AGRO PRODUCTIVIDAD

Colegio de Postgraduados

Light Quality Produced by LED Combinations on the Growth of Cucumber Seedlings (*Cucumis sativus* L.)

Zazueta-Torres, Norma D.[1]; Cázarez -Flores, Luz Ll.[2]; Rojas-Pérez, Héctor[1]; Román-Román, Leonardo[2]; Mendoza-Gómez, Aurelia[3*], Yáñez-Juárez, Moisés G.[2]; Partida-Ruvalcaba, Leopoldo[2]

[1] Tecnológico Nacional de México/ ITS Eldorado, Av. Tecnológico S/N Col. Rubén Jaramillo, C.P. 80450. Eldorado, Culiacán, Sinaloa, México.

[2] Universidad Autónoma de Sinaloa, Facultad de Agronomía, Carretera Culiacán-Eldorado km 17.5, Apartado Postal 25, C.P. 80000. Culiacán, Sinaloa, México.

[3] Instituto de Ciencias Agrícolas, Carretera a Delta/Oaxaca s/n, Ejido Nuevo León, C.P. 21705, Valle de Mexicali, Baja california.

* Correspondence: aurelia.mendoza@uabc.edu.mx

ABSTRACT

Objective: To determine the influence of light quality on the growth of cucumber plants (*Cucumis sativus* L.), through the intensity of expression of different characteristics.

Design/methodology/approach: A completely randomized block design was used with four treatments and 10 repetitions. The treatments consisted of combinations of white (B), red (R) and blue (A) LEDs placed in growth chambers, with percentages of: 100B-0R-0A, 70B-30R-0A, 80B-0R- 20A and 60B-27R-13A, growth chambers with LED-based lighting systems lamps were used. Seeds of the 'Top 1056' cultivar, Persian type, were sown. The response variables evaluated in the cucumber plants were plant height, stem diameter, leaf greenness, leaf area, fresh and dry biomass of leaves, stem and root of the plants.

Results: The light spectrum emitted by the LEDs influenced the morphology of the cucumber seedlings. With the 80B-0R-20A treatment, where there was greater blue light emission, greater leaf greenness and stem diameter were achieved. In contrast, the 70B-30R-0A treatment, with more red light, increased plant height and leaf area. Fresh and dry biomass of leaves and stem were also modified by light quality. Plants grown in the 70B-30R-0A treatment produced the greatest amounts of fresh and dry biomass, both stem and leaves.

Limitations on study/implications: The use of artificial lighting systems, with different spectral compositions for production in controlled environments presents a viable opportunity to enhance crop growth. Therefore, it is important to investigate how the light spectrum of different LED combinations affects the growth of cucumber seedlings.

Findings/conclusions: The light spectrum emitted by LED combinations influenced the morphology of cucumber seedlings, since with 80B-0R-20A treatment, resulted in greater leaf greenness and stem diameter, while the 70B-30R-0A treatment increased the height and leaf area of the plants.

Keywords: white ligh, red light, blue light.

Citation: Zazueta-Torres, N. D., Cázarez –Flores, L. Ll., Rojas-Pérez H., Román-Román, L., Mendoza-Gómez, A., Yáñez-Juárez, M. G., & Partida-Ruvalcaba, L., (2024). Light Quality Produced by LED Combinations on the Growth of Cucumber Seedlings (*Cucumis sativus* L.). *Agro Productividad*. https://doi.org/10.32854/agrop.v17i11.3116

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Daniel Alejandro Cadena Zamudio

Received: May 23, 2024.
Accepted: September 05, 2024.

Agro Productividad, 17(11) supplement. November. 2024. pp: 49-55.

INTRODUCTION

Light-emitting diodes (LEDs) represent a promising technology for the greenhouse industry and are currently being tested for horticultural applications (Mitchell *et al.*, 2012). A LED is a unique type of semiconductor diode. The wavelength of the emitted light (light color) depends on the properties of the semiconductor material.

LEDs can have peak emission wavelengths ranging from UV-C (∼250 nm) to infrared (∼1000 nm) and are the first light source capable of controlling the spectral composition. This allows wavelengths to be matched with plant photoreceptors to enhance optimization, production, and influence the morphology and composition of plants (Bourget, 2008). Plant species have the ability to respond in various ways to light quality (color or wavelength), light intensity (photon flux density or irradiance), and the combination of both (Nguy-Robertson *et al.*, 2015).

The plant response to the received light spectrum is determined by the action of different photoreceptors. According to Xie *et al.* (2019), these can be grouped based on the region of the electromagnetic spectrum they detect: phytochromes detect red (600 to 700 nm) and far-red (700 to 750 nm) light in a dynamic photoequilibrium relationship, while cryptochromes and phototropins respond to blue light from 350 to 500 nm (Fantini *et al.*, 2019).

Light quality affects plant growth, development, and morphology (Fukuda *et al.*, 2008). The photosynthetic organs of plants (leaves and green stems) absorb photons more efficiently in the blue and red regions of the incident visible radiation spectrum, while absorption in the green and infrared regions is minimal, as most of these photons are reflected as diffuse radiation (Lazo and Ascencio, 2010). On the other hand, tomato and pepper seedlings grown under blue light, either alone or in combination with red light, exhibit reduced stem height (Javanmardi and Shandiz, 2013). Additionally, blue light supplementation promotes the growth of spinach, radish, and lettuce under red light (Yorio *et al.*, 2001).

MATERIALS AND METHODS

The research was conducted at the Plant Physiology and Anatomy Laboratory of the Faculty of Agronomy, Autonomous University of Sinaloa, in Culiacán, Sinaloa, Mexico. Growth chambers with LED-based lighting systems were used. Cucumber seeds cv. 'Top 1056', a Persian type, were sown in polystyrene trays with 128 cavities.

A completely randomized block design was used with four treatments and ten replications. The treatments consisted of: 100% white light, 0% red, and 0% blue (100B-0R-0A) emitted by white LEDs (B); 70% white light, 30% red, and 0% blue (70B-30R-0A) from a combination of white and red LEDs (R); 80% white light, 0% red, and 20% blue (80B-0R-20A) achieved by combining white and blue LEDs; and 60% white light, 27% red, and 13% blue (60B-27R-13A), generated by using a mix of white, red, and blue LEDs. These treatments were applied in the respective growth chambers, where the percentages of light for each treatment were determined based on the number and types of LEDs installed.

The spectral distribution achieved with the LED combinations used is shown in Figure 1. Additionally, the absolute quantities of photosynthetic photon flux (PPF), red light (RL),

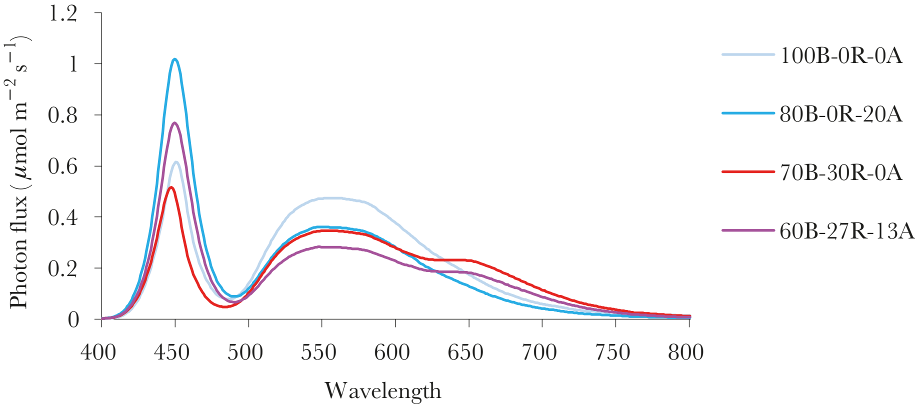

Figure 1. Spectral distribution (400-800 nm) of light emitted by combinations of white (B), red (R), and blue (A) LEDs.

far-red light (FRL), and blue light (BL), as well as the relative amounts of RL and BL with respect to PPF, and the proportions between RL, BL, and FRL, are detailed in Table 1.

The light quality (Table 1), expressed in terms of the corresponding PPF, for the wavelength intervals of 400 to 700 nm (photosynthetically active radiation), 400 to 500 nm (blue light), 600 to 700 nm (red light), and 700 to 800 nm (far-red light) was determined using a spectroradiometer (FieldSpec Pro®VNIR, Analytical Spectral Devices, USA). The combination of white and red LEDs (70B-30R-0A) emitted more red light (20.87 μmol m^{-2} s^{-1}), which was 52.78%, 26.1%, and 12.69% higher than the respective combinations of white and blue LEDs (80B-0R-20A), white, red, and blue LEDs (60B-27R-13A), and white LEDs alone (100B-0R-0A). With 70B-30R-0A, conditions had the highest amount of far-red light (4.48 μmol m^{-2} s^{-1}), followed by the quantities of μmol m^{-2} s^{-1} generated by 60B-27R-13A, 100B-0R-0A, and 80B-0R-20A.

Table 1. Spectral characteristics of light emitted by LED combinations.

Parameters	**Treatment**			
	100B-0R-0A	**70B-30R-0A**	**80B-0R-20[a]**	**60B-27R-13[a]**
FFF (400-700 nm)[x]	81.31	70.51	79.15	68.76
LA (400-500 nm)[x]	19.67	15.73	33.08	24.85
LR (600-700 nm)[x]	18.52	20.87	13.66	16.55
RL (700-800 nm)[x]	2.78	4.48	1.68	3.26
LA: FFF [(400-500/400-700 nm)*100][y]	24.20	22.31	41.80	36.13
LR: FFF [(600-700/400-700 nm)*100][y]	22.77	29.60	17.26	24.06
LA: LR (400-500/600-700 nm)[z]	1.06	0.75	2.42	1.50
LA: LRL (400-500/700-800 nm)[z]	7.07	3.51	19.70	7.62
LR: LA (600-700/400-500 nm)[z]	0.94	1.33	0.41	0.67
LR: LRL (600-700/700-800 nm)[z]	6.66	4.56	8.13	5.07

PPF=Photosynthetic Photon Flux. BL=Blue Light, RL=Red Light, FRL=Far-Red Light. B=% White LEDs, R=% Red LEDs, A=% Blue LEDs. Absolute quantities × (μmol m^{-2} s^{-1}), relativey (%), and proportionalz (dimensionless).

Regarding blue light emission, the combination of LEDs 80B-0R-20A produced 33.08 μmol m^{-2} s^{-1}, which was 110.3%, 68.17%, and 33.12% higher than the blue light emitted by the combinations of LEDs 70B-30R-0A, 100B-0R-0A, and 60B-27R-13A, respectively. The photosynthetic photon flux varied from 68.76 μmol m^{-2} s^{-1} to 81.31 μmol m^{-2} s^{-1}.

The response variables evaluated in the cucumber plants were: plant height, measured with a tape measure; stem diameter, obtained with a digital caliper (6MP, Truper Tools, Mexico); leaf greenness, estimated with a chlorophyll meter (SPAD 502, Konica Minolta, Japan); leaf area, calculated using the formula:

$$LA_{leaf} = \left(Lenght * Width\right) \wedge 0.851$$

proposed by Blanco and Follegati (2003); and fresh and dry biomass of leaves, stem, and roots, determined using a precision balance (CP622, Sartorius, Germany), after drying in an oven (292, Felisa, Mexico) at 70 °C until a constant dry weight was achieved. The data obtained were subjected to analysis of variance and mean comparison using Tukey's test at 95% confidence level, using the Minitab 19 statistical package.

RESULTS AND DISCUSSION

The quality of light emitted by the LED combinations had significant effects ($P \leq 0.05$) on the height, greenness, and leaf area of cucumber plants (Table 2). The highest amount of red light (20.87 μmol m^{-2} s^{-1}), the highest red light to photosynthetic photon flux ratio (29.60%), and the highest red light to blue light ratio (1.33), emitted by the LED combination with 70B-30R-0A, caused plant height to increase by 20.6%, 12.1%, and 3.2% compared to the height achieved by those grown under the LED combinations of 80B-0R-20A, 100B-0R-0A, and 60B-27R-13A, respectively. These results are consistent with those of Ding *et al.* (2010), who observed that *Paeonia suffruticosa* seedlings were taller when grown under red light, as well as with those of Juwei *et al.* (2016), who reported that *Morus alba* plants exhibited greater stem length under red light.

The results show that higher absolute quantities (Table 2), relative, and proportional (Table 1) of red light promoted increased stem length, while the highest amount of blue light in the light environment had the opposite effect. This is because blue light directs

Table 2. Influence of light quality emitted by white, blue, and red LEDs on stem length and diameter, leaf greenness, and leaf area in Persian cucumber seedlings 'Top 1056'.

Tratamiento	Plant height (cm)	Stem diameter (mm)	Greenery (Spad units)	Leaf area (cm^2/plant)
100B-0R-0A	7.72±1.29 ab	2.81±0.19 a	30.77±2.12 ab	23.81±4.14 b
70B-30R-0A	8.65±0.59 a	2.87±0.28 a	27.85±1.98 c	27.98±3.65 a
80B-0R-20A	7.17±1.44b	2.62±0.21 a	32.38±2.45 a	16.25±2.02 c
60B-27R-13A	8.38±1.38 ab	2.66±0.39 a	28.82±2.78 bc	15.31±3.01 c

*B=% White LEDs, R=% Red LEDs, A=% Blue LEDs. =Means ± standard deviation; values with the same letter within each column are statistically similar (Tukey, $p \leq 0.05$).

plant behavior towards photosynthetic efficiency rather than stem elongation, resulting in more compact and efficient plants. This reduction in stem growth is consistent with the findings of Dougher and Bugbee (2001), who reported that under high light intensities, blue light strongly inhibits stem elongation. Similarly, Javanmardi and Shandiz (2013) found that tomato and pepper seedlings had shorter heights when grown under blue light, either alone or in combination with red light. In terms of stem diameter, the results were inverse to those for plant height, although no statistical differences were observed (Table 2). However, leaf greenness was more intense in plants that received more blue light (33.08 μmol m^{-2} s^{-1}, as indicated in Table 1) from the 80B-0R-20A LED combination, with SPAD values exceeding those of plants that received less blue light (15.73 μmol m^{-2} s^{-1}) from the 70B-30R-0A combination by 16.2%. Light quality also caused significant modifications in leaf dimensions. Thus, the leaf area of plants grown with 70B-30R-0A, which had the highest amount of red light (20.87 μmol m^{-2} s^{-1}), a high red light: PFF ratio (29.60%), and a red light: blue light ratio (1.33), was 72.1% and 82.7% larger than that of plants grown under the influence of 80B-0R-20A and 60B-27R-13A, respectively. The latter combinations had the highest absolute, relative, and proportional amounts of blue light and the lowest amounts of red light, which is often associated with increases in the transmission of photosynthetically active radiation and blue light (Costa *et al*., 2010; Hogewoning *et al*., 2010; Souza *et al*., 2011). With a relatively low PFF (100 μmol m^{-2} s^{-1}), blue light can alter leaf morphology and photosynthesis (Hogewoning *et al*., 2010; Terfa *et al*., 2013).

Table 3 shows that the production of fresh biomass exhibited significant differences ($P \leq 0.05$) due to light quality. Plants grown under 80B-0R-20A conditions accumulated 36.8% more fresh weight in leaves compared to those grown under 60B-27R-13A. The same table also shows that fresh biomass accumulation in stems varied significantly; plants grown in the 70B-30R-0A environment produced 38.18% more fresh weight in stems compared to those grown under 80B-0R-20A. No statistical differences were observed in the fresh biomass of roots.

However, in relation to dry weight (Table 4) of the organs in question, it was found that plants grown in an environment with a higher amount of red light (20.87 μmol m^{-2} s^{-1}), emitted by the LED combination of 70B-30R-0A, produced 63.5% more dry weight of leaves compared to the leaves from plants grown under 80B-0R-20A.

Table 3. Influence of light quality emitted by combinations of white, blue, and red LEDs on the fresh biomass of Persian cucumber seedlings 'Top 1056'.

Treatment	Fresh weight (g)		
	Leaves	Stem	Root
100B-0R-0A	0.258±0.059 ab	0.435±0.052 a	0.508±0.217 a
70B-30R-0A	0.233±0.029 ab	0.470±0.050 a	0.313±0.069 a
80B-0R-20A	0.368±0.302 a	0.330±0.065 b	0.333±0.170 a
60B-27R-13A	0.162±0.044 b	0.305±0.066 b	0.364±0.177 a

B=% of white LEDs, R=% of red LEDs, A=% of blue LEDs. Means ± standard deviation with the same letter within each column are statistically similar (Tukey, $p \leq 0.05$).

Table 4. Influence of Light Quality Emitted by Combinations of White, Blue, and Red LEDs on the Dry Biomass of Persian Cucumber 'Top 1056' Seedlings.

Treatment	**Dry Weight (g)**		
	Leaves	**Stem**	**Root**
100B-0R-0A	0.0239±0.0053 a	0.0127±0.0026a	0.0215±0.0120 a
70B-30R-0A	0.0224±0.0041 ab	0.0115±0.0038 a	0.0134±0.0031 ab
80B-0R-20A	0.0137±0.0058 c	0.0084±0.0048 a	0.0158±0.0076 ab
60B-27R-13A	0.0170±0.0060bc	0.0243±0.0095 a	0.0110±0.0035 b

B=% of white LEDs, R=% of red LEDs, A=% of blue LEDs. Means ± standard deviation with the same letter within each column are statistically similar (Tukey, $p \leq 0.05$).

Although no statistical differences were found in the dry weight of the stem, the 70B-30R-0A treatment resulted in a 36.9% increase compared to that produced with 80B-0R-20A. Meanwhile, for root dry weight, a high ratio of blue light to red light (2.42 μmol m^{-2} s^{-1}, indicated in Table 1) emitted by 80B-0R-20A influenced the plants to produce 17.91% and 43.63% more root biomass compared to that produced by plants grown under the respective conditions of 70B-30R-0A or 60B-27R-13A, which emitted lower amounts of blue light (15.73 or 24.85 μmol m^{-2} s^{-1}, respectively).

The results can be linked to the fact that red light increases the photosynthetic rate of plants, leading to increases in dry weight (Nishimura *et al.*, 2009). This is why authors like Ayala-Tafoya *et al.* (2015) found that the dry weight of leaves and stems in pepper plants increased when cultivated under red netting, due to the interaction of higher fluxes of total radiation, photosynthetically active radiation, and red light. Similarly, Casierra-Posada *et al.* (2012) have noted that under blue light conditions, there is a decrease in the total dry weight of plants such as strawberry, beetroot, and broccoli.

CONCLUSIONS

The light spectrum emitted by combinations of white (B), red (R), and blue (A) LEDs influenced the morphology of cucumber seedlings. With 80B-0R-20A, where there was higher blue light emission, greater leaf greenness and stem diameter were achieved. Conversely, with 70B-30R-0A, which provided more red light, plant height and leaf area were increased. This influence of light quality was also observed in the characteristics of fresh and dry biomass of leaves and stems, as plants grown under 70B-30R-0A illumination showed the highest average biomass. However, this was not the case for the root system.

REFERENCES

Ayala-Tafoya F., Yáñez-Juárez M.G., Partida-Ruvalcaba L., Ruiz E.F.H., Campos G.H., Vásquez M.O., Velázquez-Alcaraz T.J., Díaz-Valdés T. (2015). Producción de pepino en ambientes diferenciados por mallas de sombreo fotoselectivo. *ITEA 111*(1):3-17. DOI: http://dx.doi.org/10.12706/itea.2015.001

Blanco F.F., Folegatti M.V. (2003). A new method for estimating the leaf area index of cucumber and tomato plants. *Horticultura Brasileira 21*(4):666-669. Print version ISSN 0102-0536On-line version ISSN 1806-9991.DOI: http://dx.doi.org/10.1590/S0102-05362003000400019

Bourget C.M. (2008). An introduction to light-emitting diodes. *HortScience* 43: 1944-1946. DOI: https://doi.org/10.21273/HORTSCI.43.7.1944.

Casierra-Posada F., Peña-Olmos J.E., Ulrichs C. (2012). Basic growth analysis in strawberry plants (*Fragaria* sp.) exposed to different radiation environments. *Agronomía Colombiana 30*(1):25-33. http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0120-99652012000100000

Costa L.C.B., Pinto J.E.B.P., Castro E.M., Alves E., Bertolucci S.K.V., Rosal L.F. 2010. Effects of coloured shade netting on the vegetative development and leaf structure of *Ocimum selloi*. Bragantia, Campinas 69: 349-359. ISSN 0006-8705 DOI: https://doi.org/10.1590/S0006-87052010000200012

Ding Y., He S., Teixeira da Silva J.A., Li G., Tanaka M. 2010. Effects of a new light source (cold cathode fluorescent lamps) on the growth of tree peony plantlets *in vitro*. *Scientia Horticulturae 125*(2): 167-169. DOI: https://doi.org/10.1016/j.scienta.2010.03.019

Dougher T.A.O., Bugbee B.G. 2001. Differences in the response of wheat, soybean and lettuce to reduced blue radiation. *Photochemistry Photobiology 73*(2):199-207. DOI: https://doi.org/10.1562/0031-8655(2001)0730199DITROW2.0.CO2

Fantini, E.; Sulli, M.; Aprea, G.; Jiménez-Gómez, J.; Bendahmane, A.; Perrotta, G.; Giuliano, G. and Facella, P. 2019. Pivotal roles of cryptochromes 1a and 2 in tomato development and physiology. *Plant Physiol. 179*(2):732-748. www.plantphysiol.org/cgi/doi/10.1104/ pp.18.00793.

Fukuda N., Fujitan M., Sase S., Ezura H. 2008. Directional blue light irradiation triggersepidermal cell elongation of abaxial side resulting in inihibition of leaf epinasty in geranium under red light condition. *HortSciense* 115:176-182. DOI: https://doi.org/10.1016/j.scienta.2007.08.006

Hogewoning S.W., Trouwborst G., Maljaars H., Poorter H., Ieperen W., Harbinson J. 2010. Blue light dose-responses of leaf photosynthesis, morphology, and chemical composition of *Cucumis sativus* grown under different combinations of red and blue light. *Journal of Experimental Botany* 61: 3107-3117. DOI:10.1093/jxb/erq132

Javanmardi J., Shandiz E. 2013. Response of tomato and pepper transplants to light spectra provided by light emitting diodes. *International Journal of Vegetable Science* 19:138-149. ISSN: 1931-5260 print / 1931-5279 online DOI: 10.1080/19315260.2012.684851.

Juwei H., Xin D., Guangyu S. 2016. Morphological and physiological responses of *Morus alba* seedlings under different light qualities. *Horti Agrobo, 2016, 44*(2):382-392. Print ISSN 0255-965X; Electronic 1842-4309.DOI:10.15835/nbha44210486

Lazo J.V., Ascencio J. 2010. Efecto de diferentes calidades de luz sobre el crecimiento de *Cyperus rotundus*. *Bioagro 22*(2):153-158.

Mitchell C.A., Both A.J., Bourget C.M., Burr J.F., Kubota C., Lopez R.G., Morrow R.C., Runkle E.S. 2012. LEDs: the future of greenhouse lighting. *Chronica Horticulturae* 52: 6-10. ISSN :0578-039X

Morrow R.C. 2008. LED Lighting in Horticulture. *HortScience. 43*(7):1947-1950. DOI: https://doi.org/10.21273/HORTSCI.43.7.1947

Nguy-Robertson A., Suyker A., Xiangming X. 2015. Modeling gross primary production of maize and soybean croplands using light quality, temperature, water stress, and phenology. *Agricultural and Forest Meteorology* 213:160-172. DOI: https://doi.org/10.1016/j.agrformet.2015.04.008

Nishimura T.K., Ohyama E., Inagaki N. 2009. Concentrations of perillaldehyde, limonene, and anthocyanin of perilla plants as affected by light quality under controlled environments. *Scientia Horticulturae* 122:134-137. DOI: https://doi.org/10.1016/j.scienta.2009.03.010

Souza GS, Castro EM, Soares ÂM, Santos AR, Alves E. 2011. Teores de pigmentos fotossintéticos, taxa de fotossíntese e estrutura de cloroplastos de plantas jovens de *Mikania laevigata* Schultz Bip. ex Baker cultivadas sob malhas coloridas. *Semina: Ciências Agrárias, Londrina* 32: 1843-1854. DOI: http://dx.doi.org/10.5433/1679-0359.2011v32n4Sup1p1843

Terfa M.T., Solhaugb K.A., Gislerøda H.R., Olsena J.E., Torre S. 2013. A high proportion of blue light increases the photosynthesis capacity and leaf formation rate of *Rosa hybrida* but does not affect time to flower opening. *Physiol. Plant*. 148, 146–159. DOI: 10.1111/j.1399-3054.2012.01698.

Xie, B.; Wei, J.; Zhang, Y.; Song, S.; Su, W.; Sun, G.; Hao, Y. and Liu, H. 2019. Supplemental blue and red light promotes lycopene synthesis in tomato fruits. *J. Integr. Agric. 18*(3):590- 598. https://doi.org/10.1016/52095-3119(18)62062-3.

Yorio N.C., Goins G.D., Kagie H.R., Wheeler M.R., Sager J.C. 2001. Improving spinach, radish, and lettuce growth under red light emitting diodes (LEDs) with blue light supplementation. *Hortscience 36*(2):380-383. DOI: http://dx.doi.org/10.5897/AJB11.1191