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VARIATION IN GROWTH AND PHYSIOLOGICAL CHARACTERISTICS OF TOMATO SEEDLINGS EXPOSED TO DIFFERENT LEDS LIGHT QUALITY

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Abstract

The present study was to evaluate variation in growth, physiological characteristics of tomato (*Lycopersicon esculentum* Mill.) exposed to different LEDs. Seedlings of the cultivar 'Baolai 303' were cultured under FL, B, BR1:1, R and Y LEDs, at a PPFD of 120 μ mol $m^{-2}\cdot s^{-1}$ for 12· d^{-1} photoperiod for about 30 days. The fresh and dry mass, stem width, root and stem length, pigment content, sucrose, soluble sugar levels, leaf thickness, spongy tissue, palisade tissue, photosynthetic rate, and the area and frequency of stomata were higher than FL. The palisade tissue arranged compactly under BR1:1. The palisade tissue also arranged tidy under B in comparison to FL. Starch contents in leaves and stems were the highest under R. BR1:1, promoted the tomato growth, and it can use for cultivation of tomato under the controlled conditions.

Keywords: LEDs; Tomato; *Lycopersicon esculentum* Mill.; Photosynthetic rate; Leaf anatomy; Stomata.

Introduction

Light wavelength is significant for the plant growth; it can also affect the physiological characteristics, photosynthesis, cells, and tissues growth (Xu *et al.*, 2012; Li *et al.*, 2017). Plants can react to the variations in their exposure environment by adjustment the structural, physiological characteristics of the leaves (Guan *et al.*, 2011), the typical leaf mass, rate of net photosynthesis expressed on a dry weight basis. Initial growth is an important factor in subsequent survival and development. Structural carbon concentration is optimally distributed with respect to light to maximize carbon gain (Coble & Cavaleri, 2015). Soluble sugar can protect the cells in case of oxidation damage, while sucrose is the major storage, accumulation, and translocation energy form of the plant. Not only can sucrose supply the energy needed for growth and metabolism, it is also a somatically active solute playing a key role under stress conditions (Mustafa *et al.*, 2007). Stomata regulate gas diffusion towards leaf interior, while leaf anatomy, leaf morphology, biochemical points, makes up internal carbon dioxide (CO_2) distribution to positions of carboxylation (Warren, 2008).

The tomato plants of growth and physiology are the greatly affected by their quality (Hamamoto *et al.*, 2000). Tomato (*Lycopersicon esculentum* Mill.) was the plants that prefer a high light radiation rate (Liu *et al.*, 2011b; Chand *et al.*, 2020; El-Zohri *et al.*, 2020). Weak light is one of the most limited factors for breeding baby seedlings. Typically, the seedlings are bred in greenhouses which use artificial lights instead of natural sunlight. The artificial lights commonly applied for cultivating plants are fluorescent lamps, incandescent lamps, high-pressure sodium lamps, metal halide lamps, which also include dispensable wavelengths that are not very considerable in plant growth (Kim *et al*., 2004). Red, blue lights are fundamental in light spectrum for vegetables. However, the light-emitting diodes was optimized the light spectrum for plant, and they have been used for the light sources in seedling production, horticulture, zoological tests for plant chambers (Stutte, 2009).

The light-emitting diodes have been already used to incubate some horticultural varieties, such as: Chinese cabbage, lettuce, *Cucumis sativus*, cherry tomato, non-heading Chinese cabbage, and tomato etc. (Avercheva *et al.*, 2009; Li & Kubota, 2009; Sander *et al.*, 2010; Liu *et al.*, 2011a; 2011b; Li *et al.*, 2012; Fan *et al.*, 2013a; 2013b). However, the anterior researchers have found that light quality effects on morphological, physiological of plants. However, the optimal light for plant growth depends on the plant species or cultivar. Therefore, selecting appropriate light for industrial culture of tomato is essential. The study objective was to measure the effects of FL (the control), B, BR1:1, R, Y LEDs on the growth, physiological characteristics, leaf anatomy and stomata characteristics of tomato in order to select the appropriate light for cultivation of tomato under the Phytotron.

Materials and Methods

Plant materials: The experiments were carried out in RXZ-1 Phytotron (Ningbo Jiangnan Instrument Factory CO., Ningbo, China) at Anhui Science and Technology University. The plant material is tomato (*Lycopersicon esculentum* Mill.) of cultivar 'Baolai 303'. The seeds were sowed in cell trays filled with the volume ratio of 1:1 with peat and vermiculite. The temperature and relative humidity were set up at 24-25ºC and 50-55%. About ten days later, when the seedlings having two expanded leaves were transplanted into nutritive cube which also used the peat and vermiculite (1:1).

Light treatments: Tomato were cultured under the FL (fluorescent lamp, the control), B (blue), BR1:1 (blue plus red), R (red) and Y LEDs (yellow) for 30 days. During the experiments, the seedlings were irrigated with water at regular intervals, depending on the soil moisture status. The photosynthetic photo flux density (PPFD) was set at 120 μmol $m^{-2}\cdot s^{-1}$ and a $12\cdot d^{-1}$ photoperiod. Tomato plants were random placement to each treatment and the number of lights keeping the same PPFD. Spectral-energy distribution of lights was measured (Fig. 1).

Measurements: Thirty seedlings from each treatment were random extraction for biomass analysis. Pigment content was measured with Ethanol extraction method for determination. Photosynthetic activity was conducted with LI-6400 photosynthesis measurement system. Using the sulfuric acid anthrone method conducted the soluble sugar. Sucrose and starch were measured using the phloroglucinol method. Paraffin sectioning were used for leaf anatomy. Methods to observe the stomata using the nail polish and transparent tape (Siringam, 2009; Li *et al.*, 2010; Zeng *et al.*, 2012; Li *et al.*, 2017).

Statistical analyses: Statistical analyses were conducted using SPSS 16.0. Using analysis of variance and the Tukey's multiple comparison test ($p<0.05$) analyzed the data. The measurements were repeated three times.

Results

Changes in morphology: Fresh mass was highest under BR1:1 LEDs, which showed significant difference compared to B, R, Y and FL; it was 14.07%, 35.48%, 42.15% and 43.93% higher than the fresh mass under B, R, Y and FL. However, there was no significant difference among the fresh mass under B, R, Y and FL. The dry mass was greatest under BR1:1 LEDs treatment, followed by B. It was also significantly higher than under R, Y and FL. However, there was no significant difference among the dry mass under R, Y and FL treatments. Root length was highest under BR1:1 LEDs and showed significant difference compared to B, R, Y and FL treatments. The stem length was significantly longer under BR1:1 LEDs than under B, R, Y and FL. It was the shortest under the FL. Stem width was the widest under BR1:1 LEDs and the smallest under FL (Table 1). We concluded that BR1:1 LEDs promote the tomato seedlings growth.

Changes in pigments: Total chlorophyll, chlorophyll a, chlorophyll b contents were the highest under BR1:1, and significant higher than B, R, FL and Y LEDs. They were the lowest under R ($p<0.05$). The carotenoid content was highest under BR1:1 LEDs significantly higher under the Y, B, FL and R LEDs (by 17.31%, 19.61%, 27.08% and 35.56%, respectively), and the smallest under R (Fig. 2). The results showed that BR1:1 might be advantageous for pigments accumulation in tomato.

Changes in photosynthetic rate: Photosynthetic rate was highest under BR1:1, subsequently B, they are obviously greater (by 34.62%, 26.82%, 41.82%, 17.88%, 11.05% and 29.05%) compared to the rates of Y, R and FL. However, there were no significant differences among R, Y and FL (Fig. 3). These results demonstrate that BR1:1 LEDs might promote photosynthetic activity of tomato seedlings.

Changes in photosynthetic productions: Soluble sugar was highest under BR1:1 significantly higher than under R, FL, B and Y light and the lowest under FL in leaves. Although, there were no noticeable differences in soluble sugar among R, B and Y treatments. Starch content was the greatest under R LEDs, that followed BR1:1 LEDs, and was significantly greater than that obtained under FL, B and Y treatment. However, there were no significant differences among FL, B and Y. The sucrose content was highest under BR1:1 LEDs, that followed R and was noticeable greater than under FL, B and Y treatment. However, there had no obvious differences between FL, B and Y (Fig. 4). Soluble sugar was highest for under BR1:1LEDs, that followed R, and was obviously greater than under FL, B and Y treatment in stem. Starch was the greatest under R, followed by BR1:1; it was the lowest under FL. Sucrose content was the highest under BR1:1 LEDs, that followed R, and was obviously greater than under FL, B and Y treatments (Fig. 5). This indicate that BR1:1 and R might promote the photosynthetic products accumulation.

Changes in leaf anatomy: Thickness of leaf, spongy, palisade tissue were highest under BR1:1 LEDs treatment, that followed B LEDs treatment, which were obviously greater than under R, Y and FL. The leaf anatomy structure was well-developed, and the closely packed mesophyll cells contained many chloroplasts under BR1:1 and B LEDs treatments. However, mesophyll cells were loosely arranged under R LEDs (Table 2; Fig. 6). Results demonstrate that BR1:1 LEDs and B LEDs might be profit for leaf development of tomato seedlings.

Changes in leaf stomata: Adaxial and abaxial stomates were highest under BR1:1 LEDs, that followed B LEDs. They were obviously greater than R, Y and FL. Although, the area between the adaxial and abaxial surfaces showed no significant differences. The leaves stomata frequency was the greatest under BR1:1 LEDs in the adaxial and abaxial surfaces, that followed B, which showed obviously greater values than R, Y and FL. Meanwhile, the frequency of abaxial surface was almost two times higher than the frequency of adaxial surface. These results indicate that BR1:1 and B might be profit for stomatal developed (Table 3, Fig. 7). The results also showed B and BR1:1 might be good for the stomatal opening in tomato.

Table 1. Effects of different lights on the morphology of tomato seedlings.

Light treatment	Fresh mass (g)	Dry mass (g)	Root length (cm)	Stem length (cm)	Stem width (cm)
FL	3.21 ± 0.15b	0.32 ± 0.03c	8.78 ± 0.51c	18.32 ± 1.20c	2.92 ± 0.40c
B	4.05 ± 0.28b	0.43 ± 0.03b	10.24 ± 0.38b	21.21 ± 1.16b	4.24 ± 0.16b
BR1:1	4.62 ± 0.15a	0.52 ± 0.02a	12.42 ± 0.67a	24.46 ± 1.23a	5.67 ± 0.22a
R	3.41 ± 0.25b	0.35 ± 0.03c	9.76 ± 0.25b	20.45 ± 1.05b	3.95 ± 0.19b
Y	3.25 ± 0.31b	0.33 ± 0.02c	9.01 ± 0.27c	20.35 ± 1.53b	3.87 ± 0.53b

Note: FL: Fluorescent lamp; B: 100% blue light; BR1:1: 50% blue light and 50% red light; R: 100% red light; Y: 100% yellow light. Values are the mean ± standard deviation. Different letters within the column indicate significant differences at $p<0.05$ according to Tukey's test (n=3). The same as below

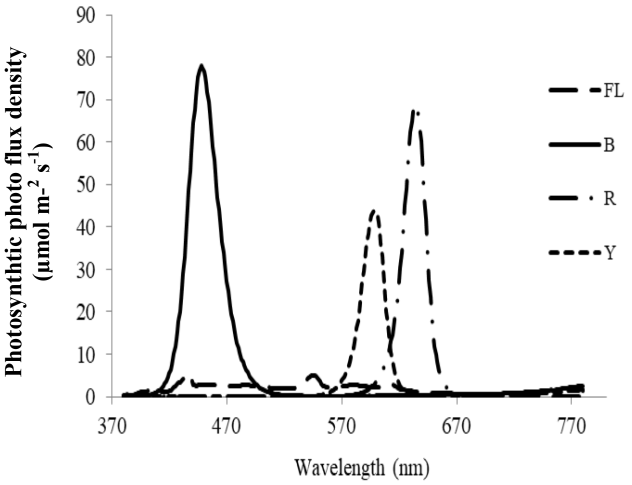

Fig. 1. Spectral distribution of lights.
FL: Fluorescent lamp; B: 100% blue light; R: 100% red light; Y: 100% yellow light

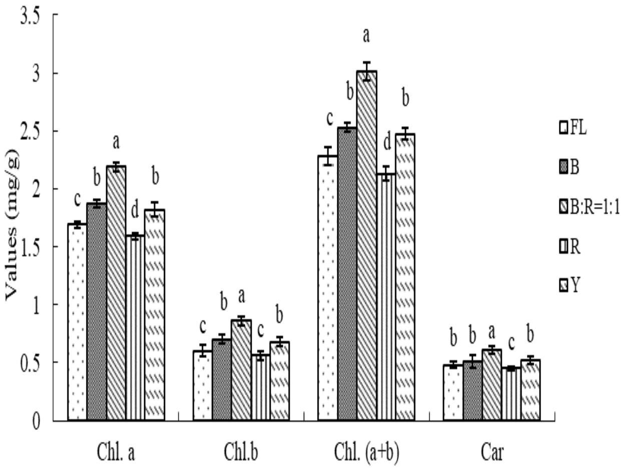

Fig. 2. Effects of different light treatments on pigment content of tomato seedlings
Note: FL: Fluorescent lamp; B: 100% blue light; BR1:1: 50% blue light and 50% red light; R: 100% red light; Y: 100% yellow light. Different letters indicate significant differences at $p<0.05$ according to Tukey's test (n=3). The bars represent the Standard Error.

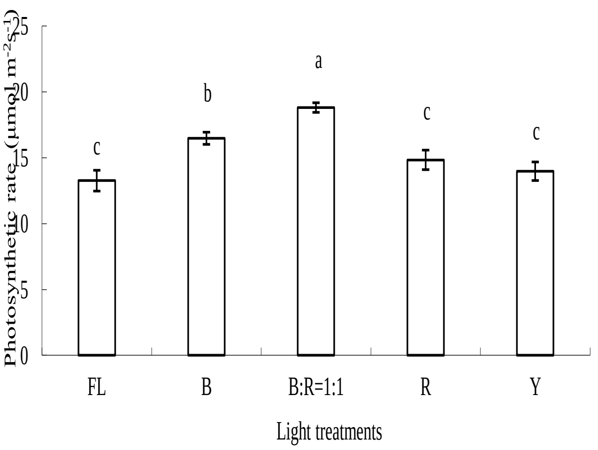

Fig. 3. Effects of different lights on the photosynthetic rate of tomato seedlings.

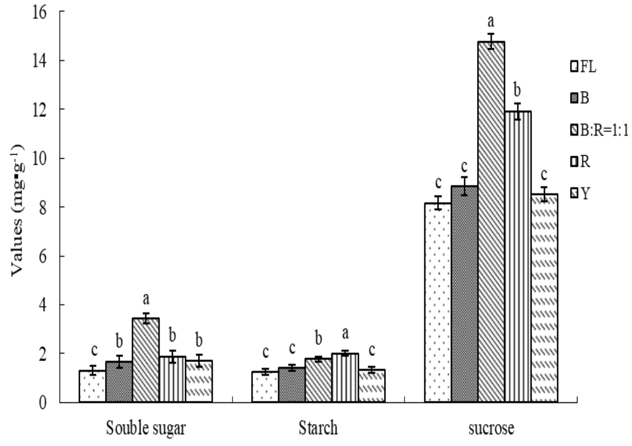

Fig. 4. Effects of different lights on photosynthetic production in leaves of tomato seedlings.

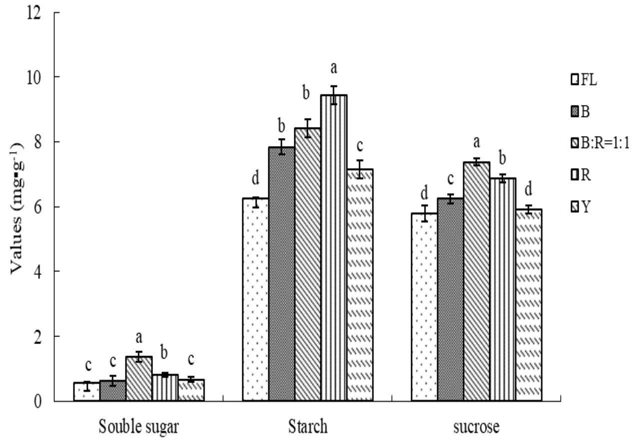

Fig. 5. Effects of different lights on photosynthetic production in stems of tomato seedlings.

Table 2. Effects of different lights on leaf anatomy of tomato seedlings.

Light treatment	Leaf thickness (μm)	Palisade tissue thickness (μm)	Spongy tissue thickness (μm)
FL	190.32±6.45d	65.81±2.05d	78.93±2.12d
B	258.36±7.46b	86.24±3.35b	103.16±2.41b
BR1:1	287.23±9.41a	96.42±5.36a	114.45±2.25a
R	228.40 ± 6.01c	77.04±4.25c	95.81±2.03c
Y	195.34± 7.78d	68.61±3.94d	81.04±3.34d

Discussion

The suitable lights for plant: Light acts a key function in plant growth and development. Presently, many crops are cultured under LEDs. They have many advantages over the other lights and are well received in crop culture. Many grew well under certain B plus R, such as B:R 4:1 (banana), 3:7 (strawberry), 1:8; 1:6 (non-heading Chinese cabbage), 3:1 (rapeseed) plantlet, and 1:8 (upland cotton) (Nhut *et al.*, 2003a; 2003b; Li *et al.*, 2012; Fan *et al.*, 2013a; Li *et al.*, 2013; Li *et al.*, 2017). The results in the study demonstrate that BR1:1 have obviously superior to FL in tomato growth (Table 1). A suitable combination of B plus R combines the superiorities of monochromatic R and monochromatic B and eliminates the inferiorities (Li *et al.*, 2010). However, the best blue plus red-light ratio might depend on the plant species (Li *et al.*, 2013). Therefore, identifying the optimal light combination is key for accelerating seedling growth for crops.

Higher crop photosynthesis was resulting in the crop use better light distribution and light efficiency in the canopy (Mao *et al.*, 2014). The study showed BR1:1 had obviously superior to FL for tomato growth (Table 1) and that the photosynthetic rate was also greatest under BR1:1 LEDs, and the smallest under FL (Fig. 3). The BR1:1 LEDs might facilitate the tomato seedlings growth, and growth parameters may correlate with the photosynthetic rate.

How LEDs affect the photosynthetic products of seedlings: Soluble sugar, sucrose, and starch contents were the highest under R in upland cotton plantlets and seedlings (Li *et al.*, 2010; Li *et al.*, 2017), while the starch content was the highest under R in non-heading Chinese cabbage (Li *et al.*, 2012), and under R in rapeseed (Li *et al.*, 2013). The results in this study demonstrate that sucrose and soluble sugars contents were the greatest under BR1:1, that followed R. Starch content was highest under R LEDs (Fig. 4; Fig. 5). From the present study it is evident that BR1:1, and R promote the photosynthetic products accumulation in tomato seedlings.

We also found that the starch content was the greatest under R, but the photosynthetic rate was smaller under R LEDs (Figs. 3-5). Excessive accumulation of starch was inhibition of photosynthesis (Bondada & Syvertsen, 2005). Our results indicate that R promote the starch accumulation, but the photosynthesis is might prevented of tomato.

Table 3. Effects of different lights on leaf stomata of tomato seedlings.

Light treatment	Area of a stoma (μm^2)		Stoma frequency (number / mm^2)	
	Adaxial surface	Abaxial surface	Adaxial surface	Abaxial surface
FL	6.25 ± 0.10d	6.86 ± 0.16c	317.11 ± 10.47d	956.70 ± 23.10d
B	8.47 ± 0.12b	8.86 ± 0.18b	378.16 ± 11.07b	1165.13 ± 27.12b
BR1:1	9.11 ± 0.11a	9.32 ± 0.12a	412.34 ± 12.36a	1231.70 ± 20.36a
R	7.03 ± 0.15c	7.23 ± 0.12c	356.23 ± 10.40c	1049.40 ± 30.52c
Y	6.35 ± 0.23d	6.95 ± 0.19c	318.45 ± 10.38d	1024.00 ± 28.13c

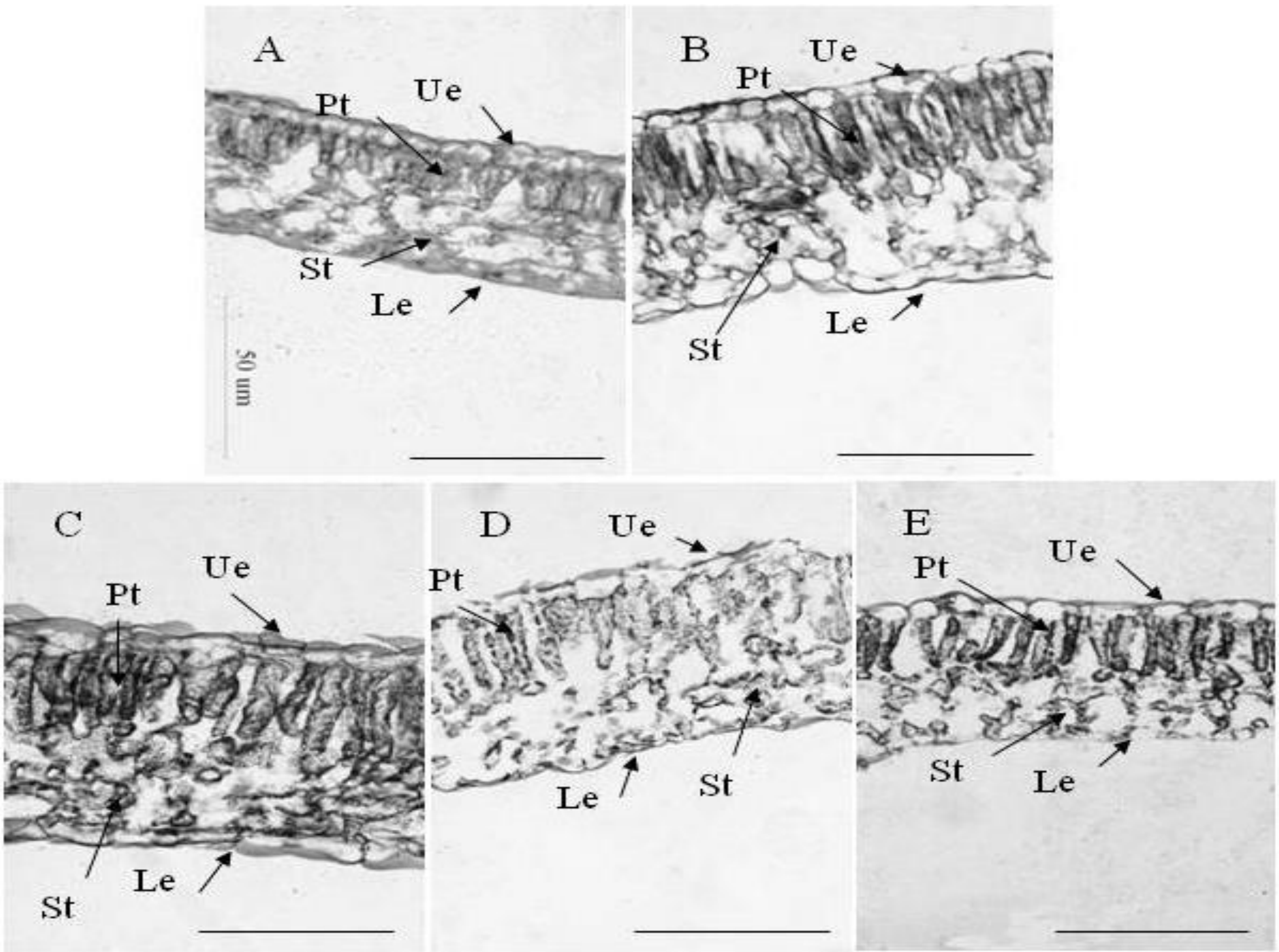

Fig. 6. Effects of different lights on anatomical features of leaves in tomato seedlings
Note: A: Fluorescent lamp; B: 100% blue light; C: 50% blue light and 50% red light; D: 100% red light; E: 100% yellow light. Ue: Upper epidermis, Le: Lower epidermis, Pt: Palisade tissue, St: Spongy tissue, Bar= 50μm.

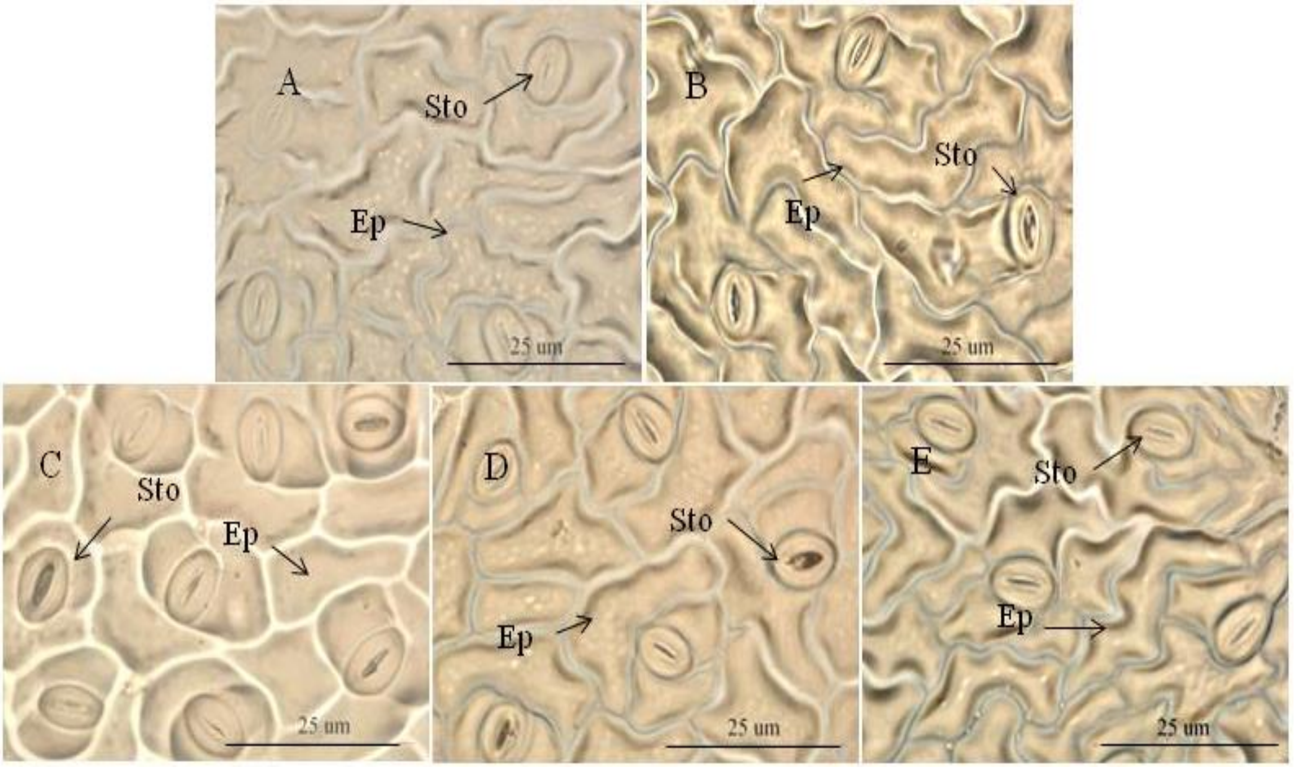

Fig. 7. Effects of different lights on the abaxial surface stomata of leaves in tomato seedlings.
Note: A: Fluorescent lamp; B: 100% blue light; C: 50% blue light and 50% red light; D: 100% red light; E: 100% yellow light. Sto: Stomata, Ep: Epidermis. Bar=25 μm.

Variations in leaf anatomy and stomata in seedlings under different LED lights: Earlier research has shown that the palisade tissue and spongy tissue in cherry tomato under B plus R treatment are especially well developed (Liu *et al.*, 2011a). Leaf, spongy tissue length and thickness of palisade tissue were the highest in upland cotton under B (Li *et al*., 2010; Li *et al.*, 2017). Although, the thicknesses of leaf, and spongy tissue were the highest under red, BR 3:1 in rapeseed (Li *et al.*, 2013). Tomato is sun plant. Anatomical features of sun leaves form a thicker mesophyll, more palisade cell layers and well-developed sclerenchyma tic tissues (Robakowski *et al.*, 2004). The results of our study showed that leaf thickness, spongy and palisade tissue thickness were highest under BR1:1, that followed B (Table 2; Fig. 6), thus BR1:1, and B might be beneficial for the tomato leaves growth. In addition, leaf anatomy is foundation of its physiological function, and structure changes highly influence plant growth (Janda *et al.*, 2014). In addition, the study also showed that BR1:1 LEDs stimulated the tomato seedlings growth better than FL (Table 1). Therefore, BR1:1 might benefit leaf development and the growth of tomato plants and leaf development may be correlated with growth. However, the optimal lights for plant growth and development are likely dependent on the plant species or cultivar.

The photosynthetic rate and stomata area of cherry tomato enlarged under B treatment (Liu *et al.*, 2011b). Li *et al.* (2017) also found that photosynthetic rate and stomatal area were highest under B in upland cotton. Our results demonstrate that the area of stomata was higher under BR1:1 LEDs and B than the others (Table 3, Fig. 7). In addition, the photosynthetic rate was higher under BR1:1 and B than the others (Fig. 3). The stomata size and the opened or closed state in the leaves greatly influence photosynthesis (Dzierzynska, 2006). Therefore, enlarged stomata probably enhance the tomato photosynthetic rate under BR1:1 and B LEDs. They might also be correlated with the fast opening of stomata and promoted photosynthesis.

In this study, the pigment and the area of stomata were greatest under BR1:1 and B LEDs (Fig. 2; Table 3). The fast stomata opening might correlate well with high pigment values.

Conclusion

In the present study, tomato seedlings grew well under BR1:1 LEDs, and pigment content, as well as photosynthetic rate and photosynthetic product content were higher than in seedlings grown under others light sources. The leaves and stomata also developed well under BR1:1 LEDs. Thus, the optimal light that promoted the morphology and physiological index of tomato was B plus R LEDs (1:1).

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