Scientia Agraria Paranaensis – Sci. Agrar. Parana.
ISSN: 1983-1471 - Online
http://dx.doi.org/10.18188/1983-1471/sap.v15n4p446-452

LIGHT SPECTRAL QUALITY ON PRODUCTION OF LETTUCE, CUCUMBER AND SWEET PEPPER SEEDLINGS

Eliamara Marques da Silva[1]; Geany Giovana Silva da Costa[1]; Agner Freitas Andrade[1]; Hellen Cristina Pereira Ferreira[1]; Fábio Steiner[1]*

SAP 13415 Data envio: 10/01/2016 Data do aceite: 14/04/2016
Sci. Agrar. Parana., Marechal Cândido Rondon, v. 15, n. 4, out./dez., p. 446-452, 2016

ABSTRACT - The response of lettuce (*Lactuca sativa*), cucumber (*Cucumis sativus*) and sweet pepper (*Capsicum annuum*) seedlings to light spectral quality when grown under continuous illumination was investigated in relation to the growth, dry matter, and seedling quality index. Different light quality treatments were applied during the germination and plant growth steps, using cool-white fluorescent bulbs (CWF) or red and blue light-emitting diodes (LEDs) at an fluence of 30 and 25 µmol m^{-2} s^{-1} photosynthetic photon flux density (PPFD), respectively. Treatments were arranged in a completely randomized design in a 3×2 factorial: three vegetable species (lettuce, cucumber and sweet pepper) and two light quality treatments (white fluorescent light or red and blue LEDs), with four replications. Results showed that the vegetables had distinct growth responses to different light-quality treatments. Number of leaves was significantly greater under blue and red LEDs light compared to the CWF lighting, for the three vegetable species. Shoot length and root collar diameter of lettuce and sweet pepper were significantly greater under blue and red LEDs light compared to the CWF light, while cucumber seedlings showed no significant differences. Root length, root dry matter and Dickson quality index (DQI) of the cucumber seedlings was significantly greater under blue and red LEDs light compared to the CWF light, while lettuce and sweet pepper seedlings showed no significant differences. Shoot dry matter (SDM) and total dry matter (TDM) of the lettuce and cucumber seedlings were greater when grown under blue and red LEDs light. The lighting with blue and red wavelengths from LEDs resulted in better quality cucumber seedlings compared to the cool-white fluorescent light. The shoot growth rate of lettuce seedlings was favored by blue and red LEDs light. Different spectral qualities have little effect on growth and development of sweet pepper seedlings.
Key words: *Capsicum annuum*, *Cucumis sativus*, *Lactuca sativa*, LEDs, seedling quality.

PRODUÇÃO DE MUDAS DE ALFACE, PEPINO E PIMENTÃO EM FUNÇÃO DA QUALIDADE DO ESPECTRO LUMINOSO

RESUMO - A resposta de mudas de alface, pepino e pimentão à qualidade do espectro luminoso em condições de iluminação contínua foi investigada em relação ao crescimento da planta, produção de matéria seca e índices de qualidade das mudas. Os diferentes tratamentos de qualidade de luz foram aplicados durante as etapas de germinação e crescimento de mudas, utilizando lâmpadas fluorescentes brancas ou diodos emissores de luz (LEDs) vermelha e azul à uma fluência de 30 e 25 µmol m^{-2} s^{-1} de densidade de fluxo de fótons fotossintéticos, respectivamente. Os tratamentos foram dispostos em um delineamento experimental inteiramente casualizado em esquema fatorial 3×2: três espécies de hortaliça (alface, pepino e pimenta doce) e dois tratamentos de qualidade de luz (luz fluorescente branca ou LEDs vermelha e azul), com quatro repetições. Os resultados mostraram que as hortaliças possuem distintas respostas de crescimento para os diferentes tratamentos de qualidade de luz. O número de folhas foi significativamente maior sob luz de LEDs azul e vermelha em comparação com a luz fluorescente branca, para as três espécies de hortaliças. O comprimento da parte aérea e o diâmetro do coleto das mudas de alface e pimentão foram significativamente maiores sob luz de LEDs azul e vermelha em comparação à luz fluorescente branca, enquanto as mudas de pepino não apresentaram diferenças significativas. O comprimento das raízes, a matéria seca de raízes e o índice de qualidade de Dickson (IQD) das mudas de pepino foram significativamente maiores sob luz de LEDs azul e vermelha, enquanto as mudas de alface e pimentão não foram afetadas significativamente. A matéria seca da parte aérea (MSPA) e a matéria seca total (MST) das mudas de alface e pepino foram maiores quando cultivada sob luz de LEDs azul e vermelha. A iluminação com comprimentos de onda azul e vermelha com LEDs resultou em mudas de pepino de melhor qualidade em comparação com a luz fluorescente branco fria. O crescimento da parte aérea das mudas de alface foi favorecido pela luz de LEDs azul e vermelha. As diferentes qualidades do espectro luminoso têm pouco efeito no crescimento e no desenvolvimento de mudas de pimentão.
Palavras-chave: *Capsicum annuum*, *Cucumis sativus*, *Lactuca sativa*, LEDs, qualidade de mudas.

[1]Universidade Estadual de Mato Grosso do Sul, UEMS, Unidade Universitária de Cassilândia, Rodovia MS 306, km 6,4, CEP 79540-000, Cassilândia, Mato Grosso do Sul, Brasil. E-mail: steiner@uems.br. *Corresponding author

INTRODUCTION

The quality of seedlings used is a major factor that determines the success of vegetable production. The survival of seedlings, growth performance, length of production period, and yield and quality of vegetables produced are greatly influenced by the quality of seedlings transplanted (SOUZA et al., 2008; MEDEIROS et al., 2008). Thus, the seedling production step can be considered as one of the most important stages in the cultivation of vegetables.

One variable that has been shown to affect plant growth and seedling quality is light spectral quality. Light is an essential environmental factor in the growth and development of plants. It has been proven that plants exhibit a high degree of physiological, morphological and anatomical plasticity to changes in spectral quality (HOSSEN, 2007). Plant leaves have highly absorb light in the blue and red regions of the spectrum, high reflectance in the green and far-red regions and high transmittance in the far-red region (LARCHER, 2000). The red and blue wavelengths correspond to the absorption peak of chlorophyll a (660 nm) and chlorophyll b (460 nm) (TAIZ; ZEIGER, 2010).

Plant cultivation experiments are using light-emitting diodes (LEDs), which are potential light sources for fully controlled plant production factories (TAMULAITIS et al., 2005; HOSSEN, 2007; JOHKAN et al., 2010). The use of light-emitting diodes (LEDs) as a radiation source for plants has attracted considerable interest in recent years because of its high potential for commercial application (HOSSEN, 2007; MASSA et al., 2008; JOHKAN et al., 2010; HOGEWONING et al., 2010; JOHKAN et al., 2012; LI et al., 2013; KOKSAL et al., 2015). The LEDs have features which are better than the commonly used radiation source-fluorescent, metal halide, high pressure sodium and incandescent lamps. The most attractive features of LEDs are small mass, volume, low energy consumption, solid state construction and long lifetime (BROWN et al., 1995).

Previous studies showed that the combination of red and blue light was an effective light source for several crops. Matsuda et al. (2004) found that rice plants grown under a combination of red (660 nm) and blue (470 nm) LEDs sustained higher leaf photosynthetic rates than did leaves from plants grown under red LEDs only. This result was due to higher nitrogen content of the blue light-supplemented plants. Similarly, strawberry plantlets had a higher growth in 70% red + 30% blue LEDs (NHUT et al., 2003). It is known that red light is important for shoot/stem elongation, phytochrome responses, photosynthesis and changes in plant anatomy (SCHUERGER et al., 1997). In contrast, blue light is important in chlorophyll biosynthesis (SCHUERGER et al., 1997), stomatal opening, phototropism, maturation of chloroplasts, and for inhibition of hypocotyl elongation, and plant gene activation, among others (TAIZ; ZEIGER, 2010). However, the spectral light changes evoke different morphogenetic and photosynthetic responses that can vary among different vegetables species.

This research was carried out to investigate the effects of light spectral quality on the production of lettuce (*Lactuca sativa* L.), cucumber (*Cucumis sativus* L.) and sweet pepper (*Capsicum annuum* L.) seedlings grown under continuous illumination. The hypothesis is that seedlings would grow best and faster when provided red and blue LEDs lighting than a plant grown under white fluorescent light.

MATERIAL AND METHODS

Plant material, growth conditions and light treatments

Seeds of lettuce (*Lactuca sativa* L., cv. Quatro Estações), cucumber (*Cucumis sativus* L., cv. Aodai) and sweet pepper (*Capsicum annuum* L., cv. Rubi Gigante) were planted in 128-cell expanded polystyrene trays filled with substrate composed from 30% cattle manure, 30% soil, 20% sand, and 20% vermiculite. Two seeds were sown per cell, and three days after emergence, they were thinned to one seedling per cell. Seedlings were grown in two plant growth chambers under continuous illumination: one chamber provided light from cool white fluorescent bulbs at an fluence of 30 ± 2 μmol m^{-2} s^{-1} photosynthetic photon flux density (PPFD) and the other chamber provided red (620-630 nm) and blue (455-475 nm) wavelengths at the ratio of 90% (red) and 10% (blue) from light-emitting diodes (LEDs) at an fluence of 28 ± 2 μmol m^{-2} s^{-1} PPFD. Temperature in both chambers was maintained at 24 ºC (± 2 ºC) during all period. The treatments were arranged in a completely randomized design in a factorial 3×2: three vegetable species (lettuce, cucumber and sweet pepper) and two light quality treatments (white fluorescent light or blue and red lights), with four replications of ten seedlings.

Measurements of plant growth and quality indices

All vegetable species were evaluated at 21 days after plant emergence. Seedlings in all treatments were removed from the trays and washed with water to remove substrate adhered to the roots. Posteriorly, the seedlings were separated into roots and shoots, dried in a forced air circulation oven for three days at 65 ºC, and then weighed. The results of shoot dry matter (SDM) and root dry matter (RDM) were expressed in grams per seedling. The shoot length (SL, in cm) and root length (RL, in cm) were measured using meter scale (cm). Collar diameter (CD, in mm) was measured by using a digital caliper with accuracy of 0.01 mm. From these measurements were calculated total dry matter (TDM), shoot:root dry matter ratio [SRR; shoot dry matter (g)/root dry matter (g)], sturdiness quotient [SQ; shoot length (cm)/collar diameter (mm)] and Dickson Quality Index [DQI = TDM/(SRR + SQ] (DICKSON et al., 1960).

Statistical analyses

The normality of data was previously tested by the Kolmogorov-Smirnov test and then data were submitted to analysis of variance (ANOVA), and means of treatments were compared by the Tukey test at the 0.95 level of confidence. All analyses were performed using Sisvar version 5.3 software for Windows (Statistical

Analysis Software, UFLA, Lavras, MG, BRA) (FERREIRA, 2011).

RESULTS AND DISCUSSION

A summary of the analysis of variance for the measurements of initial seedling growth and seedling quality of vegetables is shown in Table 1. Analysis of variance showed that the interaction effects between vegetable species and light spectral quality were significant ($p<0.05$) for all investigated traits except number of leaves and sturdiness quotient (Table 1). This significant interaction between the main effects of vegetables and lighting quality for most of the evaluated characteristics indicates that plant species have different behavior with regard to the quality of the light spectrum.

TABLE 1. Summary of the analysis of variance for the measurements of plant growth and seedling quality of vegetables.

Causes of variation	Probability > F									
	NLP	SL	RCD	RL	SDM	RDM	TDM	SRR	SQ	DQI
Species (S)	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	0.081	<0.000
Light (L)	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	0.506	0.125	0.002
S x L	0.189	0.001	0.008	0.007	0.011	0.007	0.005	0.011	0.332	0.014
C.V. (%)	4.35	5.82	5.95	6.77	6.97	10.98	6.08	14.98	7.79	9.80

NLP: number of leaves per plant; SL: shoot length; RCD: root collar diameter; RL: root length; SDM: shoot dry matter; RDM: root dry matter; TDM: total dry matter; SSR: shoot:root dry matter ratio; SQ: sturdiness quotient (shoot length/root collar diameter); DQI: Dickson quality index.

Effect of light quality on growth of vegetable seedlings

The vegetables showed distinct growth responses to different light-quality treatments (Figures 1 and 2). Number of leaves for the three species of vegetables were higher when grown under blue and red LEDs light (Figure 1A). The increase in the number of leaves per seedling of lettuce, cucumber, and sweet pepper was 39%, 17% and 23% with the blue and red wavelengths from LEDs compared to the lighting with cool-white fluorescent (CWF) bulbs. This increase in new leaf emission rate suggests that the development of the seedlings was favored by blue and red LED lighting. Koksal et al. (2015) also found that the number of leaves of pansy (*Viola cornuta*) was increased by supplemental red and orange LEDs lighting (40 µmol m^{-2} s^{-1} PPFD) compared to the control, at the rate of 47%. However, Johkan et al. (2010) reported that lighting with blue and red LEDs and white fluorescent light did not influence the number of lettuce leaves at 17 (mean of three leaves per plant) and 45 days (mean of 17 leaves per plant).

The shoot length of lettuce and sweet pepper seedlings were significantly greater under blue and red LEDs light compared to the CWF light, while cucumber seedlings showed no significant differences (Figure 1B). The general rule is that light causes the developing seedling to cease rapid elongation and adopt a strategy of shoot growth appropriate for the light environment. Exposure to only red LED light resulted in both plant elongation and reduced dry matter production of lettuce (HOENECKE et al., 1992). Blue LED light is important for leaf expansion and enhances the leaf area and dry matter production (HOGEWONING et al., 2010; JOHKAN et al., 2012). Bantis et al. (2016) showed that the treatments with high red:far-red ratio induced the lowest growth rate resulting in the formation of the shortest shoots of two sweet basil cultivars (*Ocimum basilicum*). The greatest growth of the shoots under blue and red LEDs light compared to white fluorescent light has been reported for different vegetable species such as lettuce (KIM et al., 2004; JOHKAN et al., 2010; LIN et al., 2013), pepper (SCHUERGER et al., 1997), cucumber (BRAZAITYTE et al., 2009), tomato (BRAZAITYTE et al., 2010), and rapeseed (LI et al., 2013).

Root collar diameter of the lettuce and sweet pepper seedlings were significantly greater under blue and red LEDs light compared to the CWF light, while cucumber seedlings showed no significant differences (Figure 1C). The increase in root collar diameter is important for providing greater robustness to the seedlings. Root collar diameter has been appointed as the best and most practical characteristics for classification and identification of high quality seedlings, and therefore can be considered a good predictor of outplanting survival. Ivetić et al. (2013) reported that collar diameter was the most important grading characteristic, followed by root volume and shoot height.

Root length of the cucumber was significantly greater under blue and red LEDs light (20.0 cm) compared to the CWF light (14.2 cm), while lettuce and sweet pepper seedlings showed no significant differences (Figure 1D). Root length of cucumber was increased at 41% under blue and red LEDs lighting compared to the CWF lighting (Figure 1D). Positive response in the root growth of plants grown under blue and red LED light compared to the white fluorescent light has been reported in lettuce (KIM et al., 2004; JOHKAN et al., 2010), pepper (SCHUERGER et al., 1997), and sweet basil (BANTIS et al., 2016). However, Lin et al. (2013) reported that lighting with blue and red LEDs and white fluorescent light did not influence the growth of lettuce roots, at 35 days after sowing.

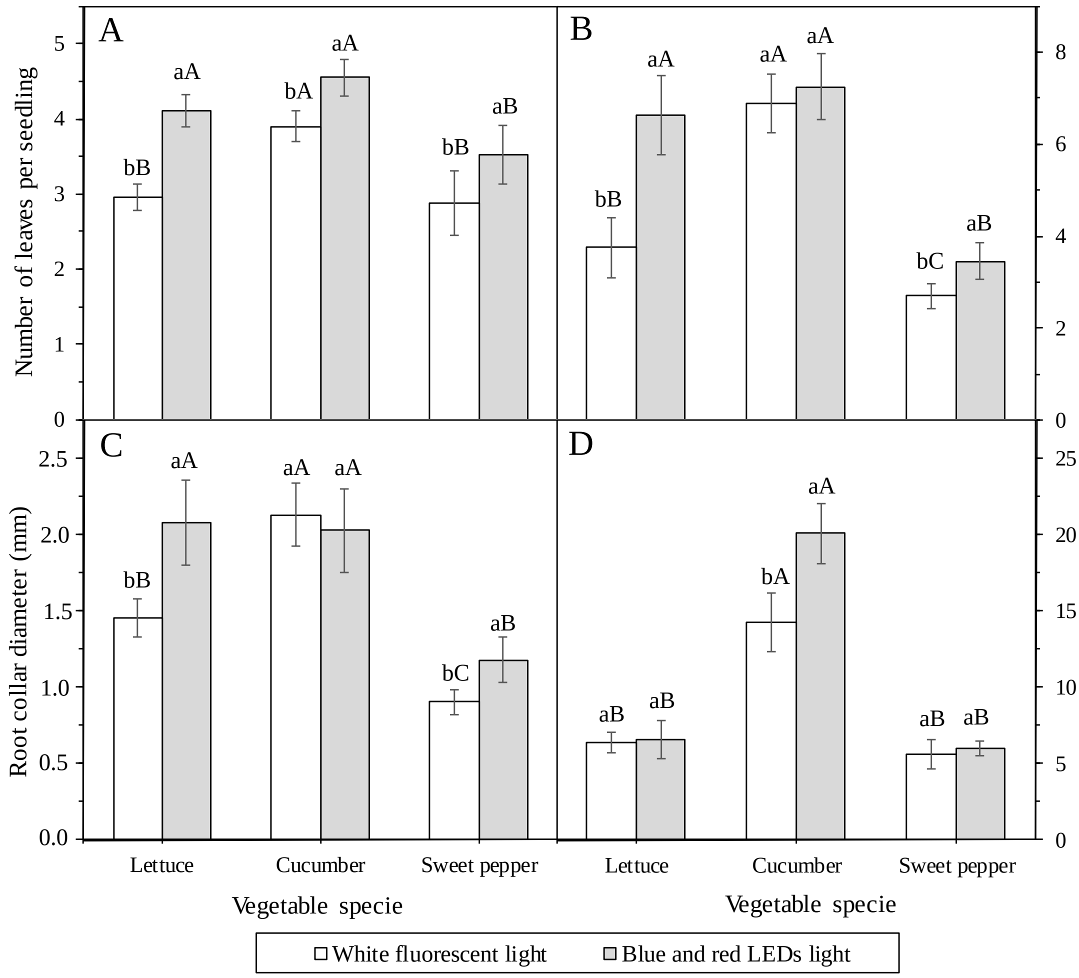

FIGURE 1 - Effects of light spectral quality on number of leaves (A), shoot length (B), root collar diameter (C), and root length (B) of different vegetable species. Bars followed by the same lower case letters, for the light quality or same upper case letters, between the vegetable species are not significantly different by Tukey test at the 0.05 level of confidence. Data refer to mean values (n = 4) ± standard error.

Shoot dry matter (SDM) of the lettuce and cucumber seedlings were greater when grown under blue and red LEDs light (Figure 2A). The SDM of lettuce and cucumber seedlings significantly increased at 125% and 29% with the blue and red wavelengths from LEDs compared to the CWF light. As for the SDM, seedlings grown under blue and red LEDs light exhibited greater values of total dry matter. The TDM of lettuce and cucumber seedlings were significantly increased at 82% and 34% with the blue and red wavelengths from LEDs compared to the CWF light, respectively (Figure 2C). In turn, the SDM, RDM and TDM of sweet pepper seedlings were not significantly affected by different spectral qualities (Figures 2A, 2B and 2C).

Studies over the last decade have described distinct responses to spectral quality of light incident on the plants. Yorio et al. (2001) reported that there was higher SDM accumulation in lettuce grown under blue and red LEDs light than in lettuce grown under red LEDs light alone. Kim et al. (2004) showed that when photosynthetic photon flux density (PPFD) is kept constant, the lettuce grown in a combination of red, blue, and green LED light had larger leaf area and higher SDM than those grown exclusively under red or blue alone. According to the authors the interpretation for this result is that although red and blue light are more effective for promoting photosynthesis, green light might penetrate plant leaves more efficiently and increase carbon fixation (KIM et al., 2004; TERASHIMA et al., 2009). However, different results were reported by Dougher and Bugbee (2001), who found that the TDM of lettuce was greater when grown under blue and red light (0% yellow light) compared to those grown in light from white fluorescent lamps (17% yellow light). Lin et al. (2013) showed that the SDM of lettuce plants were the greatest when grown under blue, red and white LEDs light, and lowest under lighting of blue and red LEDs and fluorescent lamps. In turn, the SDM of lettuce plants irradiated with blue LED light decreased compared with that of white LED light (OHASHI-KANEKO et al., 2007). Kim et al. (2004) argue that this discrepancy might result from the different cultivars and species used, as well as the differences in the quality and quantity of lights used. Although the LED light sources show some promising results, there are still variations among the different species.

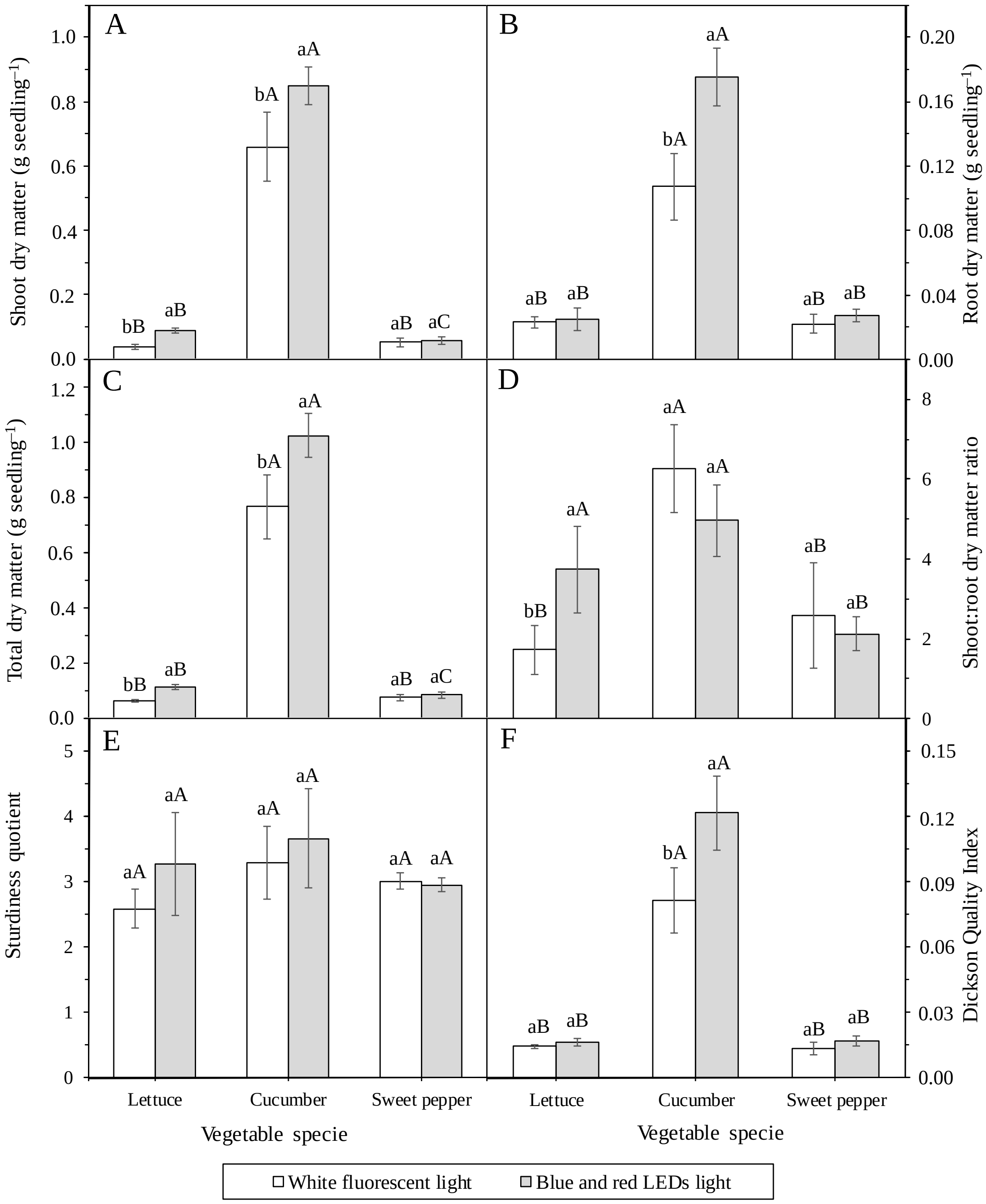

FIGURE 2 - Effects of light spectral quality on shoot dry matter (A), root dry matter (B), total dry matter (C), shoot:root dry matter ratio (D), sturdiness quotient (E) and Dickson quality index (F) of different vegetable species. Bars followed by the same lower case letters, for the light quality or same upper case letters, between the vegetable species are not significantly different by Tukey test at the 0.05 level of confidence. Data refer to mean values (n = 4) ± standard error.

The light quality treatments significantly affected the root dry matter (RDM) of cucumber, while the RDM of lettuce and sweet pepper were not significantly affected by different spectral qualities (Figure 2B). The RDM of cucumber seedlings were increased at 64% with the blue and red LEDs lighting compared to the CWF lighting (Figure 2B). In general, effects of light spectrum quality in the production of RDM are still very contradictory and inconclusive. Koksal et al. (2015) found that the RDM of pansy plants grown under supplemental red and orange LEDs lighting were increased at 52% when compared to those ones grown without supplemental light. In turn, Lin et al. (2013) reported that the RDM of lettuce plants were not affected by lighting of blue and red LEDs and fluorescent lamps.

Shoot:root dry matter ratio (SRR) of the lettuce was significantly greater under blue and red LEDs light (3.74) compared to the CWF light (1.72), while cucumber and sweet pepper seedlings showed no significant differences (Figure 2D). These results indicate that there was a lower photoassimilate partition from shoot to the roots of lettuce seedlings grown under blue and red LEDs lighting. Bantis et al. (2016) showed that shoot:root ratio of sweet basil plants was favored under LED light with high blue and green, high red:far-red and 1% ultraviolet, whereas the fluorescent tubes had the lowest impact.

Different spectral qualities not significantly affect (P = 0.125) the sturdiness quotient (shoot length/collar diameter ratio) for the three vegetable species (Figure 2E). The sturdiness quotient of seedlings ranged from 2.60 to 3.65. In general, studies on production of nursery seedlings indicate that a high quality seedling should have a value of sturdiness quotient ranging from 2.5 to 3.5, and a sturdiness quotient greater than 4.0 can be indicative of etiolating of seedlings.

The lighting with blue and red wavelengths from LEDs resulted in high quality cucumber seedlings, as reported by the higher value of the Dickson quality index (DQI = 0.12) (Figure 2F). The DQI is considered a promising integrated measure of morphological traits (JOHNSON; CLINE, 1991) and thought to be a good indicator of seedling quality as its calculation computes robustness and dry matter partitioning while considering several important parameters, such as height, diameter and dry matter (FONSECA et al., 2002). The higher value of DQI, the higher the seedling quality and they are more vigorous when they are transplanted in the field. A value greater than or equal to 0.10 for the DQI has been cited to identify seedlings of high quality vegetables (MELLO et al., 2016).

CONCLUSIONS

The lighting with blue and red wavelengths from LEDs resulted in better quality cucumber seedlings compared to the cool-white fluorescent light.

The shoot growth rate of lettuce seedlings was favored by blue and red LEDs light.

Different spectral qualities have little effect on growth and development of sweet pepper seedlings.

REFERENCES

BANTIS, F.; OUZOUNIS, T.; RADOGLOU, K. Artificial LED lighting enhances growth characteristics and total phenolic content of *Ocimum basilicum*, but variably affects transplant success. **Scientia Horticulturae**, v.198, n.1, p.277-283, 2016.

BRAZAITYTE, A.; DUCHOVSKIS, P.; URBONAVICIUTE, A.; SAMUOLIENE, G.; JANKAUSKIENE, J.; KASIULEVICIUTE, B.; BLIZNIKAS, Z.; NOVICKOVAS, A.; BREIVE, K.; ZUKAUSKAS, A. The effect of light-emitting diodes lighting on cucumber transplants and after-effect on yield. **Zemdirbyste-Agriculture**, v.96, n.3, p.102-118, 2009.

BRAZAITYTE, A.; DUCHOVSKIS, P.; URBONAVICIUTE, A.; SAMUOLIENE, G.; JANKAUSKIENE, J.; SAKALAUSKAITE, J.; SABAJEVIENE, G.; SIRTAUTAS, R.; NOVICKOVAS, A. The effect of light-emitting diodes lighting on the growth of tomato transplants. **Zemdirbyste-Agriculture**, v.97, n.2, p.89-98, 2010.

BROWN, C.S.; SCHUERGER, A.C.; SAGER, J.C. Growth and photomorphogenesis of pepper plants under red light-emitting diodes with supplemental blue or far-red lighting. **Journal of the American Society for Horticultural Science**, v.120, n.5, p.808-813, 1995.

DICKSON, A.; LEAF, A.L.; HOSNER, J.F. Quality appraisal of white spruce and white pine seedling stock in nurseries. **Forest Chronicle**, v.36, n.1, p.10-13, 1960.

DOUGHER T.A.O.; BUGBEE, B. Evidence for yellow light suppression of lettuce growth. **Photochemistry and Photobiology**, v.73, n.2, p.208-212, 2001.

FERREIRA, D.F. Sisvar: a computer statistical analysis system. **Ciência e Agrotecnologia**, v.35, n.6, p.1039-1042, 2011.

FONSECA, É.P.; VALÉRI, S.V.; MIGLIORANZA, É.; FONSECA, N.A.N.; COUTO, L. Padrão de qualidade de mudas de *Trema micrantha* (L.) Blume, produzidas sob diferentes períodos de sombreamento. **Revista Árvore**, v.26, n.4, p.515-523, 2002.

HOENECKE, M.E.; BULA, R.J.; TIBBITTS, T.W. Importance of ‘‘Blue’’ photon levels for lettuce seedlings grown under red light-emitting diodes. **HortScience**, v.25, n.5, p.427-430, 1992.

HOGEWONING, S.W.; TROUWBORST, G.; MALJAARS, H.; POORTER, H.; VAN-IEPEREN, W.; HARBIN-SON, J. 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**, v.61, n.11, p.3107-3117, 2010.

HOSSEN, Z. Light emitting diodes increase phenolics of buckwheat (*Fagopyrum esculentum*) sprouts. **Journal of Plant Interactions**, v.2, n.1, p.71-78, 2007.

IVETIĆ, V.; DAVORIJA, Z.; VILOTIĆ, D. Relationship between morphological and physiological at - tributes of hop hornbeam seedlings. **Bulletin of the Faculty of Forestry**, v.108, n.1, p.39-50, 2013.

JOHKAN, M.; SHOJI, K.; GOTO, F.; HASHIDA, S.; YOSHIHARA, T. Blue light-emitting diode light irradiation of seedlings improves seedling quality and growth after transplanting in red leaf lettuce. **HortScience**, v.45, n.12, p.1809-1814, 2010.

JOHKAN, M.; SHOJI, K.; GOTO, F.; HAHIDA, S.; YOSHIHARA, T. Effect of green light wavelength and intensity on photomorphogenesis and photosynthesis in *Lactuca sativa*. **Environmental and Experimental Botany**, v.75, n.1, p.128-133, 2012.

JOHNSON, J.D.; CLINE, M.L. Seedling quality of Southern pines. In: DURYEA, M.L.; DOUGHERTY, P.M. (Eds.). **Forest regeneration manual**. Netherlands: Klumer Academic, 1991. p.143-162.

KIM, H.H.; GOINS, G.D.; WHEELER, R.M.; SAGER, J.C. Green-light supplementation for enhanced lettuce growth under red- and blue-light-emitting diodes. **HortScience**, v.39, n.7, p.1617-1622, 2004.

KOKSAL, N.; INCESU, M.; TEKE, A. Supplemental LED lighting increases pansy growth. **Horticultura Brasileira**, v.33, n.4, p.428-433, 2015.

LARCHER, W. **Ecofisiologia vegetal**. São Carlos: Rima, 2000. 531p.

LI, H.; TANG, C.; XU, Z. The effects of different light qualities on rapeseed (*Brassica napus* L.) plantlet growth and morphogenesis in vitro. **Scientia Horticulturae**, v.150, n.2, p.117-124, 2013.

LIN, K.H.; HUANG, M.Y.; HUANG, W.D.; HSU, M.H.; YANG, Z.W.; YANG, C.M. The effects of red, blue, and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (*Lactuca sativa* L. var. *capitata*). **Scientia Horticulturae**, v.150, n.1, p.86-91, 2013.

MASSA, G.D.; KIM, H.H.; WHEELER, R.M.; MITCHELL, C.A. Plant productivity in response to LED lighting. **HortScience**, v.43, n.7, p.1951-1956, 2008.

MATSUDA, R.; OHASHI-KANEKO, K.; FUJIWARA, K.; GOTO, E.; KURATA, K. Photosynthetic characteristics of rice leaves grown under red light with or without supplemental blue light. **Plant and Cell Physiology**, v.45, n.12, p.1870-1874, 2004.

MEDEIROS, D.C.; FREITAS, K.C.S.; VERAS, F.S.; ANJOS, R.S.B.; BORGES, R.D.; CAVALCANTE-NETO, J.G.; NUNES, G.H.S.; FERREIRA, H.A. Qualidade de mudas de alface em função de substratos com e sem biofertilizante. **Horticultura Brasileira**, v.26, n.2, p.186-189, 2008.

MELLO, B.F.F.R.; TREVISAN, M.V.; STEINER, F. Quality of cucumber seedlings grown in different containers. **Revista de Agricultura Neotropical**. v.3, 2016. (no prelo).

NHUT, D.T.; TAKAMURA, T.; WATANABE, H.; OKAMOTO, K.; TANAKA, M. Responses of strawberry plantlets cultured *in vitro* under super bright red and blue light-emitting diodes (LEDs). **Plant Cell, Tissue and Organ Culture**, v.73, n.1, p.43-52, 2003.

OHASHI-KANEKO, K.; TAKASE, M.; KON, N.; FUJIWARA, K.; KURATA, K. Effect of light quality on growth and vegetable quality in leaf lettuce, spinach and komatsuna. **Environmental Control in Biology**, v.45, n.3, p.189-198, 2007.

SCHUERGER, A.C.; BROWN, C.; STRYJEWSKI, E.C. Anatomical features of pepper plants (*Capsicum annuum* L.) grown under light-emitting diodes supplemented with blue or far-red light. **Annals of Botany**, v.79, n.3, p.273-282, 1997.

SOUZA, S.R.; FONTINELE, Y.R.; SALDANHA, C.S.; ARAÚJO-NETO, S.E.; KUSDRA, J.F. Produção de mudas de alface com o uso de substrato preparado com coprólitos de minhoca. **Ciência e Agrotecnologia**, v.32, n.1, p.115-121, 2008.

TAIZ, L.; ZEIGER, E. **Plant physiology**. 5th ed. Sunderland: Sinauer Associates, 2010. 781p.

TAMULAITIS, G.; DUCHOVSKIS, P.; BLIZNIKAS, Z.; BREIVE, K.; ULINSKAITE, R.; BRAZAITYTE, A.; NOVICKOVAS, A.; ZUKAUSKAS, A. High-power light-emitting diode based facility for plant cultivation. **Journal of Physics D: Applied Physics**, v.38, n.17, p.3182-3187, 2005.

TERASHIMA, I.; FUJITA, T.; INOUE, T.; CHOW, W.S.; OGUCHI, R. Green light drives leaf photosynthesis more efficiently than red light in strong white light: Revisiting the enigmatic question of why leaves are green. **Plant and Cell Physiology**, v.50, n.4, p.684-697, 2009.

YORIO, N.C.; GOINS, G.D.; KAGIE, H.R.; WHEELER, R.M.; SAGER, J.C. Improving spinach, radish, and lettuce growth under red light-emitting diodes (LEDs) with blue light supplementation. **Horticultural Science**, v.36, n.2, p.380-383, 2001.