher than that of 'Alabama'. The least SOD activity of 'Pink Champion' was reached in B, but 'Alabama' obtained the minimum SOD activity at R; they were different, and they all showed no significant difference between B and R treatments.

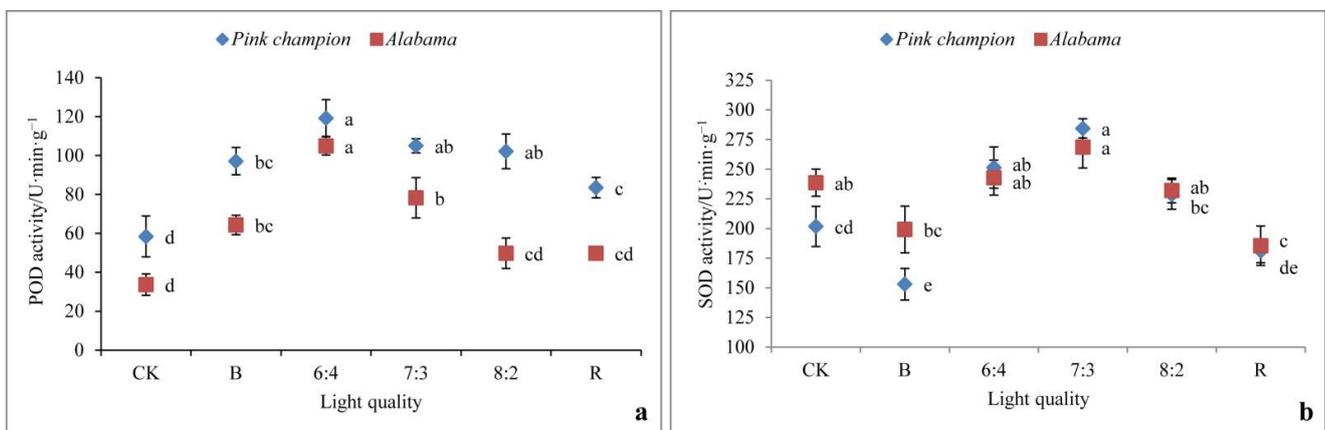


Figure 7. Effects of different light qualities on POD (a) and SOD (b) activity of *Anthurium* 'Pink Champion, Alabama'. The statistical analysis has been carried out separately for each cultivar. Vertical bars indicate standard error ($n = 5$). Different letters represent a significant difference at $p < 0.05$ among treatments by the Duncan's multiple range test.

4. Discussion

Light quality was flagged as a regulatory role in plant growth, morphogenesis, photosynthesis, and substance metabolism [27]. Therefore, the external morphological characteristics of plants were the most intuitive expression of their adaptability to light environment. This study investigated the effects of different light quality ratios on the growth of *Anthurium andreanum* ('Pink Champion' and 'Alabama') under low light conditions, and it showed that 'Pink Champion' and 'Alabama' obtained larger leaf width at B than R. 'Pink Champion' had lower plant height, leaf number, root number, root length, shoot fresh weight, root, and total dry weight at R than B; these indicators were significantly weaker than that of monochromatic blue light treatment. This suggested that blue light promoted the elongation growth and dry matter accumulation of *Anthurium andreanum*, which was consistent with the results on cucumber and tomato [54,55]. However, it was different from the research conclusion of Kurilcik et al. [56], which may be caused by different spectrum absorption range in different plant materials and varieties [57]. The root number, root length, root fresh, and dry weight of 'Pink Champion' and 'Alabama' were slightly higher in R than B, which was consistent with the results on hemerocallis and cucumber [58,59]. Root activity under red light was slightly lower than that under blue light, which was similar to the research conclusions of Pu et al. [60]. 'Pink Champion' and 'Alabama' both obtained significantly bigger values of root length, shoot and root fresh weight, and total fresh weight under 7:3 treatment than B and R, which indicated that the composite light of red and blue was more conducive to the morphogenesis, movement, and accumulation of photosynthates of *Anthurium andreanum* than monochromatic light, which was consistent with the research on cucumber, hemerocallis, and tomato [45,59,61]. The phenomenon showed that combined red and blue light might be regarded as a relatively good light quality to support normal growth of *Anthurium andreanum* under a low-light environment. In addition, the values of plant height, leaf number, root number, root fresh and dry weight of 'Pink Champion' were higher than 'Alabama', which showed that the 'Pink Champion' had better adaptability and a higher response mechanism to light quality than 'Alabama'.

Photosynthetic pigment, as the material basis for photosynthesis, was a direct expression of the photosynthetic capacity of plants. The increase of its content was conducive to fixing more light energy for plants. This study found that the values of Chl a, Chl b, and Chl a + b of 'Pink Champion' and 'Alabama' under monochromatic blue light were higher than that of monochromatic red light, composite light of red and blue treatments were higher than that of monochromatic light and CK, and they had relatively higher values in 7:3 and 6:4, respectively. This result was similar to the research on hemerocallis and tobacco [59,62]. These observations might reflect the beneficial effects of combined red and blue light on morphogenesis as well as the synthesis and accumulation of photosynthetic pigments via light-induced transformations of the phytochrome system. The Chl a/b of 'Pink Champion' and 'Alabama' obtained relatively lower values in 7:3 and 6:4, respectively, which indicated that composite light of red and blue treatments were conducive to enhancing the shade plant characteristics of plants [24,63]. 'Pink Champion' had higher Chl a and Chl b contents than 'Alabama' in all the treatments overall, but the carotenoids contents were the opposite. This might have something to do with the fact that 'Alabama' was a red flower variety that required more anthocyanin than 'Pink Champion'.

Chlorophyll content directly affected the photosynthetic fluorescence parameters of plants. In addition, photosynthetic fluorescence parameters were the effective probes for studying the photosynthetic physiological state of plants [24,64]. This showed that the chlorophyll fluorescence parameters Φ PSII and qP under B were better than R, which was similar to the trend of chlorophyll content. The values of Fv/Fm in this research indicated that there was no stress effect on the growth of 'Pink Champion' and 'Alabama' under each treatment. The Φ PSII of 'Pink Champion' and 'Alabama' were slightly higher in monochromatic blue light than red without a significant difference, and they obtained the bigger Φ PSII values under 7:3 and 6:4 treatment, respectively. 'Pink Champion' and 'Alabama' showed the largest qP under 7:3, and had little overall difference from other

treatments. This indicated that they had the same assimilation efficiency of light energy, and the 7:3 treatment was the best. At the same time, the NPQ under 7:3 treatment was also relatively higher than others, which indicates that they could effectively exhaust excess light energy as heat energy under 7:3 treatment and maintain their rapid growth. It showed that the plantlets' photosynthetic fluorescence parameters under a combined red and blue light were better than that under monochrome light [65,66], and it was best under 7:3 treatment, which implied that the improvement of combining red and blue light on chlorophyll fluorescence parameters was mediated by a complex mechanism and was not simply a result of a superposition effect.

Photosynthesis, which depended on the fluorescence parameters of chlorophyll and chloroplast, was a key factor affecting plant assimilation and yield [67], which was closely related to light quality. This study showed that 'Pink Champion' and 'Alabama' had the biggest values of g_s under 6:4 treatment. The P_n , E , and C_i were different between 'Pink Champion' and 'Alabama'. They did not all show up in a single treatment, but all in composite light of red and blue treatments, and the photosynthetic parameters of monochromatic blue and red light treatments were smaller than others. This was similar to the results on cucumber [61]. It could be seen that the absence of red or blue light could result in photosynthetic inefficiencies, the appropriate higher red light ratio could promote the photosynthesis of *Anthurium andraeanum*, and the composite light of red and blue could effectively improve and maintain better photosynthetic performance of plants than the monochromatic light. Notably, the beneficial effects of the composite light treatment on photosynthesis were also associated with a complex mechanism and were not simply due to the additive effects of the red and blue light treatments.

Photosynthate was a direct feedback of plant photosynthesis and could react to plant metabolism and physiology. Soluble sugars and proteins, such as photosynthates and osmotic regulatory substances, could directly or indirectly regulate the growth and development process of plants [68]. This research found that the soluble sugars content was higher in B than R. The soluble proteins content was the opposite: it was lower in B than R. This indicated that blue light was beneficial to the synthesis and accumulation of soluble sugar, which was similar to the conclusion on apple [69]. Red light was beneficial to the synthesis and accumulation of soluble proteins. This was consistent with the results of Wu et al. [70]. This phenomenon might be related to the indoor low-light environment simulated in this study. 'Pink Champion' and 'Alabama' obtained the relatively larger soluble sugars and proteins contents in 6:4 and 7:3, respectively. The accumulation of photosynthate under composite light of red and blue treatment was better than monochromatic light on the whole, which was consistent with the results on photinia [71]. 'Pink Champion' was more sensitive to the response of secondary metabolite synthesis and accumulation under blue light.

Antioxidant enzymes SOD and POD were protective enzymes of plants, and their activities directly affect the growth and development of plants. As a signal factor, light quality could activate the antioxidant enzyme system [72]. Yu et al. found that the activity of POD enzyme in grapes was increased under red light, while Normanly et al. found that red light reduced the activity of POD [73,74]. This study found that the POD activities of 'Pink Champion' and 'Alabama' were relatively higher in B than R. This was consistent with the findings on *Rehmannia glutinosa* and tomato [75,76]. This indicated that blue light could more effectively promote its POD activity under a low-light environment. 'Pink Champion' and 'Alabama' obtained the relatively larger POD activities under 6:4 and larger SOD activities at 7:3 treatment. Simlat et al. also had a similar conclusion on stevia [77]. This result indicated that composite light of red and blue treatment significantly increased the antioxidant enzyme activity of *Anthurium andraeanum*, and made the antioxidant enzyme activity of *Anthurium andraeanum* behave like a sun plant. This had a protective effect on the antioxidant enzyme defense mechanism. The POD activity of 'Pink Champion' was higher than 'Alabama' as a whole, and there was little difference in SOD activity of 'Pink

Champion' and 'Alabama'. It suggested that the antioxidant enzyme mechanism of 'Pink Champion' was more sensitive and efficient than 'Alabama' under a low-light environment.

5. Conclusions

In summary, 'Pink Champion' and 'Alabama' showed better physiological indexes, including growth indexes, pigment content, photosynthetic fluorescence parameters, photosynthetic indexes, photosynthetic products and antioxidant enzyme activities in composite light of red and blue 7:3 and 6:4 treatments, which were significantly better than those of other treatments. In addition, 7:3 was the best overall treatment among them under a low-light environment. This was a suitable light environment for the growth of 'Pink Champion' and 'Alabama' and made the physiological characteristics of *Anthurium andraeanum* more like that of sun plants. This could be used as the preferred light quality ratio in the large-scale production and application of *Anthurium andraeanum*. However, a different red-blue light mass ratio had a complex regulation effect on the growth of *Anthurium andraeanum*, and the specific mechanism was still unclear and would need to be further studied.

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