Acta Scientiarum
http://www.periodicos.uem.br/ojs/
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v44i1.55284

CROP PRODUCTION

Photosynthetically active radiation intensity used as an extended photoperiod to increase quality in basil seedlings

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ABSTRACT. The use of a protected environment for vegetable seedling production has become one of the best alternatives to minimize the adverse micrometeorological effects of the external environment and guarantee quality and production throughout the year. Inside the protected environment, it is essential to study the physiological responses of plants to the wavelength, periodicity, intensity, and direction of light in the photosynthetic process. Thus, the aim of this study was to investigate the effect of different intensities of photosynthetically active radiation (PAR) used as an extended photoperiod in a greenhouse on the production of basil seedlings. A completely randomized design, in a 2 × 4 factorial scheme, with four replications of 20 seedlings per plot was used. Two basil varieties, sweet basil (green color) and purple basil (purple color), were evaluated under three intensities of supplementary PAR, which were 375, 411, and 438 μmol m^{-2} s^{-1}, and control, in the absence of supplementary PAR. The seedling height, stem diameter, shoot dry matter, root dry matter, total dry matter, leaf area, ratio between plant height and stem diameter, ratio between plant height and shoot dry matter, ratio between shoot dry matter and root dry matter, and Dickson quality index were evaluated. Results show that higher intensities of PAR used as an extended photoperiod favor the quality of basil seedlings produced in a protected environment.

Keywords: *Ocimum basilicum*; light-emitting diode; protected environment.

Received on August 17, 2020.
Accepted on December 17, 2020.

Introduction

Basil (*Ocimum basilicum*) belongs to the Lamiaceae family, originates in the tropical Asia region, and is adapted to areas with varied climates (Vlase et al., 2014). According to Blank, Souza, Paula, and Alves (2010), basil has more than 60 different subspecies, with variations in parameters such as size, leaf shape, aroma, and color. Basil is commercially grown for its use as an aromatizing and condiment product from its leaves and essential oil (Blank, Souza, Arrigoni-Blank, Paula, & Alves, 2007).

Basil propagation can be conducted using seeds or by the cutting process. According to Pereira and Moreira (2011), *O. basilicum* has great adaptability to various climatic conditions. However, its growth is favored in regions with a hot climate, where it can be cultivated throughout the year. The use of a protected environment is an alternative in the cultivation of vegetables, as such an environment minimizes adverse micrometeorological effects of the external environment, guaranteeing production throughout the year with quality and productivity (Gomes, Silva, & Faquim, 1999). Guerra, Silva, and Evangelista (2020) reported that protected environment favors the development of basil, increasing the production and yield of essential oil.

Within the protected environment, it is essential to study plant's physiological responses to the wavelength, periodicity, intensity, and direction of the light in the photosynthetic process, as roofing materials limit and modify light irradiation. As an alternative to sunlight or as a supplement to it, light bulbs with a light-emitting diode (LED) might be used in horticulture, as these allow for the adjustment of irradiance according to crop needs and the selection of light spectrum (Singh, Basu, Meinhardt-Wollweber, & Roth, 2015). According to Rocha, Oliveira, Scivittarol, and Santos (2013), LED lamps have a specific wavelength, a longer lifespan, a greater efficiency in light generation without high heat emission, and a lower energy consumption. Through this technology, it is possible to partially meet the demand for light retained by the protected environment, providing the supplement photosynthetically active radiation, which is directly involved in the growth and development of the plant. As PAR is a part of the complete spectrum, which involves the visible spectrum, and is directly linked to the plant photochemical process, it also alters the spectral balance of the cultivation environment, as PAR emit specific wavelengths that are captured by the plant's photoreceptors, resulting in changes in the morphophysiological behavior of the vegetable.

However, information on the use of PAR supplements using LEDs in protected environments for seedling production, especially for basil, is scarce. It has been shown that this technique has the potential to increase basil seedling production, with adjustments necessary to promote high seedling quality (Mello et al., 2020).

As PAR emission is an alternative to the production of quality seedlings in a protected environment, this aim of this study was to evaluate the effect of different intensities of PAR used as extended photoperiod in a greenhouse on the physiological aspects of basil seedlings.

Material and methods

The experiment was conducted in a greenhouse with temperature and relative air humidity control, closed on the sides, and covered with a double layer of 150-micron low-density polyethylene film and light diffuser and aluminum thermo-reflective mobile screen with 35% shading under the film. The greenhouse was equipped with a porous/exhaust type (pad/fan Humil Cool, CELDEX®) (A Van der Hoeven, Artur Nogueira, São Paulo State, Brazil) system that was 1.2-m high and 0.15-m thick. The environment contained 1.10-m high metal benches and concrete floor.

For this study, two basil varieties, sweet basil (green color) and purple basil (purple color), were sown and cultivated in 128-cell trays filled with a substrate composed of Sphagnum peat, expanded vermiculite, limestone, gypsum, and nitrogen, phosphorus, and potassium fertilizer. Chemical analysis of the substrate was performed, as presented in Table 1.

Table 1. Substrate chemical attributes used to grow basil seedlings.

Attributes	Unit	Value
pH	-	6.15
C:N	Ratio	18.8
cation exchange capacity	mmol kg^{-1}	850.0
organic matter	g kg^{-1}	250.0
N	g kg^{-1}	14.0
P_2O_5	g kg^{-1}	3.6
K_2O	g kg^{-1}	11.0
Ca	g kg^{-1}	9.1
Mg	g kg^{-1}	42.0
S	g kg^{-1}	3.0
Cu	g kg^{-1}	0.06
Fe	g kg^{-1}	17.5
Mn	g kg^{-1}	2.4
Zn	g kg^{-1}	0.36
B	g kg^{-1}	0.08

After sowing, the trays were placed on a bench under the different PAR intensities with extended photoperiod, from 00:00 to 11:00 h (Figure 1). Supplemental PAR was provided by LED lamps (red LEDs with wavelengths of 620–630 nm, blue LEDs with wavelengths of 440–445 nm, white LEDs of 5,500–6,500 k and 2,500–3,300 k, infrared LEDs with a wavelength of 730 nm, and ultraviolet LEDs with wavelengths of 380–410 nm, in the following proportions: 67, 15, 10, 5, and 3% of LEDs in each wavelength, respectively) on each bench. A height-adjustable support was built to support the lamps (Figure 1A). Different PAR intensities were obtained using lamps with different powers at two heights as follows: 32,000 lm (lumens) at 64 cm, 32,000, and 51,300 lm at 50 cm (Figure 1B).

PAR was monitored using Apogee MQ-200 Quantum (manual meter with separate sensor) (Apogee Instruments, Logan, UT, USA) daily at 10:30 AM, avoiding the measurement on cloudy days. The device was positioned in four regions of the trays, and the following PAR averages were obtained: 295 μmol m^{-2} s^{-1} (control), 375 μmol m^{-2} s^{-1} obtained by 32,000 lm at 64 cm, 411 μmol m^{-2} s^{-1} obtained by 32,000 lm at 50 cm, and 438 μmol m^{-2} s^{-1} obtained by 51,300 lm at 50 cm, in the different treatments.

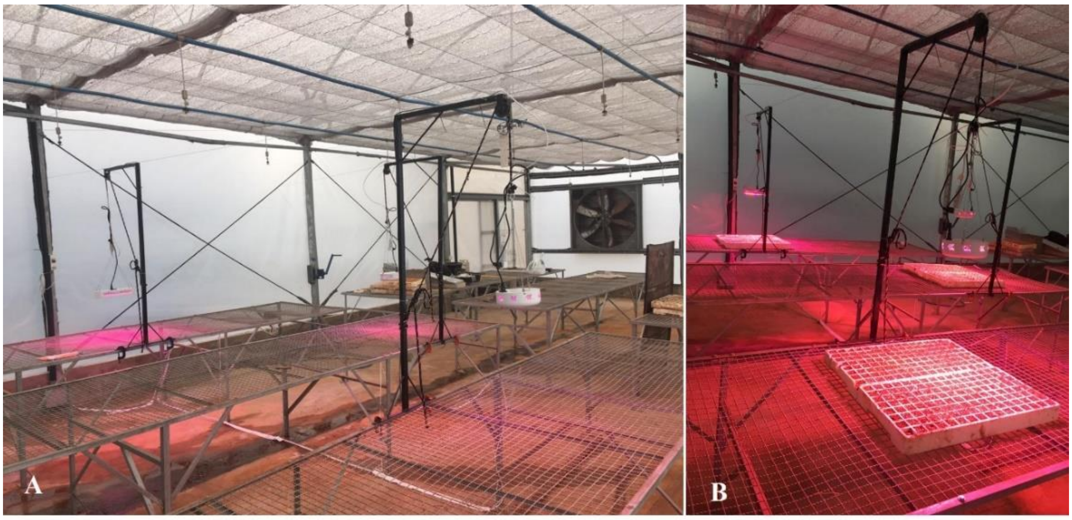

Figure 1. (A) Light-emitting diodes installed inside protected environment over bench and (B) use of photosynthetically active radiation as extended photoperiod in basil seedlings produced in trays.

Seedling emergence began on the fifth day after sowing (DAS), with subsequent emergence stabilization at 10 DAS when thinning was performed, allowing the growth of only one seedling per cell. The PAR did not affect seedling emergence, which was ≥ 98%.

Irrigation was performed according to the crop demand manually, with the aid of a spray pump, keeping the substrate moist and avoiding saturation. Seedlings were fertilized at 15 DAS, applying 10 g of a fertilizer composed of 15% nitrogen, 5% phosphorus, 10% potassium, 1% calcium, 1% magnesium, 13% sulfur, 4% sulfate (SO_4), 0.06% boron, 0.05% copper, 0.2% iron, 0.1% manganese, 0.005% molybdenum, and 0.2% zinc diluted in 1 L of water. During the experiment, air temperature was adjusted to 25 ± 2°C and the relative humidity was ± 84%.

At 30 DAS, the basil seedlings had four leaves and the biometric assessments were performed as described below.

Seedling height (SH) was determined by measuring the distance from the substrate surface to the highest part of the seedling in centimeters.

Stem diameter (SD, in millimeters) was determined using a digital caliper.

The seedlings were divided into shoots and roots and subsequently dried in a forced air circulation oven at 65°C for 72h. Dry matter was weighed on a precision scale to obtain the shoot dry matter (SDM) and root dry matter (RDM) expressed in g seedling^{-1}. The sum of SDM and RDM was used to estimate the total dry matter (TDM) expressed in g seedling^{-1}.

Leaf area (LA) was obtained by comparing the mass of a known area of the paper with the weight of the perimeter cutouts of leaves. For this, heliographic copies of paper sheets were made, and from the same paper sheet, a figure with a square shape was removed in which the area was dimensioned. By interpolating the mass of the figure of a known area and the weight of the "impression" cut out of the paper sheet, the area was determined.

The plant height: stem diameter ratio (H:D) was obtained by the equation: H:D = SH/SD.

The shoot dry matter: root dry matter ratio (S:R) was obtained by the equation: S:R = SDM/RDM.

The plant height: shoot dry matter ratio (H:S) was obtained by the equation: H:S = SH/SDM.

The Dickson quality index (DQI) was determined by the equation: DQI = TDM/(SH/SD + SDM/RDM).

The experiment was carried out in a completely randomized design for each biometric assessment in a basil variety × PAR factorial arrangement, with four replications of 20 seedlings per plot. The data were submitted to analysis of variance, and when significant, the means were compared by Tukey test at a 0.05-confidence level for the factor PAR intensity.

Results

The interaction between the varieties and PAR intensities influenced the LA, SH, SDM, TDM, and the relationship between SH and SDM expressed as H:S (Table 2).

Table 2. Leaf area (LA), seedling height (SH), shoot dry matter (SDM), total dry matter (TDM), and the ratio between seedling height and shoot dry matter (H:S) of seedlings of two basil varieties grown under four photosynthetically active radiation intensities used as extended photoperiod.

PAR intensity	Variety	
	Sweet basil	Purple basil
	LA (cm^2)	
295 µmol m^{-2} s^{-1} - control	*66.57 aA	65.81 aA
375 µmol m^{-2} s^{-1}	43.05 aB	43.79 aB
411 µmol m^{-2} s^{-1}	46.15 aB	20.31 bC
438 µmol m^{-2} s^{-1}	16.07 aC	13.64 aC
C.V (%)	19.2	
	SH (cm)	
295 µmol m^{-2} s^{-1}- control[1]	7.18 aA	5.75 bA
375 µmol m^{-2} s^{-1}	5.73 aB	5.75 aA
411 µmol m^{-2} s^{-1}	4.77 aB	3.45 bB
438 µmol m^{-2} s^{-1}	3.14 aC	3.20 aB
	11.8	
	SDM (g $seedling^{-1}$)	
295 µmol m^{-2} s^{-1} - control	0.2138 aA	0.1678 bAB
375 µmol m^{-2} s^{-1}	0.1774 aAB	0.1298 bB
411 µmol m^{-2} s^{-1}	0.1801 aAB	0.1436 aAB
438 µmol m^{-2} s^{-1}	0.1394 bB	0.1924 aA
C.V (%)	16.5	
	TDM (g $seedling^{-1}$)	
295 µmol m^{-2} s^{-1} - control	0.2878 aA	0.2289 bB
375 µmol m^{-2} s^{-1}	0.2636 aA	0.1929 bB
411 µmol m^{-2} s^{-1}	0.3028 aA	0.2491 bAB
438 µmol m^{-2} s^{-1}	0.2566 bA	0.3017 aA
C.V (%)	12.7	
	H:S	
295 µmol m^{-2} s^{-1} - control	33.84 aA	34.28 aB
375 µmol m^{-2} s^{-1}	33.49 bAB	45.53 aA
411 µmol m^{-2} s^{-1}	27.00 aAB	24.00 aBC
438 µmol m^{-2} s^{-1}	22.77 aB	17.25 aC
C.V (%)	18.5	

*Means followed by different lowercase letters in the rows and uppercase letters in the columns differ statistically from each other by the F and Tukey tests at the 0.05-confidence level, respectively.

Regardless of the variety, there was a reduction in the LA owing to the increase in the PAR intensity used as an extended photoperiod. The sweet basil variety had the largest LA with a PAR intensity of 411 µmol m-2 s-1 (Table 2). The highest SH of the sweet basil variety was observed with a PAR intensity of 295 µmol m-2 s-1. There was a decrease in SH regardless of the variety with the increase in PAR intensity (Table 2).

The sweet basil variety had higher SDM than the purple basil under PAR intensities of 295 and 375 µmol m-2 s-1. However, at a PAR intensity of 438 µmol m-2 s-1, the purple basil had a higher SDM than the sweet basil variety. At a PAR intensity of 411 µmol m-2 s-1, there was no difference between the varieties (Table 2). The increase in PAR intensity promoted an increase in the SDM of the purple basil variety, and it promoted a decrease in the SDM of the sweet basil variety (Table 2).

Except for the PAR intensity of 438 µmol m-2 s-1, the sweet basil had a higher TDM than the purple basil variety. However, in the purple basil variety, the PAR intensity of 438 µmol m-2 s-1 promoted a higher TDM than the PAR intensity of 295 and 375 µmol m-2 s-1 (Table 2). In general, with increasing PAR intensity, there was a decrease in the relationship between SH and SDM.

There was no influence of the interaction between the basil varieties and PAR intensities on the RDM, SD, H:D, S:R, and DQI (Table 3). The sweet basil variety had higher RDM than the purple basil variety; this result is attributed to the higher efficiency of the photosynthetic metabolism of sweet basil varieties, as mentioned previously.

The PAR intensities of 411 and 438 µmol m^{-2} s^{-1} promoted an increase in the RDM of the basil seedlings (Table 3). There was a gradual decrease in the H:D with the increase in PAR intensity; this was also observed in the S:R (Table 3). The PAR intensities of 411 and 438 µmol m^{-2} s^{-1} increased the DQI values of the basil seedlings.

Table 3. Root dry matter (RDM), stem diameter (SD), the ratio between seedling height and stem diameter (H:S), the ratio between shoot dry matter and RDM (S:R), and Dickson quality index (DQI) of seedlings of two basil varieties grown under four photosynthetically active radiation intensities used as extended photoperiod.

Variety	RDM (g seedling^{-1})	SD (cm)	H:D	S:R	DQI
Sweet basil	*0.08473 b	1.26 a	4.11 a	1.98 a	0.0436 a
Purple basil	0.1001 a	1.21 a	4.24 a	1.94 a	0.0484 a
PAR intensity					
295 μmol m^{-2} s^{-1} - control	0.0675 b	1.56 a	5.30 a	2.85 a	0.0335 b
375 μmol m^{-2} s^{-1}	0.0747 b	1.21 a	4.76 ab	2.05 b	0.0336 b
411 μmol m^{-2} s^{-1}	0.1140 a	1.17 a	3.47 bc	1.49 b	0.0560 a
438 μmol m^{-2} s^{-1}	0.1133 a	1.02 a	3.11 c	1.48 b	0.0608 a
C.V (%)	18.6	25.0	24.1	21.0	17.6

*Means followed by different lowercase letters in the columns differ statistically from each other by the F and Tukey test for the variety and PAR intensity, respectively, at the 0.05-confidence level.

Discussion

The advancement in technologies to produce high-quality vegetable seedlings in protected environments has resulted in guaranteed supply of food throughout the year, generating food security. In this study, we demonstrated that the use of PAR as an extended photoperiod can improve the quality of basil seedlings when the luminous intensity is used more correctly as presented in sequence.

First, the PAR used in this study did not have a positive impact on the expansion of the LA (Table 2), which was contradictory to that observed in other studies, where the PAR application favored leaf expansion in basil (Mello et al., 2020), lettuce (Kim, Wheeler, Sager, & Goins, 2004), and mint in vitro (Cunha, Silva, Bertolucci, Rocha, & Pinto, 2019). However, this result does not indicate sensitivity of basil to PAR; however, the intensity of the applied light flux, wavelength used, and exposure time are inherent to each plant species, which are facts that must be extensively investigated in later studies to elucidate the reasons for such reduction. Seedlings produced in environments with different levels of shading and, consequently, availability of PAR, have different LAs, as seen in the production of *Tabebuia aurea* (Souza & Freire, 2018), citrus (Martins, Marçal, Souza, & Coelho, 2015), and *Passiflora edulis* (Silva, Costa, Andrade, Fereira, & Steiner, 2006) seedlings.

Reduction in the size of seedlings, along with the best dry phytomass partition that provides better biometric growth rates, is a desirable attribute owing to an increase in the survival rate of compact seedlings. The use of PAR in the conditions evaluated here promotes these characteristics in basil seedlings as verified through the obtained SH values (Table 2). This occurs, in hypothesis, according to the response of the photoreceptors present in the plant, such as phytochrome. Specific wavelengths influence these photoreceptors, and the increase in the red wavelength intensity, which was emitted in greater quantity by the lamps used in this study (67%), led to a change in the active:inactive phytochrome ratio. Thus, possibly resulting in lower production of gibberellin, with a reflection on lower growth in seedlings height, which deserves to be studied in more depth in future studies.

The variation in the response of varieties to the accumulation of SDM is owing to the photosynthetic rate efficiency of each variety. Purple seedlings such as the purple basil variety are less efficient in the use of supplementary PAR than green varieties because of the high concentration of anthocyanin and flavonoids, which impairs the absorption of radiation by the chloroplasts and, consequently, the reduction of photochemical energy that is transferred to the reaction centers (Sun, Nishio, & Vogelmann, 1998). As a result, there is a reduction in the liquid photosynthesis. However, using the PAR intensity of 438 μmol m^{-2} s^{-1}, it was possible to supply the photosynthetic demand, which increased in the SDM of this variety. The results show that the use of supplementary PAR technology with LED offers the possibility of increasing growth for use in horticultural production. However, for an adequate development response, there is a need to adjust the irradiance according to the genetic traits of the species and its reactions to the environment.

PAR intensity of 438 μmol m^{-2} s^{-1} increased the dry matter of the purple basil seedlings (Table 2). This information is particularly important, and as reported by Dou, Niu, and Gu (2019), the sweet basil variety has the best response to supplementary PAR. This indicates that the results of this study have the potential to increase the quality of purple basil seedlings. The photosynthetic rate in seedlings of this variety was optimized using a PAR intensity of 438 μmol m^{-2} s^{-1} as the reduction in the LA did not hinder growth. On the contrary, it provided a higher TDM and a better H:S value.

The better distribution of biomass indirectly indicates the optimization of the photosynthetic apparatus through the application of PAR as commented earlier. This was possible due to the increase in the liquid photosynthesis rate through the use of LED lamps, as they provided an increase in the luminous intensity with quality; thus, there was an optimization of the photochemical phase of photosynthesis, which could be supported by the results verified by Gao et al. (2020). Moreover, the air conditions of the greenhouse that were favorable for stomatal opening, ensuring the supply of CO_2, and the lower rate of photorespiration and respiration due to the reduced substrate and leaf temperature resulted in an increase in the liquid photosynthetic rate. Thus, as a reflex, there was an increase in the biomass of basil seedlings and a consequent better distribution of the biomass in the plant as measured in this study. The reduction in the ratio between SH and SD indicates greater stem strength, which reduces tipping after transplanting (Medeiros et al., 2018). As provided by the results presented here, the aforementioned changes can be obtained by subjecting basil seedlings to the extended photoperiod with PAR intensity from 411 μmol m^{-2} s^{-1}. This consequently improves the distribution of dry matter in the seedlings produced in this condition, with supplementary PAR as an extended photoperiod (Table 3). These results demonstrate that although it affects leaf expansion, the use of PAR promotes enhanced biometric indices in basil seedlings, which may have been offset by the increase in the rate of liquid photosynthesis as approached earlier, promoting greater robustness in the seedlings produced.

High-quality seedlings could be quantified through the DQI (some biometric growth assessments are used to classify the quality), where the higher the value, the greater guarantee of seedling vigor (Fonseca, Valéri, Miglioranza, Fonseca, & Couto, 2002). In this study, DQI values above 0.05 were obtained, regardless of the basil variety, using PAR intensities of 411 and 438 μmol m^{-2} s^{-1} as extended photoperiods (Table 3). Thus, the adequacy of PAR could promote an increase in the quality of basil seedlings as the DQI increased.

It is necessary to highlight that the positive results of PAR used in this study are attributed to the light system adopted, which provides different wavelengths. Silva et al. (2016) studied the use of PAR in the production of cucumber seedlings and found improvement in the DQI with the use of blue and red wavelengths, using LED lamps, when compared to the seedlings produced using white fluorescent lamps.

PAR has been focused on photosynthesis (Pazuki, Aflaki, Pessarakli, Gurel, & Gurel, 2017). Here, we showed the effects of PAR on the biometrics index, which demonstrated that PAR promoted morphological changes (Table 2) that resulted in an increase in the seed quality of the basil seedlings (Table 3).

The morphophysiological behavior of the plant has a direct influence on the genotype (genetic characteristics), which could be influenced by the environment, especially solar radiation. Thus, using LEDs as an artificial source of light makes it possible to provide specific wavelengths, thus changing the spectral balance of the cultivation environment. This then influences the plant photomorphogenesis and the photochemical phase of photosynthesis, leading to changes in the pattern of growth and development of the plant, which could be exploited in a beneficial way in the production of seedlings. Consequently, high-quality seedlings could be produced in relation to the distribution of dry phytomass in the different plant organs, ensuring improved biometric growth rates as shown in this study, allowing better survival after transplantation. However, the technology has to be improved for each species and cultivar used.

Conclusion

Increase in the intensity of PAR from 411 μmol m^{-2} s^{-1} used as an extended photoperiod in a greenhouse provides a better ratio between SH and SD, adequate dry matter distribution, and quality of sweet and purple basil seedlings. Specifically, the purple basil variety must be cultivated in a greenhouse with a PAR intensity of 438 μmol m^{-2} s^{-1} to promote better seedling quality.

Acknowledgements

The authors would like to thank the *Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado do Mato Grosso do Sul* (FUNDECT-Brazil) for their financial support (FUNDECT/CNPq/PRONEM - MS, process 59/300.116/2015 - number FUNDECT 080/2015) and the *Programa Institucional de Bolsas aos Alunos de Pós Graduação* (PIBAP-Brazil) of the State University of Mato Grosso do Sul.

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