EFFECT OF SUPPLEMENTARY CYAN LIGHT TO DEEP RED AND ROYAL BLUE RANGE WAVELENGTH ON THE CULTIVATION OF TAMARA F1 PEPPER

T. Yaşar Katırcıoğlu*, Berkay Dur*, Tuğrul Karagul*, Mehmet Tabak*

ARTECS Anadolu R&D Technology Engineering and Consultancy Inc. Ankara University Teknokent Buldings D Blok No:7 06830 Gölbaşı Ankara, Turkey

ABSTRACT: *This research was conducted to investigate effect of supplementary Cyan Light on growth characteristics of pepper. Three different light sources, cyan (500 nm), red (660 nm), royal blue (440 nm), in closed environmental condition are examined. For this purpose, a 3-section shelf was prepared including Tamara F1 type pepper seeds. Temperature, water, pH, electrical conductivity (EC), fertilizer and nutrient contents were controlled at requested value. First section was lighted 18 hours a day with composing 55% deep red, %25 royal blue and 20% cyan lights. Second section was lighted same hours with first section and, and second section was composed the 65% deep red and 35% royal blue lights. Same photosynthetic photon flux density (PPFD) of 360 µmol* $m^{-2}s^{-1}$ *was used at first and second section. The third section was lighted with sunlight in order to make a comparison with natural lighting. The experiment continued to the 55 days from seeding to harvest time. The experiment showed that; additional cyan effected on 28% more size (followed with fruit length) and 191% fruit weight. Also, there is no significant effect on plant trunk thickness and fruit number.*

KEYWORDS: Cyan light, LED lighting, agriculture, greenhouses, pepper, LabVIEW

INTRODUCTION

Word population have been sharply increasing since beginning of the 19thcentury. İt is reached to reach 9 billion in 2050 [1] and food requirement will be increased proportionally. Besides, arable land hectares per person decreased from 0.367 to 0.192 between 1961 and 2016[2]. The greenhouse production could be the key to overcome this strong challenge. However, the sunlight intensity is not enough to plants grow well, and plants cannot take enough light due to continuous overcast and rainy days. The precaution of solving the light scarcity is to use artificial lighting in greenhouse.

Light - emitting diodes (LEDs) present comprehensive alternative for artificial greenhouse lighting with numerous advantages. The outstanding advantages of LEDs are lower energy demand, adjusting of require specific wavelength only for plants growing [3]. In addition to these advantages;

- Low energy consumption
- Long lifetime
- Small size
- Fire safety, do not produce excess heat
- Slow voltage

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

The deep red (660 nm) and royal blue (440 nm) lights combination, according to general assumption, are the most effective role for ideal plant growth and health [4] since photosynthesis reaction occurs near these wavelengths in the chlorophyll pigment [5].

However, various recent studies [6], [7], [8] show that using small amount green to cyan light accompanied by deep red and royal blue could improve plant growth. Besides, green to cyan light can saturate forest canopy and feed lower leaves and backside of the leaves thanks to the accessory pigments since its very little absorption [9].

The objective of this study was to evaluate the effect of small amount Cyan light (500 nm) on plant growth with subsidiary to the deep red (660 nm) and royal blue (440 nm), with the desire to find optimal lighting conditions for pepper plant growth.

MATERIALS AND METHOS

Measurements, equipment and calibration

In the experiment, 3-section shelf which first and second section covered with aluminium foils was used. These sections were ultimately dark when LEDs were turned off and interaction light between sections was blocked. Soilless system was used. Therefore, Fertilizer and other minerals were given within the irrigation fluid.


Figure 1: Drip Irrigation system


Figure 2: Humidifier

Humidifier was adjusted the air humidity at all shelf (Figure 2). 2 aquarium pumps were used in the irrigation fluid to pump the water through channels of drip irrigation system (figure 1).

Water pH sensor (Figure 3) was used every day to measure the pH in the water tank. Before taking measurement, calibration fluids at 10.01, 7.01, 4.01 was used. After the calibration, these liquids were measured 9.88, 6.95 and 4,04 pH respectively, approximately accuracy of 99%. Water electrical conductivity sensor (Figure 4) was used and recorded every day. The reference EC around 1420 µS/cm was used to calibration of EC sensor.

The EC sensor was measured with an error less than %3.

Two aluminium plates were used to installed LEDs for lighting purposes. Total PPFD value of LEDs were adjusted at 360 µmol $m^{-2}s^{-1}$, and their operational voltage was around 21.10 V for each section. Resulted amperage value was around 195 mA for each. Pictures of sections are given in Figure 5.

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

European Journal of Agriculture and Forestry Research
Vol.7, No.3, pp.30-44, August 2019
Published by European Centre for Research Training and Development UK (www.eajournals.org)

Figure 3 Water EC sensor

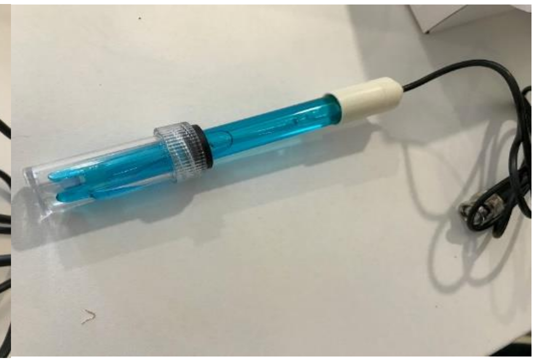

Figure 4 Water pH sensor

Figure 5 Experimental LEDs Design

Development conditions

Same six seedling seed were used in each shelf. These seedlings were placed on to rock wool (Grodan Vıtal) as a growth media figure 7.

Figure 6 Rock Wool

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

Figure 7 Growth Media

50 ml of (% 12 Calcium oxide, %1 Boron), product named CAL REFLEX, 50 ml NPK (8-8-8) product named Gentafol, ZN-EXTRA (%0,2 B, %0,6 Cu, %2 Fe, %0,5 Mn, %0,08 Mo, % 5 Zn) product named NUTRİPLUS were added in the plant nutritious. In the phenological stage, plants use the oxygen and carbon dioxide from air, hydrogen from water, other necessary nutritious for enough growth; nitrogen, potassium, calcium, magnesium, phosphorus and sulphur were given in the water [10]. 70 litres water tank, which consist of 55 litres mains water, 15 litres drinking water and aforementioned nutrients, was used. Electrical conductivity of mixture measured 1700 μS/cm which positive result for pepper growing since its ideal electrical conductivity is in the range 1400 μS/cm and 2000 μS/cm [11], [12], [13], [14]. Ph of the mixture was 5.5, which is favourable range for pepper growing [15], [16], [17]. Keeping of the electrical conductivity and Ph values in the desired value are significant since pH provide availability of elements in water; and electrical conductivity leads to nutrient deficiency or limited uptake of water.

Temperature of the shelves was kept between the 18 and 25 Celsius which is the ideal range for pepper growing in the hydroponic cultivation. The K type of thermocouples were settled to each section [18], [19]. Air humidity was kept between 50-80% [20].

İrrigation was done in the hydroponic system via pumps and dripping. This system provided the water from tank to the plants. İts range was adjusted with respect to the sensors and phenological stage from literature survey. İrrigation was started and stopped for both shelves during day and Control and automation system was created with using LabVIEW program figure 8.

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

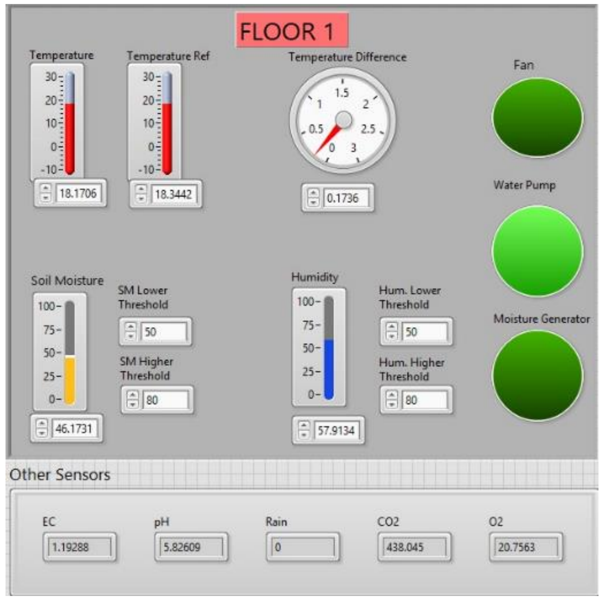

Figure 8 LabVIEW user interface

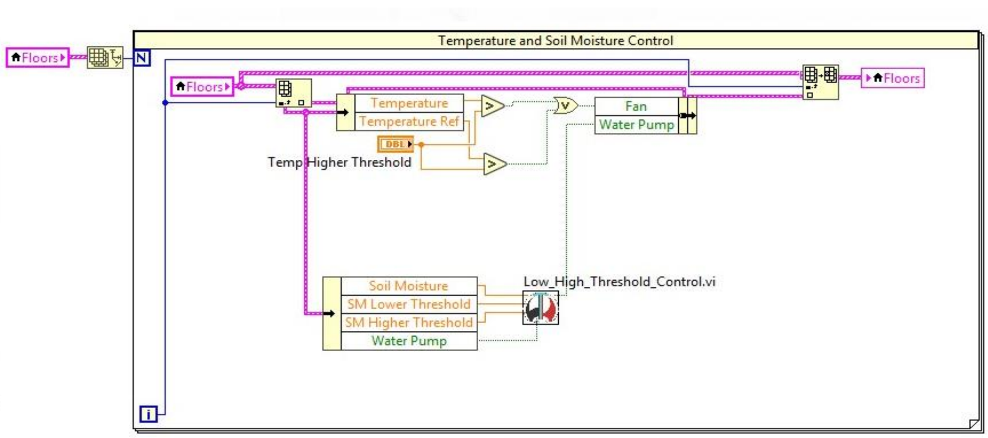

Figure 9 LabVIEW code for Hyroponıcs System

Lighting Conditions

Daily required photosynthetically active radiation (PAR) for light between 400-700 nm in 1 m^2 area with unit mol*m^{-2} per day [21], [22], is different depending on environmental conditions like latitude, clouds, time of year, etc. Some research investigates that depending on type of plant, higher than the 330 µmol m-2 s-1 of PPFD is required to achieve enough growth and nutrient value and the most suitable range is 330- 545 µmol m-2 s-1 of PPFD [23]. In this experiment, a constant PPFD of 360 µmol m-2 s-1 was used to reach maximum difference.

There different power LEDs, deep red light 660 nm, royal blue 440 nm and cyan 500 nm, were used. The exact wavelength of mentioned LEDs was measured and approved with an Ocean HR4000 spectrometer Figure 10 [8].

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

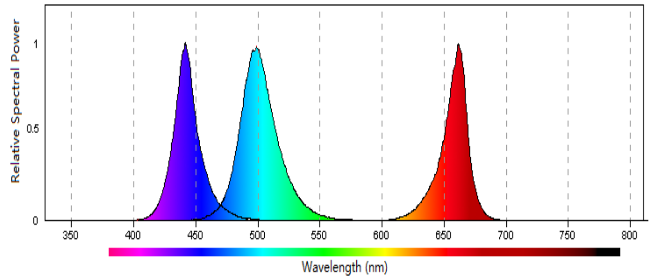

Figure 10 Wavelenghts of LEDs

Calculation of simulation sun peak power

Total Daily energy = time $\times$ PPFD $\times$ E

Time = 24 $\times$ 60 $\times$ 60 seconds = 86400 seconds

PPFD = $360 \times 10^{-6} \times 6.02 \times 10^{23}$

E = $\frac{hc}{\lambda}$, E is photon energy, h is Planck constant, c is speed of the light in vacuum and λ is wavelength of the photon. [24]

Then;

Total Daily energy = $86400 \times 360 \times 10^{-6} \times 6.02 \times 10^{23} \times \frac{(6.62607004 \times 10^{-34}) \times (299792000)}{\lambda}$ joules
= $\frac{3.71954}{\lambda}$ joules

For first section (55% red, 25% blue, 20% cyan);

$\lambda_2 = \frac{(55\times660)+(25\times440)+(20\times500)}{100}$ = 573 nm

For second section (65% red, 35% blue);

$\lambda_3 = \frac{(65\times660)+(35\times440)}{100}$ = 583 nm

Total daily energy1 = $\frac{3.71954}{0.000000573}$ joules = 6491344 joules = 6.49 MJ
(1)

Total daily energy 2 = $\frac{3.71954}{0.000000583}$ joules = 6380000 joules = 6.38 MJ
(2)

Second way of calculation for total Daily energy,

On cloudless summer afternoon sun transmit approximately 1050 W of power per m^2 on Earth's surface [25] PAR portion of energy given on Earth's surface can be estimated as [26], [27], [28]:

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

$$1050 \times 0.43 \times (4/24) = 75.25 \text{ W/m}^2$$
(3)

Total daily energy $_{\text{sun-visible}}$ = 75.25 x 60 x 60 x 24 joules = 6.5 MJ/m^2
(4)

Result of equations (1), (2) and (3) are similar. Considering the equations (4) the total given energy in the experiment was like a simulation of 16 hours a day sun peak power in the approximately 0.25 m^2 setup area.

RESULTS

The experiment lasted 55 days which started from seedling and ended with harvest. Periodically (every two days), bloom number, fruit number, fruit length, plant length, plant trunk thickness and after harvest fruit weight were measured of 13 pepper plants of each section. The reason of recording data after date 27/07/2019 is fruit length, number plant length can be more meaningful, below table describes these measures.

Table 1: Effect of LED and Sunlight on the TAMARA F1 Pepper

Average of 6 plants each section						
Red, Blue (65%, 35%)	fruit number	fruit weight	fruit length	plant length	plant trunk thinkness	bloom number
20/06/2019				14.62	4.93	
22/06/2019				14.97	4.68	
24/06/2019				15.55	4.85	
26/06/2019				16.28	4.91	
28/06/2019				16.95	5.16	
01/07/2019				17.67	5.43	
03/07/2019				17.97	5.62	
05/07/2019				17.97	5.62	
27/07/2019	1.5		41.9	17.97	5.76	3.5
29/07/2019	1.5		45.2	17.98	5.9	3
01/08/2019	1.5		51	18.01	6.04	2.5
03/08/2019	1.66		52	18.01	6.18	2.5
05/08/2019	1.66		54.6	18.03	6.31	3
08/08/2019	1.66		57.1	18.05	6.45	2.3
15/08/2019	1.66	16.1	59.8	18.05	6.59	2.3
Red, Blue, Cyan (55%. 25%. 25%)	fruit number	fruit weight	fruit length	plant length	plant trunk thinkness	bloom number

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

20/06/2019				15.11	4.8	
22/06/2019				15.3	4.87	
24/06/2019				15.29	5.05	
26/06/2019				15.75	5.73	
28/06/2019				16.28	5.39	
01/07/2019				16.61	5.48	
03/07/2019				16.88	5.58	
05/07/2019				16.88	5.58	
27/07/2019	1.5		65.44	17.2	5.84	1
29/07/2019	1.5		69.77	17.21	5.96	0.66
01/08/2019	1.5		73.77	17.21	6.08	0.83
03/08/2019	1.5		73.22	17.23	6.2	0.83
05/08/2019	1.5		76	17.38	6.32	0.83
08/08/2019	1.5		76.22	17.28	6.44	0.5
15/08/2019	1.5	47	76.55	17.28	6.56	0.33
Sunlight 100%	fruit number	fruit weight	fruit length	plant length	plant trunk thinkness	bloom number
20/06/2019				14.65	4.90	
22/06/2019				14.88	4.66	
24/06/2019				15.1	4.77	
26/06/2019				15.5	4.80	
28/06/2019				15.9	5.01	
01/07/2019				16.2	5.06	
03/07/2019				16.6	5.22	
05/07/2019				16.9	5.33	
27/07/2019	1.4		33.7	17.0	5.66	1
29/07/2019	1.4		35.8	17.1	5.79	0.55
01/08/2019	1.4		41.7	17.4	6.0	0.6
03/08/2019	1.4		44.4	17.6	6.13	0.6
05/08/2019	1.4		49.3	17.8	6.21	0.6
08/08/2019	1.4		50.7	17.8	6.36	0.5
15/08/2019	1.4	13.6	53.4	17.8	6.44	0.5

Two lighting combination red-blue and red-blue-cyan effect is shown in figure 11. Supplementary Cyan light increased the average fruit length 28% compared to the red-blue lighting. Calculation as follow;

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

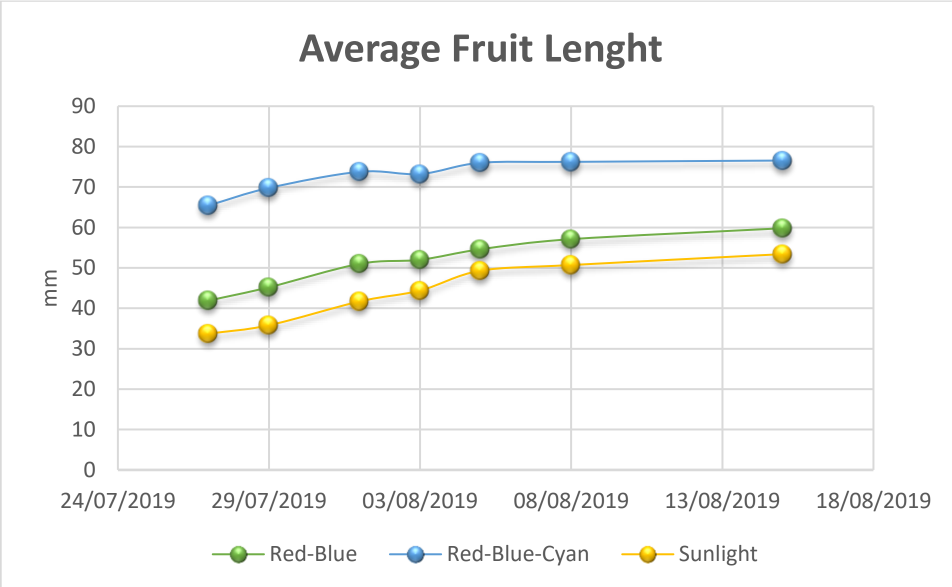

Figure 11: Average Fruit Length of Red- Blue and Red-Blue-Cyan Lighting

End of the experiment average fruit length 76.56 mm for red-blue-cyan and 59.8 mm for red-blue. Average of fruit length calculated from 19 fruits at 12 plants. Table below shows that the length of 19 fruit for last 18 days.

Figure 12: Measurment Methods of Fruit Length Lighting

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

Table 2: Effect of LED on the plant growth lenght

DATE/mm	PLANT 1	PLANT 2	PLANT 2	PLANT 2	PLANT 3	PLANT 3	PLANT 4	PLANT 5	PLANT 5	PLANT 6
27/07/2019	65	38	38	15	50	70	60	13	50	20
29/07/2019	67	39	35	24	55	73	62	18	58	21
01/08/2019	70	38	42	41	59	83	68	19	68	22
03/08/2019	75	41	46	40	57	83	69	16	70	23
05/08/2019	78	40	47	43	59	90	69	19	78	23
08/08/2019	77	41	46	36	66	89	72	18	78	48
15/08/2019	79	40	56	40	66	96	75	19	78	49
DATE/mm	PLANT 7	PLANT 8	PLANT 8	PLANT 9	PLANT 9	PLANT 10	PLANT 11	PLANT 11	PLANT 12	PLANT 13
27/07/2019	105	28	81	10	75	90	34	58	108	33
29/07/2019	105	35	85	14	84	96	35	63	111	35
01/08/2019	111	36	93	12	92	97	39	68	116	38
03/08/2019	111	37	95	13	84	98	38	66	117	40
05/08/2019	112	39	99	14	93	98	38	74	117	42
08/08/2019	112	40	94	14	93	98	38	80	117	46
15/08/2019	112	40	97	14	93	98	38	80	117	53

For red- blue; $\frac{(79+40+56+40+66+96+75+19+78+49)}{10} = 59.8\ mm$

For red- blue- cyan; $\frac{(112+40+97+14+93+98+38+80+117)}{9} = 76.56\ mm$

And to calculate efficiency; $\frac{76.56-59.8}{59.8} = 0.28$

The effect of cyan on the fruit length calculated 28%. (compering with red-blue)

Total fruits weight measured 16.1 gr for red-blue-cyan for 47 gr for 55 days table. Total efficiency for supplementary cyan measured 191% compering to red blue. Calculation as follow;

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

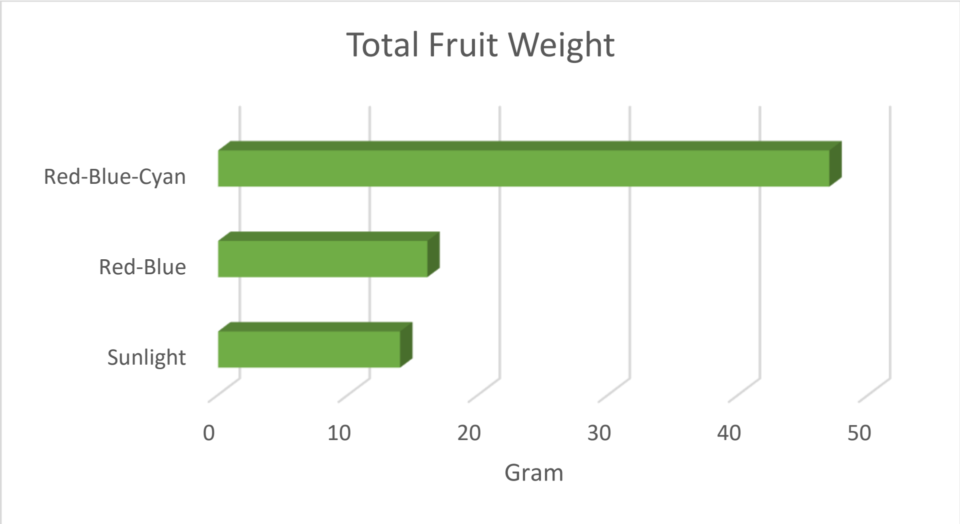

Figure 13: Total Fruit Weight

$$\frac{(47-16.1)}{16.1} = 1.91$$

Efficiency of supplementary cyan lighting increased 191% total weight.

With the cyan lighting there is no significant effect for plant trunk thickness table.

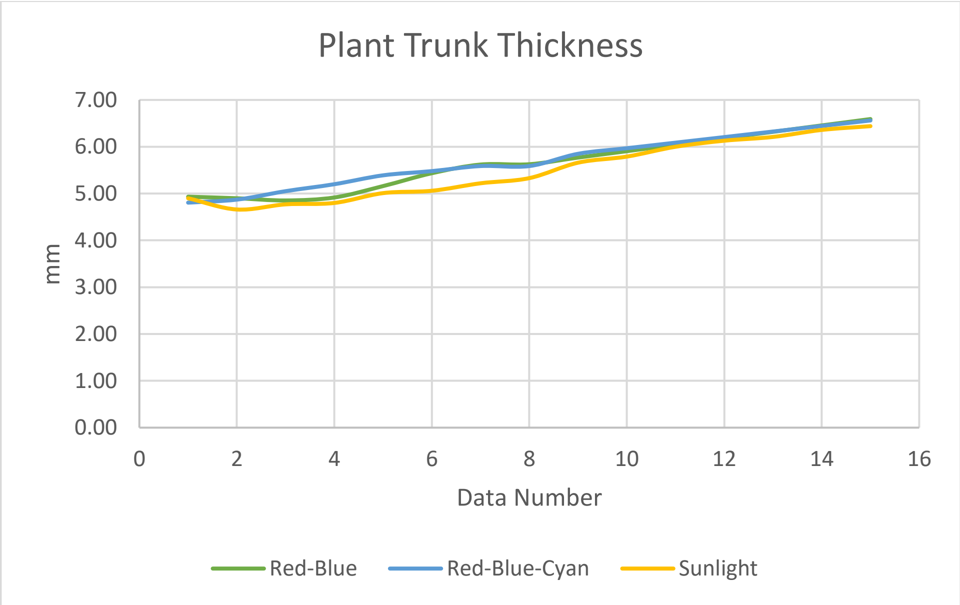

Figure 14: Plant Trunk Thichness

Average fruit number for red-blue lighting was calculated 1.66 for average of six plant and red-blue-cyan lighting was calculated 1.5 for average of six plants so supplementary cyan did not affect the average fruit number on the pepper.

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

DISCUSSION

Fruit weight in each section sunlight, red-blue lighting and red-blue-cyan lighting were measured 13.6 gr, 16.1 gr and 47 gr respectively. Its observed that supplementary cyan light has dramatically effect on fruit weight. Main reason for this cyan lighting accelerates the plant growing [29]. Sunlight section is the weakest since it contains unnecessary light combination for plant growth and lead to light deficiency [8].

Cyan lighting effect the length of fruit positively since photosynthesis absorption occurs in the chlorophyll b, chlorophyll a and carotenoids. Chlorophyll b and a highly absorb the light at 460 and 660 nm. But carotenoids absorb light at near green lights around 500 nm (cyan including) so that red-blue-cyan assemble have more impact on photosynthesis efficiency with activating the carotenoids, this provides more elongation on plant [8],[30].

Plant trunk thickness in each section became almost same. Possible reason for this, plant trunk does not make photosynthesis reaction so that cyan light and other lighting or sunlight does not any change on the trunk thickness [31]

The results are supporting supplementary cyan lighting to the red and blue lighting; but its cost also should be considered. To calculate the energy consume, LEDs can be used as a operational cost for this lighting.

- For first section;
  21.10 V, 195 Ma and one day its work 18 hours, total energy usage would indicate 0.074 kWh. The electricity price in Turkey is 0.714 TRY/kWh [32], daily cost of electricity approximate would indicate 0.052 TL/day. Consider that average price of pepper kilogram in Ankara Turkey is 8.40 TRY [33].
  For second section;
  21.11 V and 201 Ma and one day its work 18 hours, total energy usage would indicate 0.076 kWh. Then, the cost of electricity calculates as 0.054 TRY/day.

Six plant were growth in each section, considering lighting price 0.054 TRY/6 = 0.009 TRY cost added per pepper kilogram. The lighting lasted for 55 days so 0.009 x 55 = 0.495 TRY added the cost of pepper/kilogram to compensate of lighting. Improvement on elongation and efficiency on plant production considering the sunlight and red-blue lighting, supplementary of cyan lighting is evaluated as highly profitable.

CONCLUSION

In conclusion, supplementary cyan light grew much better than the other section red-blue lights. According to elongation of fruit length (table1), % 28 improvement with cyan light occurred in 55 days. Also, cyan increase the fruit weight %208 compering to the red-blue lighting, the fruit weight is crucial for market and profit. So, addition the cyan light is highly profitable.

Although industrial application suggest that red and blue lighting are the best for greenhouse [38], the results of this experiment are like aforementioned finding of studies which is about green range lights [34], [35], [36], [37]. Supplementary cyan light can boast to length of fruit and weight of fruit comparing to the red-blue lighting.

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

Effect of cyan light with different time frame will be a topic on later studies. In this study 18 hours continuous lighting was provided. However, lighting with different time frame can affect more on the plant growth due to photosynthesis reaction.

Referances

1. Global agriculture towards 2050. http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf Retrieved on: 06.08.2019
2. The World Bank https://data.worldbank.org/indicator/AG.LND.ARBL.HA.PC?end=2016&start=1961. Retrieved on: 06.08.2019
3. Using the LED Lighting in the Greenhouses. Timo Mantere, Toni Harju, Petri Välisuo and Jarmo T. Alander Dept. of Electrical Engineering and Automation, University of Vaasa, Vaasa, Finland firstname.lastname@uwasa.fi
4. Matsuda, Ryo, et al. (2004). "Photosynthetic Characteristics of Rice Leaves Grown under Red Light with or without Supplemental Blue Light." Plant and Cell Physiology, vol. 45, no. 12, pp. 1870–1874., doi:10.1093/pcp/pch203.
5.] Response of the Growth Characteristics and Phytochemical Contentsof Pepper (Capsicum annuum L.) Seedlings with Supplemental LED Light in Glass House
6. Chang, Chung-Liang, and Kuang-Pi Chang. (2014). "The Growth Response of Leaf Lettuce at Different Stages to Multiple Wavelength-Band Light-Emitting Diode Lighting." Scientia Horticulturae, vol. 179, pp. 78–84., doi:10.1016/j.scienta.2014.09.013.
7. Gioia D. Massa, Hyeon-Hye Kim, et al. (2008). "Plant Productivity in Response to LED Lighting." HortScience, vol. 43 (7), hortsci.ashspublications.org/content/43/7/1951.full.pdf html.
8. Effect of Supplementary Cyan Light to Deep Red and Royal Blue Range Wavelengths on the Seedling Period of Iceberg Lettuces T. Yaşar Katırcıoğlu* Murat Toksavul Mehmet Tabak Çağlar Terzi ARTECS Anadolu R&D Technology Engineering and Consultancy Inc. Ankara Üniversitesi Teknokent Binası D Blok No:7 06830 Gölbaşı Ankara, Turkey
9. Wollaeger, Heidi, et al. (2018) "Green Light: Is It Important for Plant Growth?" MSU Extension, www.canr.msu.edu/news/green_light_is_it_important_for_plant_growth.
10. (2019). "The Beginner's Guide to Mixing Hydroponic Nutrients." *Upstart University*, university.upstartfarmers.com/blog/mixing-hydroponic-nutrients.
11. Effects of cultural cycle and nutrient solution electrical conductivity on plant growth, yield and fruit quality of 'Friariello' pepper grown in hydroponics. Amalfitano Carmine-Vacchio Del-Somma Silvano-Cuciniello Antonio-Caruso Gianluca - Horticultural Science – 2017
12. Tadesse, T., & Nichols, M. (2003). The Effect Of Conductivity On The Yield And Quality Of Sweet Pepper (Capsicum Annuum L.). Acta Horticulturae, (609), 197–199. doi: 10.17660/actahortic.2003.609.27

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

13. Furtado, G. D. F., Cavalcante, A. R., Chaves, L. H. G., Júnior, J. A. S., & Gheyi, H. R. (2017). Growth and Production of Hydroponic Pepper under Salt Stress and Plant Density. American Journal of Plant Sciences, 08(09), 2255–2267. doi: 10.4236/ajps.2017.89151
14. Carmine, A., Del, V. L., Silvano, S., Antonio, C., & Gianluca, C. (2017). Effects of cultural cycle and nutrient solution electrical conductivity on plant growth, yield and fruit quality of 'Friariello' pepper grown in hydroponics. Horticultural Science, 44(No. 2), 91–98. doi: 10.17221/172/2015-hortsci
15. Chatterjee, C., & Dube, B. K. Nutrient Deficiency Disorders in Vegetables and their Management. Fruit and Vegetable Diseases Disease Management of Fruits and Vegetables, 145–188. doi: 10.1007/0-306-48575-3_5
16. Zu, C., Li, Z., Yang, J., Yu, H., Sun, Y., Tang, H., … Wu, H. (2014). Acid Soil Is Associated with Reduced Yield, Root Growth and Nutrient Uptake in Black Pepper (<i>Piper nigrum</i> L.). Agricultural Sciences, 05(05), 466–473. doi: 10.4236/as.2014.55047
17. Somerville, C. (2015). Small-scale aquaponic food production: integrated fish and plant farming. Rome: Food and Agriculture Organization of the United Nations.
18. Mercado, J. A., Trigo, M. M., Reid, M. S., Valpuesta, V., & Quesada, M. A. (1997). Effects of low temperature on pepper pollen morphology and fertility: Evidence of cold induced exine alterations. Journal of Horticultural Science, 72(2), 317–326. doi: 10.1080/14620316.1997.11515518
19. Uzel, R. A. (2017). Alternative Methods To Preserve Pepper Paste Quality: Effect Of Temperature And Protective Agents. ANADOLU UNIVERSITY JOURNAL OF SCIENCE AND TECHNOLOGY A - Applied Sciences and Engineering, 1–1. doi: 10.18038/aubtda.310767
20. Martínez, P., Tartoura, S., & Roca, D. (2001). Air Humidity, Transpiration And Blossom-End Rot In Soilless Sweet Pepper Culture. Acta Horticulturae, (559), 425–429. doi: 10.17660/actahortic.2001.559.64
21. Faust, James E., et al. (2005). "The Effect of Daily Light Integral on Bedding Plant Growth and Flowering" HortScience, vol. 40 (7) American Society for Horticultural Science, journals.ashs.org/hortsci/view/journals/hortsci/40/3/article-p645.xml.
22. Bula, R.j., et al. (1991). "Light-Emitting Diodes as a Radiation Source for Plants." HortScience, vol. 26, no. 2, pp. 203–205., doi:10.21273/hortsci.26.2.203.
23. Samuoliene, Giedre, et al. (2014). "Light-Emitting Diodes: a Tool for Growth and Metabolism Handle." 14th International Symposium on the Science and Technology of Lighting. Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry.
24. "Energy of Photon". Photovoltaic Education Network, pveducation.org. Retrieved: 22.03.2019 web.archive.org/web/20160712123152/http://pveducation.org/pvcdrom/2-properties-sunlight/energy-photon.
25. "Terrestrial Spectra." *Introduction to Solar Radiation*, Newport, www.newport.com/t/introduction-to-solar-radiation. Retrieved: 22.03.2019
26. Effect of Supplementary Cyan Light to Deep Red and Royal Blue Range Wavelengths on the Seedling Period of Iceberg Lettuces T. Yaşar Katırcıoğlu* Murat Toksavul Mehmet Tabak Çağlar Terzi ARTECS Anadolu R&D Technology Engineering and Consultancy Inc. Ankara Üniversitesi Teknokent Binası D Blok No:7 06830 Gölbaşı Ankara, Turkey

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)

27. “Solar.” Illumination, Innovation, Transformation, www.immunolight.com/applications/solar/.
28. Baker, Alyssa. (2019) “How to Calculate Your Peak Sun-Hours.” Solar Power Authority, www.solarpowerauthority.com/how-to-calculate-your-peak-sun-hours/.
29. (2014). Effect of light quality on growth, photosynthesis and effective components of Panax notoginseng. China Journal of Chinese Materia Medica. doi: 10.4268/cjcmm20140410
30. Farabee, M. J. (2007). “What Is Photosynthesis?” *Photosynthesis*, www2.estrellamountain.edu/faculty/farabee/BIOBK/BioBookPS.html.
31. NCERT. (2006). Biology: textbook for class Xi. New delhi: Ncert.
32. EnCazip Team. (2019) “2019 Electricity Prices.” *EnCazip*, encazip.com/elektrik-fiyatlari.
33. “Product Price Details.” Republic of Turkey Ministry of Customs and Trade Marketplace Registration System, www.hal.gov.tr/Sayfalar/FiyatDetaylari.aspx. (the price is for 27.08.2019, pepper is on page 2,)
34. Folta, K. M., and S. A. Maruhnich. (2007). “Green Light: a Signal to Slow down or Stop.” *Journal of Experimental Botany*, vol. 58, no. 12, pp. 3099–3111., doi:10.1093/jxb/erm130.
35. Wang, Yihai, and Kevin M. Folta. (2013). “Contributions of Green Light to Plant Growth and Development.” *American Journal of Botany*, vol. 100, no. 1, pp. 70–78., doi:10.3732/ajb.1200354.
36. Chang, Chung-Liang, and Kuang-Pi Chang. (2014). “The Growth Response of Leaf Lettuce at Different Stages to Multiple Wavelength-Band Light-Emitting Diode Lighting.” *Scientia Horticulturae*, vol. 179, pp. 78–84., doi:10.1016/j.scienta.2014.09.013.
37. Gioia D. Massa, Hyeon-Hye Kim, et al. (2008). “Plant Productivity in Response to LED Lighting.” *HortScience*, vol. 43 (7), hortsci.ashspublications.org/content/43/7/1951.full.pdf html.
38. Albosauce.com. “Video: Red Light vs Blue Light:How Spectrums Effect Plant Growth.” *Red & Blue LED Grow Lights, But Where's the Green???* -AlboPepper.com, albopepper.com/red-blue-LED-grow-lights-with-no-green-spectrum.php. Retrieved: 19.03.2019.

Print ISSN: ISSN 2054-6319 (Print), Online ISSN: ISSN 2054-6327(online)