The Effect of LED Lighting on The Growth of Seedlings of Hybrid Tomato

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Abstract

A study was conducted to evaluate the effect of LED lighting on the growth of seedlings of hybrid tomato plants. Four hybrids (Captain F1, Refiner F1, Coral Reef F1 and Fire F1), seven treatments of irradiators (monochromatic red, green, blue, white) and three dual light treatments (green+blue, blue+red, green+red) were carried out in the laboratory of artificial climate. Radiation with monochromatic had a role in increasing hypocotyl length, the height of plant, transpiration and stomatal connection. The results have shown a significant effect on radiation with monochromatic red on hypocotyl length (73.00mm) and the height of plant (30.94cm). Plants radiation with monochromatic blue gave the highest transpiration (4.69 mmol/m².s) and stomatal conductance (0.30 mol./m².s). The dual radiation had a role in increasing dry weight for the plant and leaf chlorophyll content (SPAD). Radiation with (green+red) provided the best stem dry weight (0.91g). Plants irradiated with (green+blue) exhibited the highest leaf dry weight and root dry weight (1.96g and 3.12g respectively). Plants radiation with (blue + red) showed the highest leaf chlorophyll content (SPAD) (559.19). In the monochromatic light, the effect of hybrid Fire F1 showed the highest hypocotyl length (64.11mm) and height of plant (29.00 cm), and hybrid Refind F1 had the highest transpiration (3.58 mmol/m².s) and stomatal conductance (0.23 mol./m².s). In the binary spectral effect, the hybrid Coral reef F1 resulted the highest stem dry weight, leaf dry weight and root dry weight (0.68 g,1.76 g and 2.39g respectively), and hybrid Refind F1 had the highest leaf chlorophyll content (SPAD) (468.27).

Keywords: Solanum Lycopersicum, Artificial Lighting, Transpiration, Intensive Cultivation, Light Spectrum, LEDs.

1. Introduction

Carbohydrates and protein are abundant in tomatoes [1], its composition is highlighted by high quantities of antioxidant components such as phenolic compounds, vitamin C, and carotenoids [2]. Because of the photoperiod extension and increase in the daily light integral, the use of artificial light in horticultural applications results in greater growth and larger yields. The primary principle of a multilayer plant production site is to produce a large number of plants in a small area, maximizing the equipment and space investment by growing plants in layers on shelves [3]. Temperature, humidity, CO₂ concentrations, light intensity and air flow must all be monitored and controlled in real time for vertical farms to work. Blue, red, and low white light-emitting diodes (LEDs) can be used to create a natural day-night cycle. This particular artificial light can deliver light directly to the plant’s needs and it is safer than direct sunlight and heat exposure [4]. LED-based plant lighting technologies are now being researched for a variety of crops. One of the advantages of these light sources appears to be the capacity to adjust the light spectrum for desired plant responses. The use of LEDs necessitates sophisticated light environment modification in accordance with crop/cultivar requirements [5]. Recently, the development of light emitting diodes (LEDs) as alternative light sources for use in energy efficient greenhouses has sparked considerable interest [6]. Traditional overhead lighting, inter-row lighting, and multi-tiered systems for growing plants are all examples of LED phyto-irradiators used in greenhouses. Overhead irradiators are designed to replace high-pressure sodium (HPS) luminaires and range in wattage from 100W to 600W. They can be rectangular or linear in shape, because LED-irradiators for multi-tiered systems have no substitutes, their volume of manufacturing is solely dependent on the rate at which innovative phyto-installations are adopted by the market [7]. LEDs also have the following advantages included they can rapidly change in intensity and spectral light composition because they do not need to be heated first, and they can be positioned close to, or even within the canopy due to their low heat emission to illuminate leaves that would normally receive low amounts of radiation, the spectral composition can be determined based on the demands of the crop, and LEDs have a long life-time [8], [9], discovered that a tomato crop
was exposed to 7, 20, or 39% green light in a background of narrow bandwidth red and blue light, as well as sunlight, for 76 days in a greenhouse experiment. The intensity supplied by lamps (171 μmol m\(^{-2}\) s\(^{-1}\)) and the red: blue ratio were similar between treatments. Adding green light (+32%) to the spectrum significantly and linearly increased plant biomass and yield (+6.5%).

To increase the efficiency of plants and speed up growth processes in protected and dense environments and areas that suffer from lack of lighting, an additional artificial lighting is needed to solve these problems. The purpose of the study is to evaluate the effect of different types of light spectrum on the phenotypic and physiological patterns of hybrids of different maturity of tomato seedlings.

2. Material and Methods

The experiment was carried out in the laboratory of artificial climate of the Russian State Agrarian University-Moscow Timiryazev Agricultural Academy. The study was conducted to evaluate the effect of LED lighting on the growth of seedlings of hybrid tomato. Plants were grown in vegetation vessels with a volume of two liters using a substrate based on neutralized top pea soil. Sowing tomato seeds on 8 September 2020. Substrate humidity was maintained at 70% of full water capacity. Four hybrids were selected by the Poisk agricultural company (Russia): Captain F1 (too early maturity), Refiner F1 (early maturity), Coral Reef F1 (medium maturity) and Fire F1 (Medium delayed maturity). In the experiment, seven treatments of irradiators were used for plants:

- Monochromatic red (photon flux density 80 μmol/m\(^2\)*s) of wavelength 660 nm.
- Green+ blue (photon flux density 160 μmol/m\(^2\)*s) of wavelength 520 nm and 460 nm in the ratio 1:1.
- Monochromatic green (photon flux density 80 μmol/m\(^2\)*s) of wavelength 520 nm.
- Blue+ red (photon flux density 180 μmol/m\(^2\)*s) of wavelength 460 nm and 660 nm in the ratio 1:1.
- Green+red (photon flux density 180 μmol/m\(^2\)*s) of wavelength 520 nm and 660 nm in the ratio 1:1.
- Monochromatic blue (photon flux density 80 μmol/m\(^2\)*s) of wavelength 460 nm.
- White (photon flux density 80 μmol/m\(^2\)*s). T\(_\text{color}\) = 5000K. Photoperiod 18 h.

There were four replicates in the study, each treatment has 16 containers with a two-factor design of the factorial experiment (hybrids - A and radiation - B) according to the RCBD design. The results were analyzed according to the SPSS statistical program and compared using the least significant difference test L.S.D at a probability level of 0.05 [10].

The following indicators were taken into account:

- Hypocotyl length (mm)
- The height of plant (cm)
- Stem dry weight (g)
- Leaf dry weight (g)
- Root dry weight (g)
- Content of leaf Chlorophyll (SPAD) Soil Plant Analysis Development
- Transpiration (mmol/m\(^2\).*s) (LI-6400XT Portable photosynthesis system)
- Stomatal conductance (mol/m\(^2\).*s) (LI-6400XT Portable photosynthesis system)

Plant sampling was conducted for 39 days after emergence.

3. Results and Discussion

3.1. Hypocotyl length

The results of table 1 show a significant difference on hypocotyl length development of tomato seedlings in response to various radiation. The highest radiation was monochromatic red (R)(72.81 mm) compared to the least radiation (blue+red) (B+R) (45.31 mm). Hybrid Fire F1 has shown a higher performance (64.11 mm) as compared to Refind F1(52.50 mm). A significant difference was observed between the interaction of hybrids and radiation.

Red light showed an important role in increasing hypocotyl length by increasing the elongation of the stem of the plant. Then followed by the radiation monochromatic green, radiation (green+ red) and radiation white, and the least effect was radiation (blue + red). Binary spectral green+red (G+R) had less effect than monochromatic light red (R) and green (G). The dual light blue+red (B+R) had less effect than monochromatic light red (R) and blue (B). The effect of dual light green+blue (G+B) was less than monochromatic light green (G) and higher than the blue(B).

Red has been known to affect stem elongation, root-to-shoot ratio, chlorophyll concentration, and photosynthetic [11-13]. Over a broad range of fluence rates, increases hypocotyl length linearly. The buildup of the flavin adenine dinucleotide (FAD) -inactive form of cryptochromes is most likely to blame [14]. Plants growing in blue light were shorter and had smaller leaves that were pointed upward obliquely [15].
Table 1. Effect of light spectral composition on hypocotyl length (mm) tomato seedlings, 39 days after emergence.

| Hybrids        | Radiation  | Mean factor A |
|----------------|------------|---------------|
|                | R          | G+B           | G          | B+R        | G+R        | B          | W          |
| Captain F1     | 77.50      | 52.50         | 83.75      | 46.25      | 67.50      | 53.33      | 60.00      | 62.98      |
| Refind F1      | 65.00      | 51.25         | 63.75      | 42.50      | 60.00      | 45.00      | 40.00      | 52.50      |
| Coral reef F1  | 60.00      | 46.25         | 62.50      | 48.75      | 66.25      | 48.33      | 60.00      | 56.01      |
| Fire F1        | 88.75      | 68.75         | 71.25      | 43.75      | 71.25      | 45.00      | 60.00      | 64.11      |
| Mean factor B  | 72.81      | 54.69         | 70.31      | 45.31      | 66.25      | 47.92      | 55.00      | 58.90      |

LSD<sub>0.05</sub> Hybrids (A) 5.344
LSD<sub>0.05</sub> Radiation (B) 7.070
LSD<sub>0.05</sub> (AB) 14.140

Radiation treatments: (R)=Monochromatic, red (G+B)=Green+blue, (G)=Monochromatic green, (B+R)=Blue+red, (G+R)=Green+red, (B)=Monochromatic blue, (W)=White.

3.2. The height of plant

The results of table 2 show a significant difference on the height of plant tomato seedlings in various light environments. The best radiation effect was monochromatic red (R) (30.94 cm) as compared to the least radiation (blue+red) (B+R) (18.41 cm). A hybrid Fire F1 showed a higher performance in the height of plants (29.00 cm) compared to Refind F1 (23.03 cm). A significant difference was found between the interaction of hybrids and radiation.

Table 2. Effect of light spectral composition on the height of plant (cm) tomato seedlings, 39 days after emergence.

| Hybrids        | Radiation  | Mean factor A |
|----------------|------------|---------------|
|                | R          | G+B           | G          | B+R        | G+R        | B          | W          |
| Captain F1     | 33.50      | 20.25         | 31.38      | 16.13      | 29.75      | 18.67      | 26.00      | 25.10      |
| Refind F1      | 28.50      | 20.25         | 24.63      | 16.00      | 27.50      | 21.33      | 23.00      | 23.03      |
| Coral reef F1  | 28.50      | 21.38         | 27.75      | 18.00      | 29.00      | 19.33      | 28.50      | 24.64      |
| Fire F1        | 33.25      | 28.75         | 30.25      | 23.50      | 37.25      | 22.00      | 28.00      | 29.00      |
| Mean factor B  | 30.94      | 22.66         | 28.50      | 18.41      | 30.88      | 20.33      | 26.38      | 25.44      |

LSD<sub>0.05</sub> Hybrids (A) 1.438
LSD<sub>0.05</sub> Radiation (B) 1.903
LSD<sub>0.05</sub> (AB) 3.805

Radiation treatments: (R)=Monochromatic, red (G+B)=Green+blue, (G)=Monochromatic green, (B+R)=Blue+red, (G+R)=Green+red, (B)=Monochromatic blue, (W)=White.

The monochromatic red light presented a significant effect on increasing cell divisions, elongating the stem, and increasing the leaves, which was reflected in the increase in the root system and thus the height of the plant. Then followed by the radiation (green+red), radiation monochromatic green and radiation white, and the least effect was radiation (blue+red). Binary spectral green+red (G+R) had less effect than monochromatic light red (R) and higher than green (G). The dual light blue+red (B+R) had less effect than monochromatic light red (R) and blue (B). The effect of dual light green+blue (G+B) was less than monochromatic light green (G) and higher than the blue (B).

Red light is recognized to be critical for shoot/stem elongation, phytochrome responses, and plant architecture alterations [16]. Phototropins and cryptochromes are at least partially sensitive to green light (blue light receptors). The canopy reflects or allows most green light to pass through. Green light, on the other hand, conveys important information about the plant's environment and guides its growth accordingly. Long petioles internodes and a high leaf temperature are characteristics of plants cultivated under green light [17]. These results are consistent with [18]. The intensity of vegetative development is increased when red light dominates the spectrum. Generally, known effects of blue light on plant shape, according to [19], are inhibition of leaf area and internode length, resulting in a compact plant.

3.3. Stem dry weight

The results of table 3 show a significant difference on stem dry weight tomato seedling in various light environments. The best radiation effect was green+red (G+R) (0.91 g) compared to the least radiation blue (B) (0.33 g). A hybrid Coral reef F1 resulted in a higher dry weight (0.68 g) compared with Refind F1 (0.57 g) and Fire F1 (0.57 g). There was also a significant difference between the interaction of hybrids and radiation.
Table 3. Effect of light spectral composition on stem dry weight (g) tomato seedlings, 39 days after emergence.

| Radiation      | Mean factor A |
|----------------|---------------|
| Hybrids        |               |
| Captain F1     | 0.73          |
| Refind F1      | 0.81          |
| Coral reef F1  | 0.74          |
| Fire F1        | 0.53          |
| Mean factor B  | 0.70          |

LSD<sub>0.05</sub> Hybrids (A) 0.082
LSD<sub>0.05</sub> Radiation (B) 0.109
LSD<sub>0.05</sub> (AB) 0.218

Radiation treatments: (R)=Monochromatic, red (G+B)=Green+blue, (G)=Monochromatic green, (B+R)=Blue+red, (G+R)=Green+red, (B)=Monochromatic blue, (W)=White.

The role of the radiation green+red (G+R) showed an effect in photosynthesis increasing, which leads to an increase in the nutrient content of the plant, which is reflected in the increase of the dry weight of the stem. It is followed by the radiation green+blue (G+B), and the least effect in the dry weight of the stem. Binary spectral green+red (G+R) had higher effect than monochromatic light red (R) and green (G). The dual light blue+red (B+R) had less effect than monochromatic light red (R) and blue (B). The effect of dual light green+blue (G+B) was higher than monochromatic light green (G) and blue (B).

Green light may be promote growth due to the alterations in vertical light dispersion [20]. Red light promotes the growth of the plant's height, as well as the strain and vigor of the stem [21]. These results are consistent with [22] and [23], who found that when blue light levels increased, dry weight decreased.

3.4. Leaf dry weight

The results of table 4 show a significant difference on leaf dry weight tomato seedlings in various light environments. The best radiation effect was green+blue (G+B) (1.96 g) compared to the least radiation monochromatic green (G) (0.65g). A higher leaf dry weight was observed in a hybrid Coral reef F1 (1.76 g) compared to Fire F1 (1.24 g). A significant difference was found between the interaction of hybrids and radiation.

Table 4. Effect of light spectral composition on leaf dry weight (g) tomato seedlings, 39 days after emergence.

| Radiation      | Mean factor A |
|----------------|---------------|
| Hybrids        |               |
| Captain F1     | 1.38          |
| Refind F1      | 1.63          |
| Coral reef F1  | 1.55          |
| Fire F1        | 1.07          |
| Mean factor B  | 1.41          |

LSD<sub>0.05</sub> Hybrids (A) 0.217
LSD<sub>0.05</sub> Radiation (B) 0.287
LSD<sub>0.05</sub> (AB) 0.573

Radiation treatments: (R)=Monochromatic, red (G+B)=Green+blue, (G)=Monochromatic green, (B+R)=Blue+red, (G+R)=Green+red, (B)=Monochromatic blue, (W)=White.
than monochromatic light red (R) and blue (B). The effect of dual light green+blue(G+B) was higher than monochromatic light green (G) and blue (B).

Green light effects crop shape, while blue light has a favorable effect on stomatal opening and chlorophyll concentration [24]. Green light penetrates deeper into canopies and individual leaves than red or blue light, and it can stimulate photosynthesis in cells and leaves not reached by red and blue light [15,25,26].

3.5. Root dry weight

The results of table 5 show a significant difference on root dry weight tomato seedlings in various light environments. The radiation effect of green+blue (G+B) had a higher performance (3.12 g) as compared to the least radiation monochromatic green (G) (0.64 g). The best hybrid was Coral reef F1 (2.39g) as compared to Fire F1 (1.91 g). There was also a significant difference between the interaction of hybrids and radiation.

| Hybrids      | R   | G+B  | G    | B+R  | G+R  | B    | W    | Mean factor A |
|--------------|-----|------|------|------|------|------|------|---------------|
| Captain F1   | 2.18| 3.87 | 0.40 | 1.71 | 3.11 | 1.66 | 2.52 | 2.21          |
| Refind F1    | 3.61| 2.21 | 0.72 | 3.35 | 3.30 | 0.43 | 2.65 | 2.32          |
| Coral reef F1| 1.91| 3.83 | 0.54 | 2.58 | 2.78 | 2.80 | 2.27 | 2.39          |
| Fire F1      | 1.53| 2.59 | 0.89 | 2.87 | 2.51 | 0.58 | 2.38 | 1.91          |
| Mean factor B| 2.31| 3.12 | 0.64 | 2.63 | 2.92 | 1.37 | 2.46 | 2.21          |

LSD<sub>05</sub> Hybrids (A) = 0.334
LSD<sub>05</sub> Radiation (B) = 0.442
LSD<sub>05</sub> (AB) = 0.884

Radiation treatments: (R)=Monochromatic, red (G+B)=Green+blue, (G)=Monochromatic green, (B+R)=Blue+red, (G+R)=Green+red, (B)=Monochromatic blue, (W)=White.

Radiation works green+blue to increase the total vegetative, increase metabolism and absorb nutrients, and thus increase the total root. Then followed by the radiation (green+red), radiation (blue + red) and radiation white, and the least effect was radiation monochromatic blue. Binary spectral green+red (G+R) had higher effect than monochromatic light red (R) and green (G). The dual light blue+red (B+R) had higher effect than monochromatic light red (R) and blue (B). The effect of dual light green+blue (G+B) was higher than monochromatic light green (G) and blue (B).

By inactivating cry1, green light can counteract blue-light-mediated stem growth inhibition. If a comparable mechanism is in place later in development, green light may be used to inactivate the cry2 receptor after blue light treatments [27]. Furthermore, green light causes shadow avoidance responses in plants and modulates secondary metabolism, although leaf thickness decreased as green light proportions increased [28]. These results are consistent with [29]. The numerous wavelength treatments improved dry mass much more than the narrow band blue, green, or red light treatments.

3.6. Leaf Chlorophyll content (SPAD)

The results of table 6 show a significant difference on leaf chlorophyll content (SPAD) tomato seedling in various light environments. The best radiation effect was found in blue+red(B+R) (559.19) compared to the least radiation monochromatic green (G) (327.25). A hybrid Refind F1 had a higher leaf chlorophyll content (SPAD) (468.27) compared to Captain F1 (381.54). A significant difference was observed between the interaction of hybrids and radiation.

The bilateral radiation played an essential role in increasing content of leaf chlorophyll content. Irradiation blue+ red (B+ R) has shown an important role in increasing photosynthesis, improving the process of transpiration and increasing the nutrient content, which increases the chlorophyll pigments. It is followed by green+ red (G+R), then radiation monochromatic red (R), monochromatic green (G) radiation had the least effect in the chlorophyll content of the leaves. Binary spectral green+red (G+R) had less effect than monochromatic light red (R) and higher than green (G). The dual light blue+red (B+R) had higher effect than monochromatic light red (R) and blue (B). The effect of dual light green+blue (G+B) was higher than monochromatic light green (G) and blue (B).
Table 6. Effect of light spectral composition on leaf chlorophyll content (SPAD) tomato seedling, 31 days after emergence.

| Radiation | Hybrids          | R    | G+B  | G    | B+R  | G+R  | B    | W    | Mean factor A |
|-----------|------------------|------|------|------|------|------|------|------|---------------|
|           | Captain F1       | 415.75 | 493.75 | 286.25 | 497.50 | 382.50 | 323.00 | 272.00 | 381.54        |
|           | Refind F1        | 440.50 | 531.75 | 362.75 | 640.25 | 485.00 | 367.67 | 450.00 | 468.27        |
|           | Coral reef F1    | 455.00 | 536.50 | 331.50 | 501.75 | 429.50 | 444.00 | 482.00 | 454.32        |
|           | Fire F1          | 431.75 | 436.00 | 328.50 | 597.25 | 382.50 | 362.33 | 230.00 | 395.48        |
|           | Mean factor B    | 435.75 | 499.50 | 327.25 | 559.19 | 419.88 | 374.25 | 358.50 | 424.90        |

LSDₐₜ Hybrids (A) 34.403
LSDₐₜ Radiation (B) 45.511
LSDₐₜ (AB) 91.022

Radiation treatments: (R)=Monochromatic, red (G+B)=Green+blue, (G)=Monochromatic green, (B+R)=Blue+red, (G+R)=Green+red, (B)=Monochromatic blue, (W)= White.

Chlorophyll (a) is the molecule that allows photosynthesis to occur, it is a pigment that absorbs red and blue light [30]. In comparison to red, adding blue to a background red could enhance stomata density and stomata aperture. Thus the blue fraction had a direct effect on stomatal development, which in turn affected photosynthesis. Photosynthesis is considered to be most efficient at red wavelengths [31]. Phototropins perceive blue directly and start a signaling cascade that leads to rapid stomata opening in the presence of red [23]. When it comes to photosynthesis, red light is the most efficient. To optimize photosynthesis, red light alone is insufficient. To avoid red light syndrome, blue light is required [32]. It implies that green light is ineffective in stimulating photosynthesis compared to red and blue light. The rate of leaf expansion is usually faster in warmer leaves. These results are consistent with [33] that photosynthetic pigments absorb red (R) and blue (B) light more efficiently than other wavelengths.

3.7. Transpiration

The results of table 7 show a significant difference on transpiration tomato seedling in various light environments. The height radiation effect was blue (B) (4.69 mmol/m².s) as compared to the least radiation monochromatic green+ blue (G+B) (1.60 mmol/m².s). The height performance was observed in a hybrid Refind F1 (3.58 mmol/m².s) compared Coral reef F1 (2.49 mmol/m².s). A significant difference was shown between the interaction of hybrids and radiation.

Table 7. Effect of light spectral composition on transpiration (mmol/m².s) tomato seedlings, 35 days after emergence.

| Radiation | Hybrids          | R    | G+B  | G    | B+R  | G+R  | B    | W    | Mean factor A |
|-----------|------------------|------|------|------|------|------|------|------|---------------|
|           | Captain F1       | 3.26 | 2.55 | 4.09 | 2.72 | 2.77 | 3.81 | 4.51 | 3.39          |
|           | Refind F1        | 4.04 | 1.94 | 4.61 | 2.87 | 3.46 | 5.87 | 2.30 | 3.58          |
|           | Coral reef F1    | 3.00 | 1.10 | 3.97 | 1.11 | 2.31 | 4.65 | 1.32 | 2.49          |
|           | Fire F1          | 2.09 | 0.82 | 4.58 | 1.02 | 2.44 | 4.45 | 5.10 | 2.93          |
|           | Mean factor B    | 3.10 | 1.60 | 4.31 | 1.93 | 2.74 | 4.69 | 3.31 | 3.10          |

LSDₐₜ Hybrids (A) 0.56
LSDₐₜ Radiation (B) 0.75
LSDₐₜ (AB) 1.49

Radiation treatments: (R)=Monochromatic, red (G+B)=Green+blue, (G)=Monochromatic green, (B+R)=Blue+red, (G+R)=Green+red, (B)=Monochromatic blue, (W)= White.

Monochromatic light was higher rate than binary light for increased transpiration. Monochromatic radiation played an important role in increasing transpiration. Irradiation monochromatic blue (B) is important for effect at the level of mesophyll cells of leaf tissue, improving stomata opening and movement of chloroplasts, increasing transpiration by photosynthesis and
increasing the radical total rate of water uptake by the plant increases with transpiration. It is followed by monochromatic green (G), white (W), red (R), emission of binary light green+red (G+ R), blue + red (B+R), green + blue (G+B) the radiation had the least transpiration. Binary spectral green+red (G+R) had less effect than monochromatic light red (R) and green(G). The dual light blue+red (B+R) had less effect than monochromatic light red (R) and blue (B). The effect of dual light green+blue (G+B) was less than monochromatic light green(G) and blue (B).

Blue light photoreceptors, phototropins, and cryptochromes all sense blue light. Stomata control and plant movement towards light are mediated by phototropins. Cryptochromes control a variety of photomorphological responses, including stem elongation inhibition. Short internodes, high dry matter content, and low leaf temperature (efficient transpiration) are all characteristics of plants produced under high blue irradiation [34]. These results are consistent with [35] blue light has been shown to increase stomata opening.

3.8. Stomatal conductance

The results of table 8 show a significant difference on stomata tomato seedling in various light environments. The height radiation effect was blue (B) (0.30 mol./m².s) compared to the least radiation monochromatic green+ blue (G+B) (0.08 mol./m².s). The height hybrid was Refind F1 (0.23 mol./m².s) compared Coral reef F1 (0.14 mol./m².s). There was a significant difference between the interaction of hybrids and radiation.

Table 8. Effect of light spectral composition on stomatal conductance (mol./m².s) tomato seedlings, 35 days after emergence.

| Radiation | Hybrids | R  | G+B | G   | B+R | G+R | B   | W   | Mean factor A |
|-----------|---------|----|-----|-----|-----|-----|-----|-----|---------------|
| Captain F1 | 0.26    | 0.14 | 0.25 | 0.15 | 0.24 | 0.22 | 0.25 | 0.21 |
| Refind F1  | 0.34    | 0.10 | 0.29 | 0.13 | 0.21 | 0.43 | 0.10 | 0.23 |
| Coral reef F1 | 0.21 | 0.03 | 0.22 | 0.04 | 0.12 | 0.29 | 0.05 | 0.14 |
| Fire F1    | 0.13    | 0.05 | 0.26 | 0.04 | 0.12 | 0.27 | 0.41 | 0.18 |
| Mean factor B | 0.23 | 0.08 | 0.25 | 0.09 | 0.17 | 0.30 | 0.20 | 0.19 |

LSD0.05 Hybrids (A) = 0.05
LSD0.05 Radiation (B) = 0.07
LSD0.05 (AB) = 0.14

Radiation treatments: (R)=Monochromatic, red (G+B)=Green+blue, (G)=Monochromatic green, (G+R)=Green+red, (B)=Monochromatic blue, (W)= White.

Blue light worked to increase the CO₂ uptake response and the entry of free potassium and other ions into the guard cells, corresponding to the inflow of water and the swelling of the guard cells, thus opening up, improving the gas exchange process, increasing stomata opening and the direct response of chloroplasts to the guard cells, thus increasing transpiration. It is followed by monochromatic green (G), red (R), white (W), light green+ red (G+R), blue + red (B+R), green + blue (G + B) the radiation had the least transpiration. Binary spectral green+red (G+R) had less effect than monochromatic light red (R) and green(G). The dual light blue+red (B+R) had less effect than monochromatic light red (R) and blue (B). The effect of dual light green+blue (G+B) was less than monochromatic light green(G) and blue (B).

Blue causes physiological responses Phototropins are responsible including as phototropism, hypocotyl elongation, leaf expansion, stomata opening, leaf anatomy, enzyme synthesis, chloroplast movements and gene expression [5,10,32]. Phototropins perceive blue directly and start a signaling cascade that leads to rapid stomata opening in the presence of red [23]. These results are consistent with [30] hypothesis that adding blue to the mix could enhance stomata density and aperture relative to red, altering photosynthesis further.

Conclusions

1. Monochromatic red light has increased the hypocotyl length and the height of tomato plant in comparison with blue and red. And monochromatic blue light has increased transpiration and stomatal conductance in comparison with green and blue.
2. The dual light blue and red has increased the leaf chlorophyll content (SPAD) of tomato plant and the dual light green and blue has increased the leaf and root dry weight in comparison with the monochromatic green. In addition the dual light green and red has increased the stem dry weight in comparison with monochromatic blue.
3. In the monochromatic light effect, the hybrid Fire F1 had the highest hypocotyl length and hybrid Refind F1 had the highest transpiration and stomatal conductance. In the binary spectral effect the hybrid Coral reef F1 had the highest stem dry weight, leaf dry weight and root dry weight. The hybrid Refind F1 had also the highest leaf chlorophyll content (SPAD).

References

[1] Aksenova N. P., Konstantinova T. N., Sergeeeva L. L., Machácková I. and Golyanovskaya S. A. 1994. Morphogenesis of potato plants in vitro. I. Effect of light quality and hormones. J. Plant Growth Regul. 13, 143–146. doi:10.1007/BF00196378.

[2] Al-Mohammadi S. M. and Al-Mohammadi F. M. 2012. Statistics and Experimental Design. Dar Osama for Publishing and Distribution . Amman. Jordan. pp.376.

[3] Appelgren, M. 1991. Effects of light quality on stem elongation of Pelargonium in vitro. Sci. Hortic. 45, 345–351. doi: 10.1016/0304-4238(91)90081-9

[4] Bures S.; M. U. Gavalan and S. Kotiranta. 2018. Artificial lighting in agriculture . Horticulture Library .p.1-47.

[5] Christie J. M. 2007. Phototropin blue-light receptors. Annu. Rev. Plant Biol. 58, 21–45. doi: 10.1146/annurev.arplant.58.032806.103951

[6] Dănilă E. and D. Lucache. 2016. Efficient Lighting System for Greenhouses . International Conference and Exposition on Electrical and Power Engineering . 20-22 October. Iasi. Romania.

[7] Dieleman J. A.; Pieter H. B; De Visser.; E. Meinen. ;J. G. Grit and T. A. Dueck. 2019. Integrating Morphological and Physiological Responses of Tomato Plants to Light Quality to the Crop Level by 3D Modeling. Frontiers in Plant Science. 10 (839):1-12.

[8] Dou H., Genhua Niu and Mengmeng Gu. 2019. Photosynthesis, Morphology, Yield, and Phytochemical Accumulation in Basil Plants Influenced by Substituting Green Light for Partial Red and/or Blue Light. HortsScience 54(10):1769–1776.

[9] Hogewoning S. W., Trouwborst G., Maljaars H., Poorter H., Van Ieperen, W. and Harbinson J. 2010. Blue light dose-responses on leaf photosynthesis, morphology and chemical composition of Cucumis sativus grown under different combinations of red and blue light. J. Exp. Bot. 61, 3107–3117. doi:10.1093/jxb/erq132.

[10] Inoue S. I., Kinoshita T., Matsumoto M., Nakayama K. I., Doi M., and Shimazaki K. I. 2008. Blue light-induced autophosphorylation of phototropin is a primary step for signaling. Proc. Natl. Acad. Sci. U.S.A. 105, 5626–5631. doi: 10.1073/pnas.0709189105.

[11] Johkan M., K. Shoji; F. Goto; S. Hashida and T. Yoshihara. 2010. Blue light-emitting diode light irradiation of seedlings improves seedling quality and growth after transplanting in red leaf lettuce. Hort science. 45(12):1809–1814.

[12] Kaisera E. b.; Weerheima K.; Schipperb R. and Dielemana J. A.. 2019. Partial replacement of red and blue by green light increases biomass and yield in tomato. Scientia Horticulturae. 249: 271–279.

[13] Lee J.S., Lim T.G. and Kim Y.H. 2014. Growth and phytochemicals in lettuce as affected by different ratios of blue to red radiation. Acta Horticulturae.1037: 843-848.

[14] Morrow R.C. .2008. LED lighting in horticulture. HortScience. 43: 1947-1950.

[15] Paradoso R., E. Meinen, J. F. H. Snel, P. De Visser, W. Van Lepenen, S. W. Hogewoning, et al. 2011. Spectral dependence of photosynthesis and light absorbance in single leaves and canopy in rose. Sci. Hortic. 127:548–554.

[16] Perveen R. 2015. Tomato (Solanum Lycopersicum) carotenoids and lycopene chemistry: metabolism, absorption, nutrition, and allied health claims: a comprehensive review. Critical Reviews in Food Science and Nutrition. 55(7): 919-929.

[17] Pfündel E. and Baake E.. 1990. A quantitative description of fluorescence excitation spectra in intact bean leaves greened under intermittent light. Photosynth. Res. 26, 19–28. doi: 10.1007/BF00048973.

[18] Prikupets, L. B.. 2018. Technological lighting for agro-industrial installations in Russia. Light & Engineering. 26 (1): 7-17.

[19] Sæbø A., Krekling T. and Appelgren M. 1991. Effects of light quality on stem elongation of Pelargonium in vitro. Sci. Hortic. 45, 345–351. doi:10.1016/0304-4238(91)90081-9

[20] Särkkä L.E., Jokinen K., Ottosen C.O., Kaukoranta T.. 2017. Effects of HPS and LED lighting on cucumber leaf chlorophyll content (SPAD). IOP Publishing

[21] Sellaro R., M. Crepy, S. A. Trupkin, E. Karayekov, A. S. Buchovsky, C. Rossi, and J. J. Casal. 2010. Cryptochrome as a sensor of the blue/ green ratio of natural radiation in Arabidopsis. Plant Physiology. 154 : 401 – 409.
9

[23] Shimazaki K. I., Doi M., Assmann S. M. and Kinoshita T.,. 2007. Light regulation of stomatal movement. Annu. Rev. Plant Biol. 58, 219–247. doi: 10.1146/annurev.arplant.57.032905.105434
[24] Snowden M. C., K. R. Cope and B. Bugbee . 2016. Sensitivity of Seven Diverse Species to Blue and Green Light: Interactions with Photon Flux. Journal. Pone. 11(10):1-23.
[25] Sun J., J. N. Nishio and T. C. Vogelmann. 1998. Green Light Drives CO2 Fixation Deep within Leaves. Plant Cell Physiol. 39:1020–1026.
[26] Terashima I., T. Fujita, T. Inoue, W. S. Chow and R. Oguchi. 2009. Green light drives leaf photosynthesis more efficiently than red light in strong white light: Revisiting the enigmatic question of why leaves are green. Plant Cell Physiology. 50:684–697.
[27] Thomas M. 2017. Vertical Farming as an Innovative Solution to Singapore’s Food Security Strategy. pp:1-18.
[28] Trouwborst G., S. W. Hogewoning, O. van Kooten and J. Harbinson. 2016. Plasticity of photosynthesis after the ‘red light syndrome’ in cucumber. Environ. Exp. Bot. 61:3107–3117.
[29] Vinha A. F. 2014. Organic versus conventional tomatoes: influence on physicochemical parameters, bioactive compounds and sensorial attributes. Food Chemical Toxicology. 67(1):139-144.
[30] Wang J., Lu W., Tong Y. and Yang Q. 2016. Leaf morphology, photosynthetic performance, chlorophyll fluorescence, stomatal development of lettuce (Lactuca sativa L.) exposed to different ratios of red light to blue light. Front Plant Sci.; 7(250):1-10. doi: 10.3389/fpls.2016.00250 PMID: 27014285.
[31] Wang Y. and Folta K.M. 2013. Contribution of green light to plant growth and development. American Journal of Botany. 100(1): 70–78. doi: 10.3732/ajb.1200354 PMID: 23281393.
[32] Wang H., Gu M., Cui J., Shi K., Zhou Y. and Yu J.. 2009. Effects of light quality on CO2 assimilation, chlorophyll-fluorescence quenching, expression of Calvin cycle genes and carbohydrate accumulation in Cucumis sativus. J. Photochem. Photobiol. B Biol.. 96, 30–37. doi: 10.1016/j.jphotobiol.2009.03.010.
[33] Wang X.Y., Xu X.M. and Cui J.. 2015. The importance of blue light for leaf area expansion, development of photosynthetic apparatus, and chloroplast ultrastructure of Cucumis sativus grown under weak light. Photosyntheticra. 53 (2): 213–222.
[34] Yakovtseva M., Govorova G. and Tarakanov I.. 2017.Supplemental lighting for greenhouse-grown strawberries: effects of different ratios of red to blue radiation. Acta Horticulturae. 1170 (2): 1011-1017.
[35] Yakovtseva M.N., Govorova G.F., Tarakanov I.G.. 2015.Photomorphogenetic regulation of growth, development and production process of garden strawberry (Fragaria x ananassa L.) plants under photoculture conditions. Journal (Известия) of the Timiryazev Agricultural Academy. (3): 25-35.