Effects of Different Treatments of Supplemental Light on Tomato Growth and Fruit

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Abstract: In exploring the effects of light supplementation measures on the growth and development, yield and quality of tomatoes, this study used 'Gassina' tomatoes as the test material and set up CK (no light supplementation), RGB treatment (Red: Green: Blue = 3:1:1, top-lighting), RGB + FR treatment (adding far-red light based on the RGB treatment, top-lighting), RGB+UV1 treatment (adding ultraviolet light based on the RGB treatment, filling light from the top), and RGB + UV2 treatment (adding ultraviolet light based on the RGB treatment, inner-lighting) to analyze the changes of morphological and physiological indices as well as fruit yield and quality of tomato plants under different fill light treatments. The results showed that the supplemental light promoted the growth of tomato and improved the yield and quality of tomato. Under different light treatments, RGB+UV2 interplant supplementation significantly promoted the growth of tomato plants compared with other treatments, and RGB treatment significantly improved the fruit quality and yield of tomato.

1 INTRODUCTION

The plant growth and development are affected by light, temperature, humidity, nutrients and other environmental factors, among which light is one of the important environmental factors for plant growth and development. Light provides energy for plant photosynthesis, and in combination with other environmental factors regulates plant life activities such as plant morphogenesis, photoperiodic reactions and metabolic substance synthesis. Light is also involved in the entire physiological process of crop seed germination (Li, 2009), stem and leaf growth (Liao, 2001), chlorophyll synthesis (Zhang, 2005), induction of flower opening (Wan, 2018; Zhang, 2020) and fruit growth (Qian, 2018), which are essential environmental factors for plant growth and development and yield quality formation. Facility agriculture, also known as environmentally regulated agriculture, is an artificially created microclimate that provides suitable environmental conditions for all stages of vegetable, fruit, flower and other horticultural products production as well as free from the constraints of the natural environment. In facility cultivation, light directly determines the thermal environment of the greenhouse, thus affecting the growth and development, yield and quality of the facility as (Sun, 2014) For sustainable development and high economic benefits, light quality, light intensity, and photoperiod are needed to meet the needs of the crop. However, often in the process of facility cultivation, covering materials such as plastic films and insulation facilities, continuous rain and snow as well as short light hours in winter cause the phenomenon of light deficiency in facilities, such as insufficient light intensity and light hours, which seriously affects the growth and development of facility crops and high quality and efficient production, limiting the production potential of facility agriculture (Hu, 2016; Li, 2020; Choi, 2021). Greenhouse light environment regulation through artificial light sources to improve the efficiency of light utilization by crops has become one of the most common light environment regulation measures at present.

At present, the application of artificial light sources in China's facilities has been very common, but the late start of facility agriculture in Qinghai Province, the relative backwardness of the facility industry, and the slow update of production technology and supporting facilities. Especially in winter and spring greenhouse insulation is covered

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mostly from 16:00 to 10:00 the next day, the light intensity and time is seriously insufficient, which seriously affects the production of winter and spring facility crops (Ji, 2013). Reasonable light supplementation measures can meet the photosynthetic requirements of vegetable crops, improve the energy utilization efficiency of vegetable crops, achieve high yield, high efficiency and high quality production of facility vegetable counter-seasonal cultivation, and meet the counter-seasonal vegetable supply in Qingha (Wang, 2019), which is of great significance for winter-spring facility vegetable cultivation in the alpine region of Qinghai. Therefore, in this study we regulated the light environment of greenhouses in Qinghai plateau based on artificial supplemental LEDs, and investigated the effects of LEDs on the growth and development and quality of tomato plants by using different light treatments to understand the effects of different supplemental light measures on tomato growth and fruit yield and quality in order to improve the yield and quality of tomatoes and provide technical support for the cultivation theory of annual production of facility tomatoes in Qinghai region.

2 MATERIALS AND METHODS

2.1 Experiment Materials

The Glorioso tomato is used throughout the experiment. The LED bar lights, provided by the Xiaotaiyang Agriculture High-tech Co., Ltd. in Zhejiang Province, are adopted as the source of the supplemental light.

2.2 Experiment Settings

The experiments were carried out in the greenhouse of the horticultural innovation base of Qinghai Academy of Agriculture and Forestry Sciences, Chengbei District, Xining City, Qinghai Province. The length, span, height, and height of the solar greenhouse are 40 m, 8 m, 3 m, and 50 cm, respectively. The covering material of the greenhouse is po film. Seedlings were raised on February 25, 2020, and seedlings with the same growth were selected and planted by the trough cultivation in the solar greenhouse on April 7, 2020. Five lighting treatments were used in the experiment, which are denoted as CK (no supplemental light), RGB (Red: Green: Blue = 3:1:1, top-lighting), RGB + FR (adding far-red light on the basis of the RGB treatment, top-lighting), RGB + UV1 (adding ultraviolet light on the basis of the RGB treatment, top-lighting), and RGB + UV2 (adding ultraviolet light on the basis of the RGB treatment, inner-lighting), respectively. There are 3 replicates for each treatment, and 15 seedlings are used in each replicate. The light duration is 5 h per day, and lighting starts before the open of the heat preservation quilt (10:00) and ends after the cover of the heat preservation quilt (16:00). The beginning and the end of the lighting were controlled by the time relay.

2.3 Measurement Items and Methods

For each treatment, 6 plants were randomly selected as sample plants to measure the growth indexes of the tomato plants and the fruit quality.

Following procedures were used to estimate the growth indexes of the tomato plants. In detail, the plant height is measured with a ruler from the plant rhizome boundary to the plant growth point. The stem diameter is the averaged value of two measures of the stem under the cotyledon from two directions by vernier caliper. The level of Chlorophyll (SPAD value) is measured by a handheld chlorophyll meter.

The fruit quality is determined by the procedures described below. The fresh fruit weight is weighed with a one-tenths balance. The sugar content is determined by Japan ATAGO digital Brix meter. Soluble sugar content is quantified by anthrone colorimetry. The soluble protein is estimated by Coomassie Brilliant Blue G- 250 staining method. The content of the organic acid is measured by the high-performance liquid chromatography method with the column temperature being 35℃, the volume ratio of mobile phases being 9 over 1 between KH2PO4 and methanol, flow rate being 0.8mL•min-1, and the sample injection volume being 20 μL. The composition and content of sugar are estimated by the high-performance liquid chromatography method. Specifically, the column temperature is 80℃. The water is used as the mobile phase with the flow rate being 1ml·min-1. The sample injection volume is 5 μL.

2.4 Data Analysis

The basic data were processed and analyzed using Microsoft Office Excel 2010 software, and statistical analysis of data was performed using SPSS 26.0 software to determine the significance of differences between treatments by analysis of variance (ANOVA), Duncan multiple range test and the significant tests with the significant level being 0.05. Origin 2019 was used for graphing.

3 RESULTS

3.1 Effects of Different Treatments of Supplemental Light on Tomato Growth

It can be seen from Table 1 that different supplemental lighting treatments have different effects on tomato growth. The plants with the RGB + UV2 treatment have the highest plant height (324 cm), which was significantly higher than that of the CK. The plants with other lighting treatments were higher than that of the CK, but there was no significant difference among them. The stem diameter and the number of leaves of the plants with the RGB + UV2 treatment were highest. But there was no significant difference compared to that of CK. Plants with RGB and RGB + FR treatment have the least number of blades, which are significantly lower than that of CK. With respect to the pitch, the RGB + UV1 group takes the largest value. Moreover, the pitch of the other groups utilizing lighting treatment is significantly higher than that of CK.

3.2 Effects of Different Treatments of Supplemental Light on Tomato Leaves

It can be seen from Table 2 that, the leaf length and width of the plants with lighting treatments are higher than that of the groups without supplemental light (the CK group). While no significant difference is observed among the groups with lighting. The chlorophyll level is highest in the RGB group and the lowest in RGB + FR group. Moreover, no significant difference is observed among the groups with other treatments.

3.3 Effects of Different Treatments of Supplemental Light on Tomato Fruit Quality

It can be seen from Figure 1 that different supplemental light treatments do affect the fruit quality of tomatoes. Except for the fruit from the plants with RGB + UV2 treatment, the sugar contents of fruits from the other groups were higher than that of CK, and the RGB + FR group takes the highest value of being 6.28 as shown in Figure 1A. The soluble sugar content of the fruit from the RGB group

Table 1: Effects of different treatments of supplemental light on tomato growth.

Treatment	Plant height/cm	Stem diameter/mm	Internode length/cm	Numbers of leaf blades
CK	299 ± 22.41b	11.8 ± 0.67ab	7.3 ± 0.67c	45 ± 6ab
RGB	305 ± 4.23b	11.27 ± 0.78ab	8.8 ± 0.55b	39 ± 4c
RGB + FR	302 ± 8.52b	10.99 ± 0.64ab	8.7 ± 0.79b	39 ± 4c
RGB + UV1	301 ± 13.65b	10.83 ± 1.30b	10.1 ± 1.09a	43 ± 4abc
RGB + UV2	324 ± 18.02a	11.96 ± 0.76a	8.4 ± 0.55b	46 ± 1a

Note: CK (no light supplementation), RGB treatment (Red: Green: Blue = 3:1:1, top-lighting), RGB + FR treatment (adding far-red light based on the RGB treatment, top-lighting), RGB+UV1 treatment (adding ultraviolet light based on the RGB treatment, filling light from the top), and RGB + UV2 treatment (adding ultraviolet light based on the RGB treatment, inner-lighting). The data followed by different lower-case letters within the same column are significantly different at 0.05 level. The same as below.

Table 2: Effects of different treatments of supplemental light on Tomato Leaves.

Treatment	Leaf length /cm	Leaf width/cm	Chlorophyll/SPAD
CK	26.76 ± 3.55ab	25.80 ± 3.23a	34.93 ± 4.77ab
RGB	29.13 ± 3.75ab	25.92 ± 2.46a	39.17 ± 2.10a
RGB + FR	28.37 ± 1.88ab	28.48 ± 4.38a	25.93 ± 6.71c
RGB + UV1	32.29 ± 4.36a	30.12 ± 3.11a	32.94 ± 4.05bc
RGB + UV2	32.23 ± 3.02a	28.48 ± 1.54a	33.42 ± 2.61ab

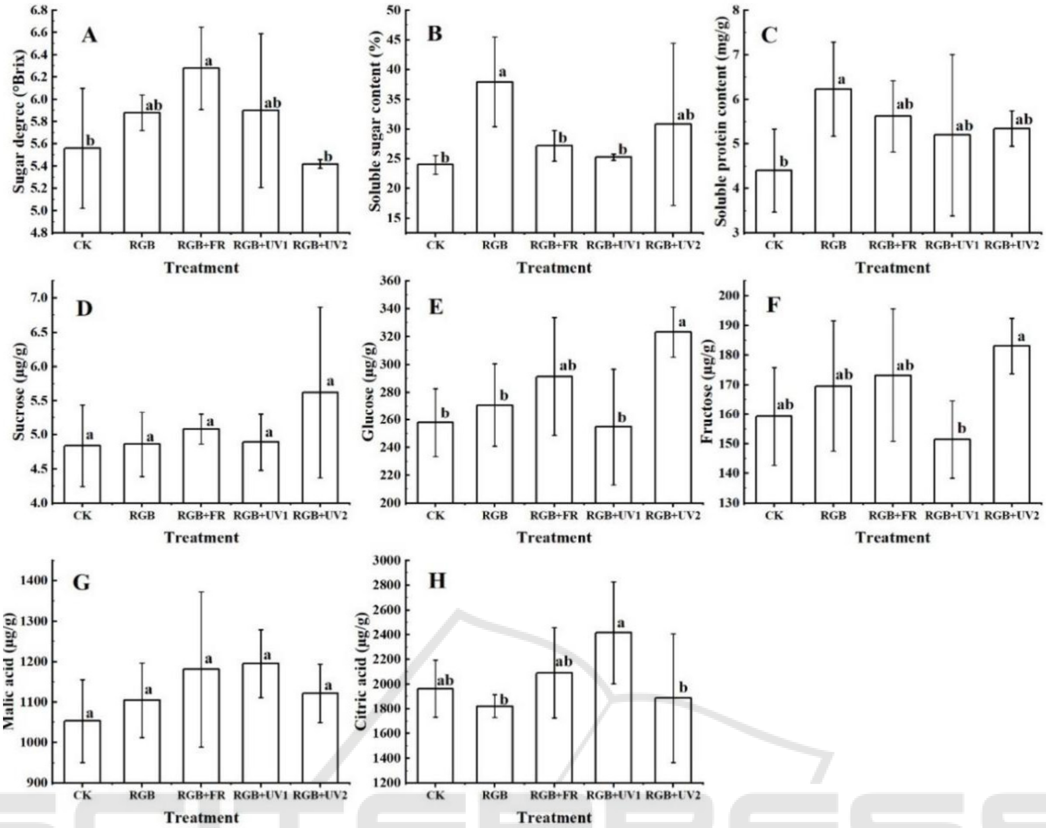

Figure 1: Effects of different treatments of supplemental light on tomato fruit quality. A: Sugar degree; B: Soluble sugar content; C: Soluble protein content; D: Sucrose; E: Glucose; F: Fructose; G: Malic acid; H:Citric acid.

was highest (increased by 58% compared with that of CK), followed by that of the RGB + UV2 group (increased by 28% compared with that of CK). Although the soluble sugar content of other treatments was higher than that of CK, there was no significant difference among those groups with lighting as shown in Figure 1B. The soluble protein content of fruit under each treatment was increased by 42%, 28%, 18%, 21% compared with that of CK, respectively. Except for the RGB treatment, the other treatments were not significantly different from CK (Figure 1C). This demonstrates that the supplemental light treatment can improve the quality of tomatoes.

It can be seen from Figure 1D-F that the glucose content in tomato fruit is highest, and the sucrose content is the least. Different supplemental light treatments have no significant effect on the content of the sucrose. The glucose content of the RGB + UV2 treatment was significantly higher than that of CK, and there was no significant difference between other treatments and CK (Figure 1E). The fructose content of RGB + UV2 treatment was the highest at 183.1μg/g, followed by RGB + FR treatment, and RGB + UV1 treatment was the lowest at 151.5 μg/g (Figure 1F). It can be seen from Figure 1G-H that the supplemental light treatment can increase the content of malic acid in tomato fruits, but it is not significant compared with that of CK. The citric acid content of RGB + UV1 treatment was the highest at 2415.3 μg/g, followed by RGB + FR at 2090.6 μg/g, and RGB was the lowest at 1821.9 μg/g.

3.4 Effects of Different Treatments of Supplemental Light on Tomato Yield

From Table 3, the following can be observed: (1) the fruit from the plant with RGB + UV1 treatment has the largest single fruit weight; (2) the fruit from the plant with RGB + UV2 treatment has the largest fruit quantity; (3) the fruit weight of fruit from the plant with RGB + FR treatment is the smallest, but the fruit quantity is significantly higher than that of CK. In other words, the supplemental light treatment can significantly increase tomato yield. Moreover, the RGB treatment increases the yield most (increased 41% compared to that of CK), followed by the RGB + UV1 strategy (39% higher than that of CK).

Table 3: Effects of different treatments of supplemental light on tomato yield.

Treatment	Single fruit weight/g	Fruit quantity/g	Yield/kg
CK	35.09 ± 6.45a	56 ± 10.67b	1965.04 ± 110.5bc
RGB	34.74 ± 7.59a	80 ± 24.83a	2779.2 ± 240.32a
RGB + FR	30.81 ± 4.83a	72 ± 22.03ab	2218.32 ± 300.96b
RGB + UV1	38.87 ± 4.25a	70 ± 15.51ab	2720.9 ± 309.8a
RGB + UV2	30.42 ± 8.81a	88 ± 17.39a	2676.96 ± 350.9a

4 DISCUSSIONS

Plant growth is a quantitative change, which is mainly manifested by plant height, stem diameter, leaf growth, etc. When the external light quality or wavelength is different, the growth effect of the plant is also different (Xu, 2015). Cui’s research shows that the red light plays an important role in promoting stem extension and accumulation of dry matter (Cui, 2009). It can be concluded from Yang's research that the mixing red and blue light can effectively optimize tomato leaf structure and chloroplast ultrastructure, thereby promoting the accumulation of dry matter of tomato seedlings (Yang, 2018). In this experiment, different supplemental light treatments can affect the growth and development of tomatoes. The plant height, leaf length and width of the plants with all supplemental light treatments are higher than that of the plants without lighting, which is consistent with the results of previous studies. Meanwhile, the chlorophyll content of the tomato plants with RGB + FR treatment was significantly lower than that of CK, and the yield was the lowest among all supplemental light treatments. This is consistent with the research results of Huang (Huang, 2017): increasing the ratio of far-red light will reduce the chlorophyll content and yield per plant. Plant height, stem diameter, number of leaves, and leaf area of the plant with the RGB + UV2 treatment are the highest. This may be because the inter-lighting supplements the light of the middle and lower leaves of the plant, which promotes the photosynthesis of the middle and lower leaves, and then promotes the growth of the plant (Yan, 2018; Hovi-Pekkanen T, 2008). The above results demonstrate that LED supplemental light can promote the growth of tomatoes, and the combination of red and blue light can promote the growth of tomatoes significantly, which is important to promote the formation of late yield.

The soluble sugar content reflects the metabolic capacity of the plant， and it is one of the main products of plant photosynthesis metabolism. Light quality not only affects the growth and development of tomato plants, but also affects fruit quality formation (Chen, 2016; Sha, 2021). Ding found that the mixing red and blue light can significantly increase the soluble solid content and soluble sugar content of tomatoes (Ding, 2016). In this experiment, the soluble sugar and soluble protein of the fruit with each supplemental light treatment were higher than that of CK, indicating that the red and blue light can effectively improve the quality of tomato fruit. The effect of different light quality on fruit yield is also very significant. Sun et al. applied the red light and the mixing red and blue light to tomatoes in the solar greenhouse, and found that the yield of tomatoes was significantly increased (Sun, 2014). In this experiment, the yield of fruits treated with supplemental light was significantly increased, and the effect of RGB treatment was the most significant. The above results demonstrate that red and blue light mixing can increase the accumulation of sugar substances in tomato fruits, which has a significant effect on yield and quality improvement.

However, since this study is the first exploratory experiment in Qinghai, due to the limited conditions and relatively simple experimental setup, there are problems such as relatively few experimental treatments, a single variety, and fewer measurement indexes, etc. Moreover, since there are many other influencing factors in the greenhouse, the final results may have certain deviations and fail to scientifically and rationally explain the scientific problems of the effect of supplemental light on tomato growth and yield, which is limited. In the future, we will focus on the scientific aspects of the effects of LED supplemental lighting on the growth and development of tomato seedlings and the fruit formation process during the growth period in Qinghai.

5 CONCLUSIONS

In summary, different light supplementation treatments had different effects on tomato growth, with RGB+UV2 (red: green: blue: ultraviolet=3:1:1:1) interplant supplementation treatment having the most significant effect on tomato plant growth than the other treatments, and RGB (red: green: blue=3:1:1) top supplementation treatment significantly improving tomato fruit quality and yield. This result can provide a theoretical basis for green, high yield and high quality cultivation in Qinghai. This result can provide a theoretical basis for green, high-yielding and high-quality tomato cultivation in Qinghai.

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