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# The quantitative effects of different light sources on the growth parameters of pepper seedlings

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**ABSTRACT**

In this research, the effects that three different light sources: a high pressure sodium lamp (HPS), an incandescent lamp (IL), a light emitting diode (LED) and two different colors (red and blue), have on the pepper seedling quality were determined in detail. The effects of light sources and colors on growth and quantitative characteristics of pepper seedlings were analyzed including the following: height of seedling, diameter of seedling, dry weights for root, stem and leaves, leaf weight ratio, stem weight ratio, root weight ratio, leaf area, leaf thickness, leaf area ratio and specific leaf area. According to the results obtained, it was seen that the effect of light sources and their colors on the growth and quantitative characteristics of pepper seedlings were different depending on the growing periods of autumn and spring. Light source treatments increased some characteristics, such as stem diameter and stem weight ratio. Under blue LED light conditions, the seedlings root, stem and leaf dry weights were much better compared to seedlings treated with other light sources. It has been determined that blue light sources, in particular, are more effective on the leaf area ratio in the autumn period. Blue LED lamps increased the leaf area in both periods, while the lowest leaf area value was found under the blue color of an IL light source in both periods. This study showed that pepper seedling growth is light limited during the spring period, and artificial LED lighting can significantly increase plant growth.

## INTRODUCTION

Pepper (*Capsicum* sp.) is one of the most varied and widely used foods in the world. All peppers are members of the Solanaceae family, which also includes tomato, tobacco and the eggplant. From the various colors to the various tastes, peppers are an important spice commodity and an integral part of many cuisines. In recent years, pepper production has increased worldwide. That could be at least in part because of the high nutritional value of peppers (Kelley and Boyhan 2009).

The plant development consists of different phases: seed sowing, planting seedlings, the period until the first blossoming, the rate of blossoming, the number of leaves, the process of plant growth and the time to harvesting (Uzun 1997). Seeding pepper directly into a field is not recommended due to the high cost of hybrid seed and the specific conditions required for adequate germination (Kandemir 2005). Most pepper is transplanted to the field from greenhouse-grown plants. Pepper transplant production is usually done in a protected structure such as a greenhouse. Significantly higher or lower temperatures can have negative effects on seedling quality. During the growth of plants, the required sources of light are provided by either the sun or by artificial lights (Kim et al. 2004). Low temperature and low light intensity can cause excessive prolongation of seedlings during winter and spring periods, and quality losses are increased when growing seedlings. For this reason, the use of artificial lighting is necessary to promote plant growth (Chia and Kubota 2010; Demirsoy et al. 2016). It has been reported that lighting applied at different wavelengths significantly affects the morphological characteristics of the seedlings, such as leaf area, fresh shoot weight and dry root weight (Demir and Çakırer 2015).

Plant development and physiology are strongly influenced by the light spectrum of the

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growth environment. Light is significantly effective for all life events in the process starting from seed germination until the death of the plant. It is also one of the major environmental limitations to optimal growth and development of seedlings. Crop yield can be characterized as a function of an organism's: 1) adaptation to its suitable, forming a leaf canopy that is able to intercept the environment; 2) ability to effectively harvest light with its photosynthetic apparatus and 3) ability to partition and translocate photosynthates economically to the organs (Balkaya et al. 2004).

The artificial light sources are used for both the seedling production and the different periods of plant cultivation when natural lighting is not sufficient. Artificial lighting for leafy vegetables in greenhouses first started in Japan in the 1980s. At the beginning of the 2000s, it began to be used in the production of fruit and vegetable seedlings (Goto 2012). Recent innovations in inexpensive lighting systems have increased interest in their use in greenhouse cultivation (Köksal et al. 2015). HPS lamps have high electrical efficiencies, a long operating life and a wide spectrum of light that is suitable for many plant species. However, the spectrum of these lamps has a low amount of blue light (Wheeler 2008; Brazaitytė et al. 2010). Nowadays, the HPS lamp, which is the closest to the spectrum of sunlight is the most widely used light source in crop cultivation, but LED lamps have begun to be used recently, more so because the light wavelength may be applied more easily under low temperature and bright light conditions (Deram 2013). The usage and duration of artificial lights depend on the light requirements of the species, the natural day length, the average sunshine duration, the angle of the sun, and the amount of structure-borne shading (Demirsoy 2016).

In published literature, it has been reported that the color of light has different effects on plants (Demirsoy 2016; Singh et al. 2015; Köksal et al. 2015; Demirsoy et al. 2016). Plants mostly use middle-wavelength rays like blue, yellow and red for photosynthesis. These rays are effective on the plant for chlorophyll formation, flowering and tissue maturation. All green plants require some light intensity for proper development. These requirements vary depending on the plant species and varieties (Bozcuk 1997; Taiz and Zeiger 2006; Demirsoy 2016). The light level in a greenhouse shows a 35 to 75% decrease due to many factors including the sunrise angle, the length of the day, the sunshine duration, the cloudiness, the structural shading, the plant density, the cover material and pollution (Dayıoğlu and Silleli 2012; Gislerød et al. 2012).

There are problems in the production of high quality seedlings in many regions of Turkey due to inadequate lighting and insufficient photosynthesis during early spring and late autumn. Artificial light is needed to supplement the natural light during these periods. Additional lighting is proven to increase seedling growth and quality in vegetable nursery greenhouses (Hernandez and Kubota 2012). There are few studies, however, investigating the quantitative effects of different light sources on pepper plant growth and development. The aim of this study was to determine the effects of different light sources with red and blue color on pepper seedling quality in Turkey.

## MATERIALS AND METHODS

This study was carried out in the greenhouse of the Vocational School at Selcuk University in 2012 and 2013. In this research, seedling production units were prepared with shading material and chipboard plates. Light, temperature and humidity data were recorded for each seedling production unit.

Plant Materials: Seedlings of the sweet pepper variety "Ilıca-256" were grown in 45 cell plug trays filled with peat and perlite (3:1 by volume) in the greenhouse. Each treatment contained 45 seedlings.

Light Treatments: Artificial light sources were used in addition to sunlight in the cultivation of sweet pepper seedling. Seedlings were grown with up to three to four leaves under three different light sources. An Incandescent Lamp (IL), a High Pressure Sodium Lamp (HPS) and a Light-Emitting Diode (LED) were used as the additional light sources. Light sources were set for red and blue lighting conditions (ILR, ILB, HPSR, HPSB, LEDR and LEDB). Another set of seedlings was left in the greenhouse as a control (CT). Lighting control was established by a small automated system. In addition to sunlight, each artificial light source was used between 06:00 to 21:00 hours while the sweet pepper seedlings were growing. During this time, the light intensity in the environment was kept above 2500 lm by automatically bringing the additional light sources into operation when required.

Measurements: Under varying light conditions, the plant height, stem diameter and root length of pepper seedlings with three to four true leaves were measured. The stem and leaf biomass were determined by cutting the stem and leaves, and the root biomass was determined after carefully removing soil from the roots. Both sets of tissues were dried in an oven set at 80 °C for 72 hours, and then dry weights were obtained. The area of each leaf was determined with a digital planimeter. Quantitative analysis of the data findings were

Table 1. The plants growth parameters for quantitative analysis

| |
|---|
| Leaf weight ratio (LWR) = Total leaf dry weight (g) / Total plant dry weight (g) |
| Stem weight ratio (SWR) = Total stem dry weight (g) / Total plant dry weight (g) |
| Root weight ratio (RWR) = Total root dry weight (g) / Total plant dry weight (g) |
| Specific leaf area (SLA) ($cm^2g^{-1}$) = Total leaf area ($cm^2$) / Total leaf dry weight (g) |
| Leaf area ratio (LAR) ($cm^2g^{-1}$) = Total leaf area ($cm^2$) / Total plant dry weight (g) |
| Leaf thickness (LT) = 1 / Specific leaf area (SLA) |

calculated using formulas according to Uzun (1996) (Table 1).

Statistical Analysis: The experiments were established using two factors (two light colors and three light sources) in randomized plots of a factorial design with three replications. For the evaluation of the obtained numerical data, quantitative analysis methods were used. The obtained data were used for statistical comparison of the standard error bars. Standard error bars were placed on the data for $p < 0.05$ and $p < 0.01$ levels. In addition, the data of certain parameters were analyzed using SPSS for Windows 11.5.0.

## RESULTS AND DISCUSSIONS

### Seedling height, stem diameter and root length

During the autumn period, the highest seedling height was measured at 10 cm for the CT, and the shortest length was 9.12 cm after LEDR treatment. In this period, light sources and their colors didn't significantly affect seedling height. In the spring period, the longest seedling height was measured after HPSB treatment at 17.06 cm and HPSR treatment produced the shortest at 10.96 cm (Fig. 1).The results of red artificial lighting were determined to give rise to the shortest seedling heights. Li et al. (2012) reported that blue LEDs benefit vegetative growth, while red LEDs, and blue plus red LEDs, support generative growth.

In this study, during the autumn period, the thickest seedling stem diameter was 1.94 mm when subjected to LEDB treatment, and the thinnest diameter was 1.63 mm for the CT. In the spring period, it was determined that there were statistically significant differences ($p < 0.01$) in sweet pepper seedling stem diameter values. The thickest seedling diameters were obtained with HPSB treatment at 2.92 mm (Fig. 2). Under low daylight conditions, different light treatments used as additional illumination, have been reported to produce significant increases in stem diameter (Hernández 2013). Özkaraman (2004) determined that the stem diameter increases at high light intensity and temperature.

It was determined that there were statistically significant differences ($p < 0.01$) between treatments in seedling root length in both growing periods. In the autumn period, the root lengths of the seedlings ranged from 4.06 cm to 8.43 cm. In the case of spring growth, this value was found to be between 6.34 cm and 12.01 cm (Fig. 3). As a result of the research, the longest root length values were found in the seedlings grown under the blue LED light source in both periods.

### Root, stem and leaf dry weight

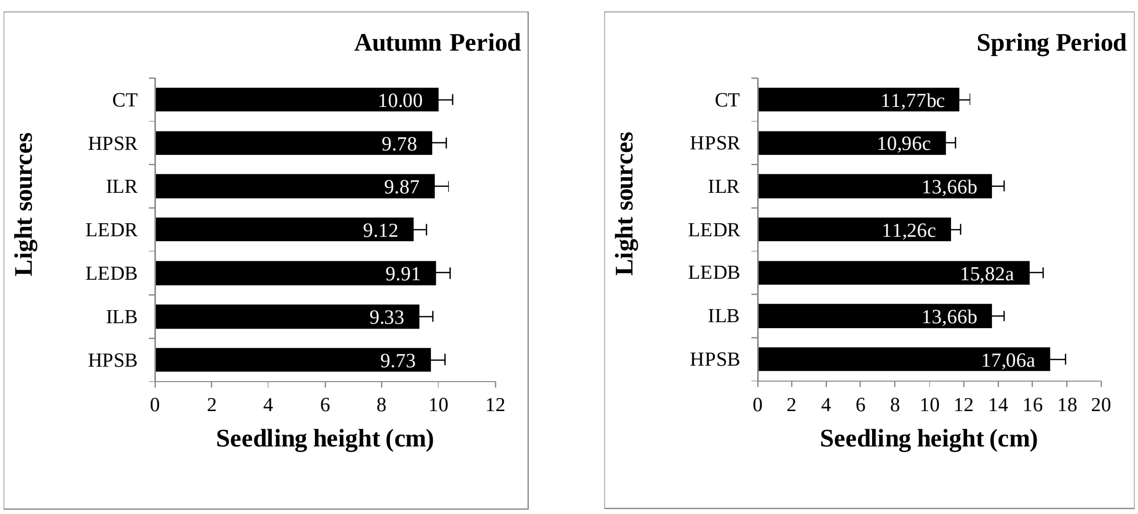


Figure 1. Height (cm) of pepper seedlings grown under different light sources

The highest seedling root dry weight value in

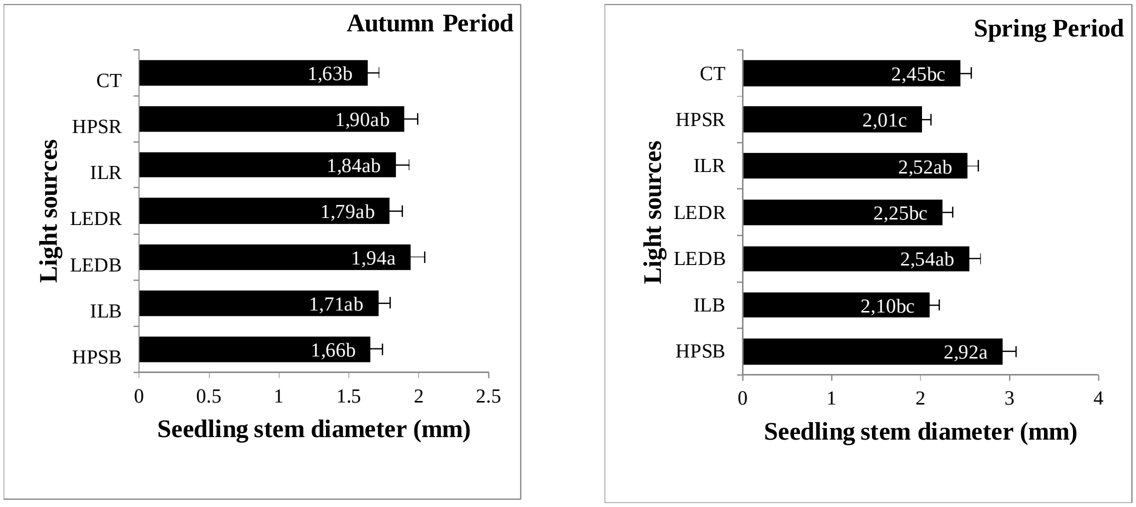


Figure 2. Stem diameter (mm) of pepper seedlings grown under different light sources

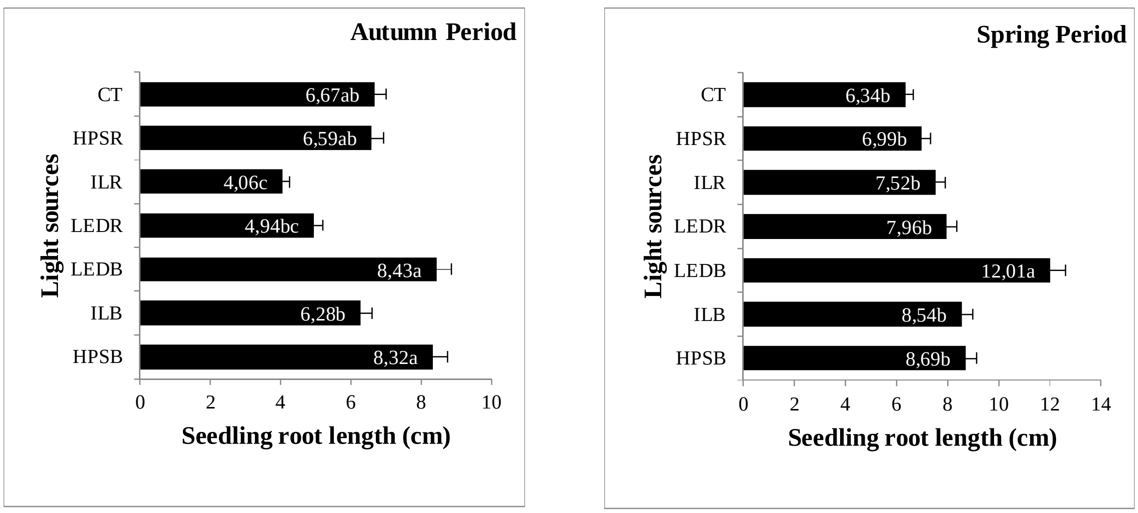


Figure 3. Root length (cm) of pepper seedlings grown under different light sources

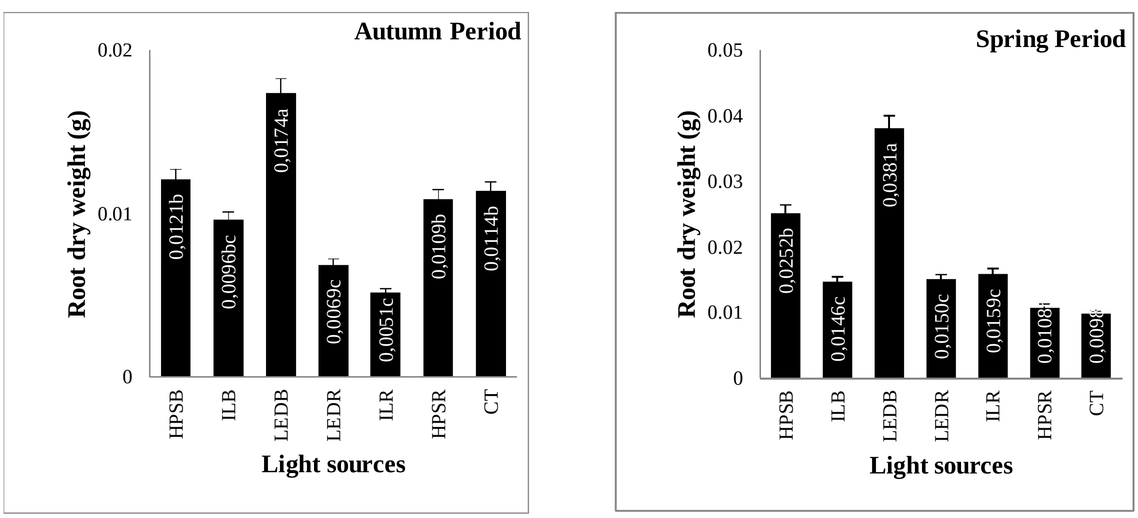


Figure 4. Root dry weight (g) of pepper seedlings grown under different light sources

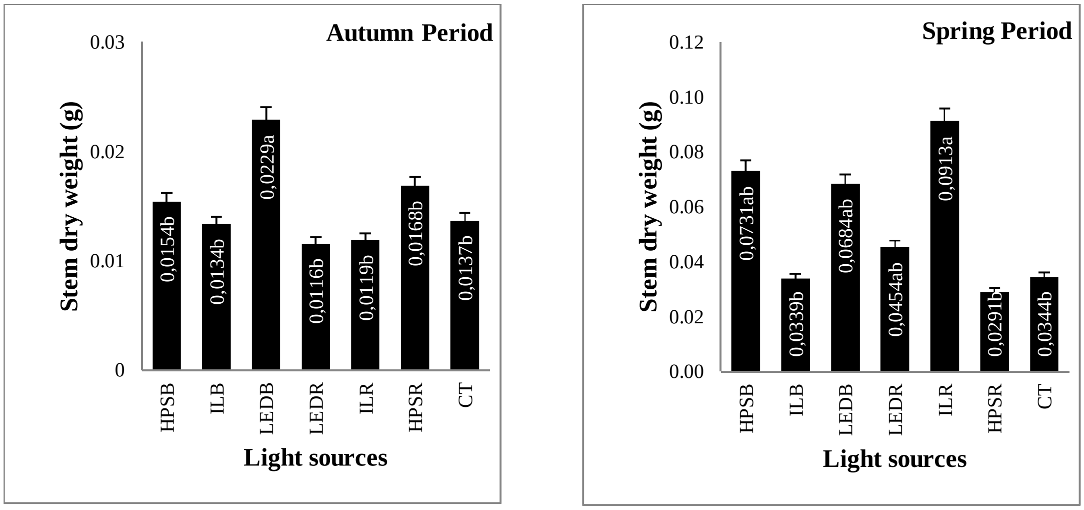

Figure 5. Stem dry weight (g) of pepper seedlings grown under different light sources

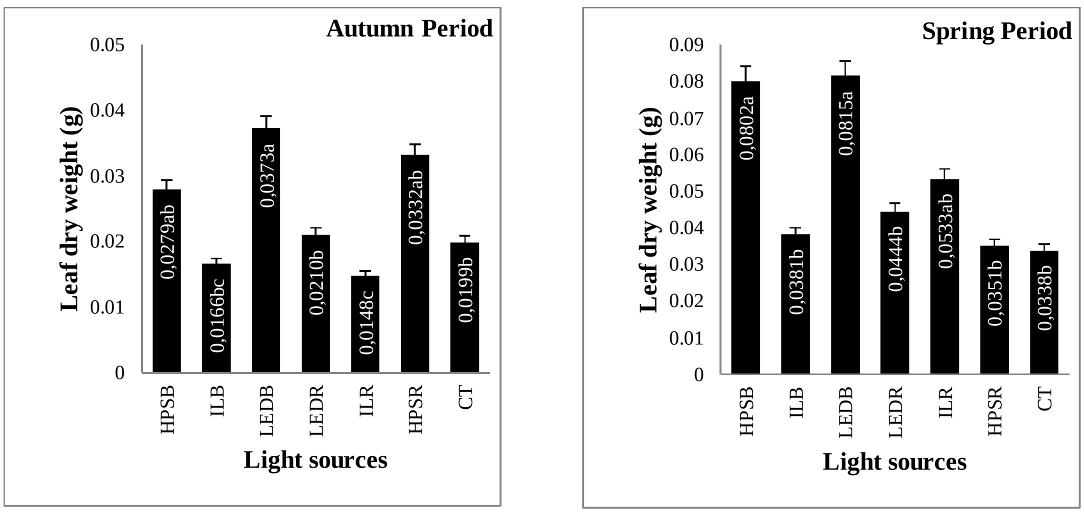

Figure 6. Leaf dry weight (g) of pepper seedlings grown under different light sources

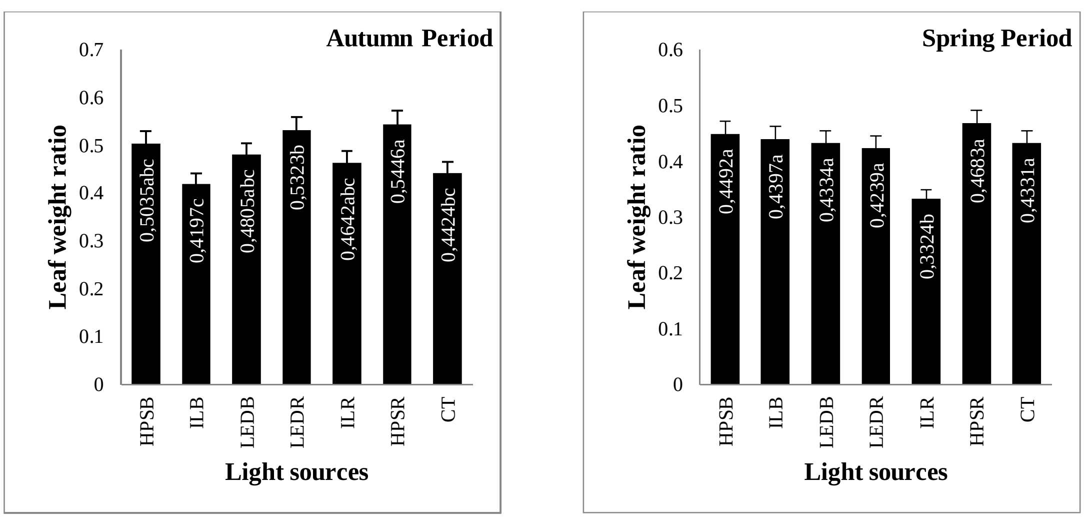

Figure 7. Leaf weight ratio of pepper seedlings grown under different light sources

pepper seedling cultivation during autumn was obtained with LEDB treatment at 0.0174 g. Similar to this data, the highest seedling root dry weight was determined to be 0.0381 g with LEDB

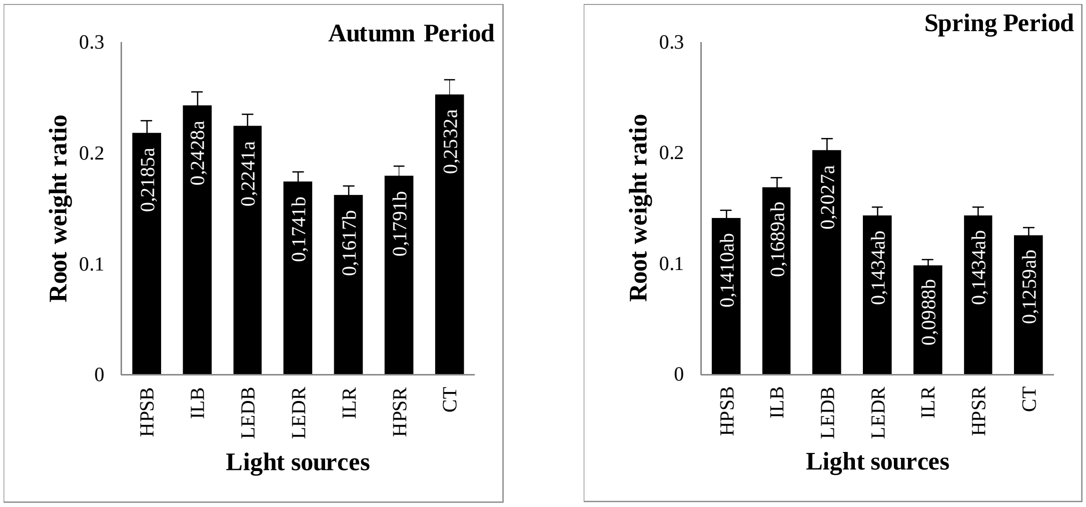


Figure 8. Root weight ratio of pepper seedlings grown under different light sources

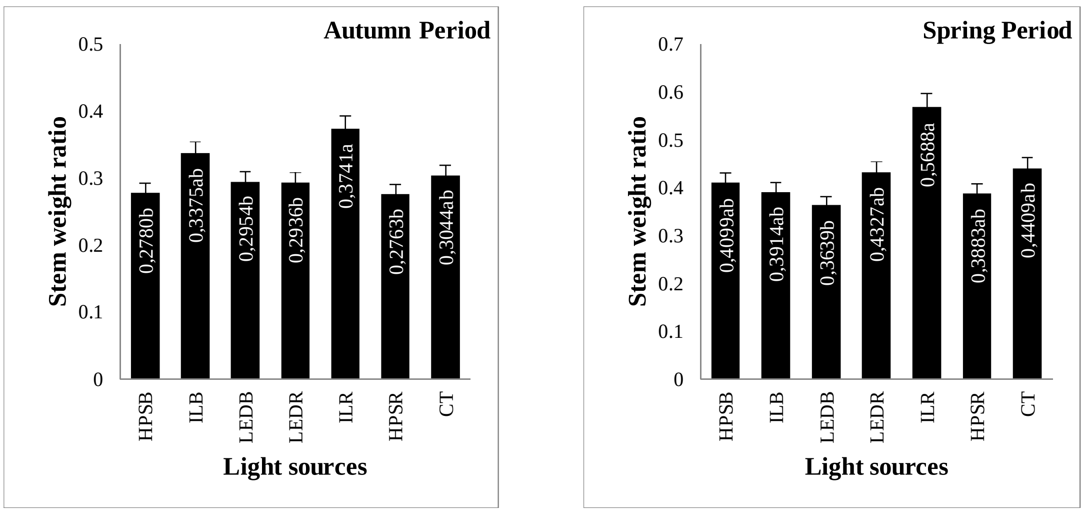


Figure 9. Stem weight ratio of pepper seedlings grown under different light sources

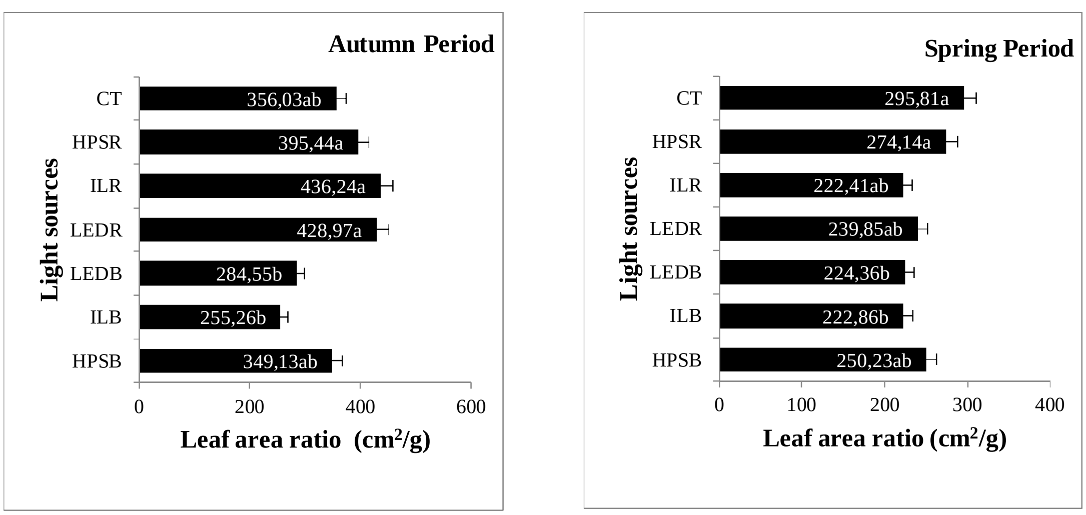


Figure 10. Leaf area ratio (cm2/g) of pepper seedlings grown under different light sources

treatment in the spring (Figure 4). Brown et al. (1995), examined the dry weights and growthcriteria of pepper plants in their study of metal halide lamps (MHL) , red LED + blue

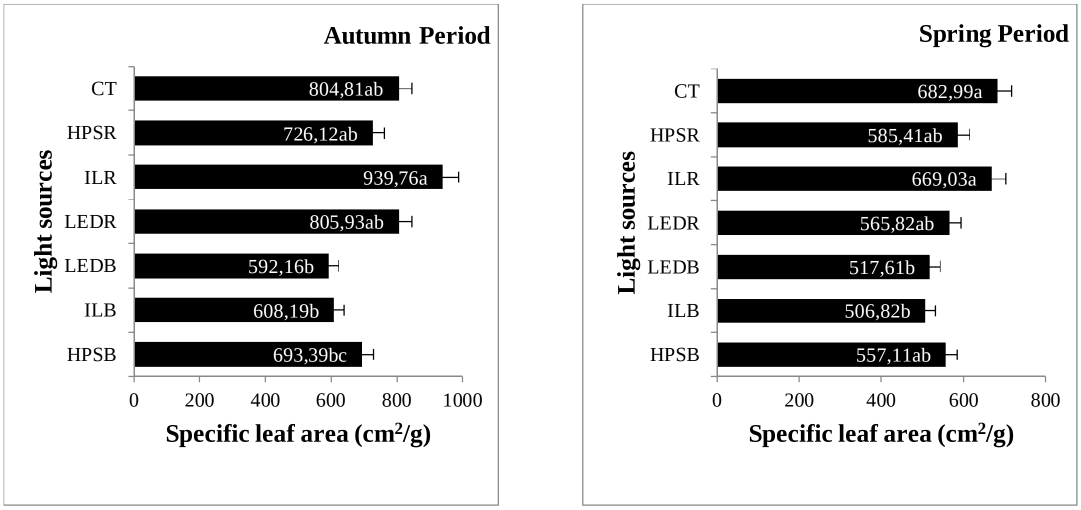


Figure 11. Specific leaf area (cm2/g) of pepper seedlings grown under different light sources

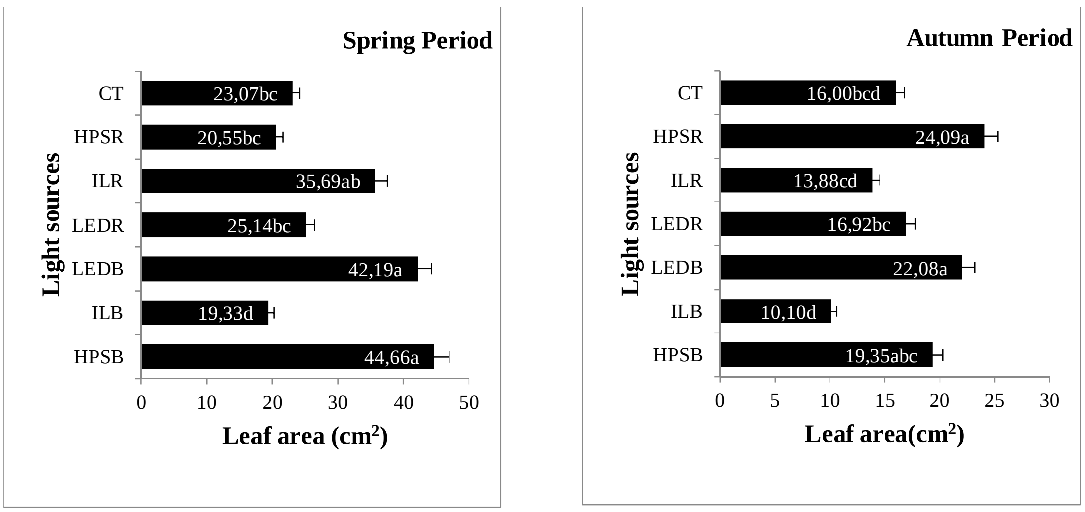


Figure 12. Leaf area (cm2) of pepper seedlings grown under different light sources

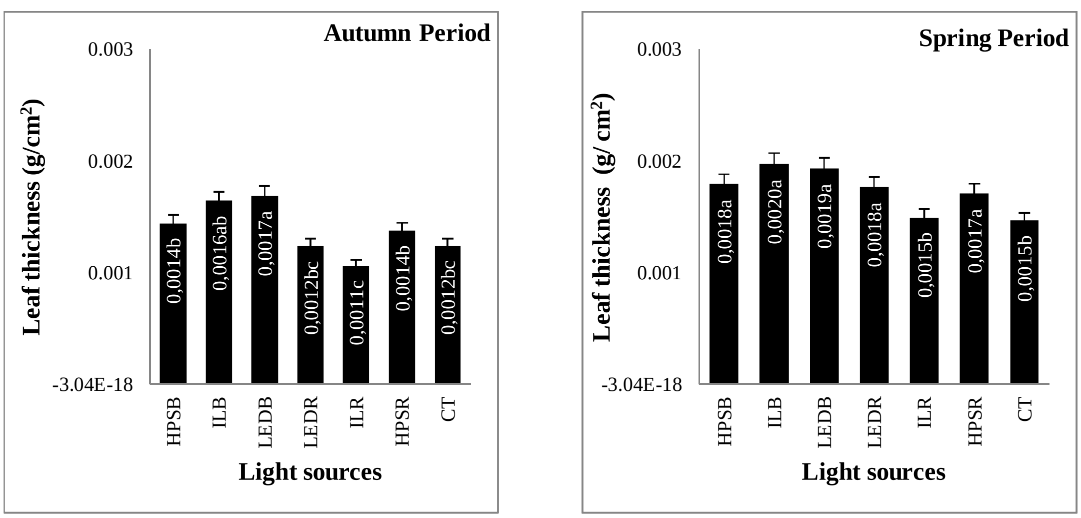


Figure 13. Leaf thickness (g/cm2) of pepper seedlings grown under different light sources

fluorescent, red LED + red-orange LED and red LED lamps. They found that the root dry weights of seedlings grown under red or red-orange LED light had significantly lower dry weights than those grown under red LED + blue fluorescence. Duong et al. (2003) found that the root weight of strawberry seedlings grown under a red LED lamp was lower than that grown under a blue LED lamp. Similar to these studies, in all light source treatments examined for pepper, the blue color was found to produce a higher root dry weight than the red color.

The highest stem dry weight in the autumn period of 0.0229 g was produced with LEDB treatment. For the spring period, the highest stem dry weight of 0.0913 g was obtained with ILR treatment, and the lowest at 0.0291 g with HPSR treatment (Fig. 5). As a result of the study, it was observed that the LEDB light source stands out in terms of promoting stem dry weight. Brown et al. (1995), studied dry weights of pepper seedlings under MHL, red LED + blue fluorescence, red LED + red-orange LED and red LED lamps. Seedlings that grew under the red LED light were reported to have an average dry weight that was significantly less than the other treatments. Piszczek and Glowacka (2005) reported that the highest dry matter content was in plants grown under blue fluorescent light.

The highest leaf dry weight in the pepper cultivation in the autumn period was measured at 0.0373 g under LEDB treatment. In the spring, the value was 0.0802 g obtained under HPSB treatment (Fig. 6). In both treatments, statistically significant differences were found in terms of leaf dry weight values. Piszczek and Glowacka (2005), grew cucurbits under fluorescent lights with white, yellow, green and blue light. The researchers reported that the highest leaf dry matter content in the field was in plants grown under blue fluorescent light. Samuolien et al. (2012), reported increased fresh and dry leaf weights in all vegetable species grown under 455 nm and 470 nm (blue) LED lamps. Brown et al. (1995), found that leaf dry weights for pepper grown under red or red-orange LED light were significantly lower than those grown under red LED + blue fluorescence. In line with these studies, it was determined that the blue color increased the leaf dry weight of the pepper seedlings at different levels depending on whether red light was, or was not also used despite the temperature difference in both periods.

**Leaf weight ratio (LWR), root weight ratio (RWR) and stem weight ratio (SWR)**

The highest LWR value for sweet pepper seedlings was found with HPSR treatment in the autumn (0.5446) and in the spring (0.4683) periods. In the autumn period, LWR values varied from 0.5446 to 0.4197, and in the spring it varied from 0.3324 to 0.4492 according to treatments (Fig. 7). Masuda et al. (2006), in the study done to determine the amount of leaf dry matter in pepper under night light and extra light, found that plants grew strongly and healthily when the light intensity was increased above 200 μmol $m^{-2}s^{-1}$. Özkaraman (2004) reported that the LWR value increased with increasing temperature and light. As a result of our study in a similar way to this literature LWR values were higher in the autumn period when temperature and sunlight were high.

It was determined that there were statistically significant differences ($p<0.01$) in the level of RWR in both growing periods. The highest value in terms of RWR in pepper seedling cultivation was obtained from the CT in the autumn period, and from the LEDB treatment in the spring period. In general, both in the autumn and in the spring periods, blue light sources increased RWR (Fig. 8).

In both periods of seedling cultivation, the SWR value was the highest under ILR treatment. As a result of the study, it was determined that the SWR values of pepper seedlings grown in the spring period were higher than in the autumn period (Fig. 9). Kandemir (2005), stated that under low temperature conditions, there is a linear increase in the SWR with a decrease in light.

**Leaf area ratio (LAR) and specific leaf area (SLA)**

The highest LAR value in the autumn seedling cultivation was found under ILR treatment with 436.24 $cm^2/g$. In the spring growing period LAR values ranged from 222.41 $cm^2/g$ to 295.81 $cm^2/g$. It has been determined that blue light sources in particular are more effective on the LAR value in the autumn period (Fig. 10).

The highest SLA value in the spring period was measured for CT with 682.99 $cm^2/g$, but there was no statistical difference between the CT and the seedlings undergoing ILR treatment. This value was determined to be 939.76 $cm^2/g$ under ILR treatment in the autumn. SLA has the highest value for ILR treatment in both periods (Fig.11). In their study of pepper seedlings, Brown et al. (1995) found that SLA values were higher in those grown under metal halide lamps compared to LED treatment. Özkaraman (2004), determined that the SLA parameter increases at low light intensity and high temperature.

**Leaf area (LA) and leaf thickness (LT)**

In the study, it was found that there were statistically significant differences ($p <0.01$) for LA in both periods. LA was measured to be a maximum of 24.09 $cm^2$ under HPSR treatment for autumn cultivation. The highest LA value was determined to be 44.66 $cm^2$ under HPSB treatment in the spring growing season (Fig. 12). McCall (1992), reported that significant increases in leaf area values occurred with the increase of artificial lighting levels in plants grown under HPS lamps.

Samuoliené et al. (2012), determined that increases in leaf area occurred in pepper species under 505 nm LED lamps. They also found that leaf area increased in all vegetable species grown under 455 nm and 470 nm LED lamps. Novičkovas et al. (2012), found that increases in leaf area occur when HPS lamps are applied together with LED lamps at 505 nm, 530 nm, 455 nm and 470 nm wavelengths for cucumber cultivation. Graham and Decoteau (1995), investigated the effect of daytime IL treatment as supplemental lighting on pepper seedling growth, which was done for one hour with a fluorescent lamp at the end of the day. It was determined that the leaves were smaller and shorter in the pepper seedlings grown under IL treatment than in the control.

As a result of the study, it was determined that there is a statistically significant difference in leaf thickness in pepper seedlings during the autumn and spring periods. In the autumn period, the highest LT of 0.0017 $g/cm^2$ was obtained with LEDB treatment, and the lowest LT of 0.0011 $g/cm^2$ was obtained with ILR treatment. The highest value for LT in the spring period was measured at 0.0019 $g/cm^2$ under LEDB treatment (Fig. 13). As a result of the research, there was no statistical difference between blue light sources in the spring period; furthermore, the highest LT values were obtained from LEDB light source treatment in both periods. Kandemir (2005), reported that the LT values of pepper reached their highest values in high light and high temperature conditions.

Light is one of the important environmental factors in plant growth and morphology. In this research, it was determined that the effect of light sources and their colors on the morphological and quantitative characteristics of pepper seedling were different according to the growing periods. In the spring period, it was determined that the shortest pepper seedlings were found as a result of artificial lighting, especially red colors. The highest root, stem and leaf dry weights were seen in the seedlings under blue LED lamps. Blue LED lamps increased LA values in both periods, while the lowest LA value was determined under an IL blue light source in both periods. In general, the blue color light source treatments increased the SWR value depending on the simultaneous use or not of red color light source treatments; also the treatment with blue light sources increased the LT value positively.

## CONCLUSIONS

According to the results, it was seen that the effect of light sources and their colors on the growth and quantitative characteristics of pepper seedlings were different depending on the growing periods of autumn and spring. Under blue LED light conditions, the seedlings root, stem and leaf dry weights were much better compared to seedlings treated with other light sources. It has been determined that blue light sources, in particular, are more effective on the leaf area ratio in the autumn period. This study also showed that pepper seedling growth is light limited during the spring period, and artificial LED lighting can significantly increase plant growth. This study provides basic information to seedling farm practitioners or seedling companies about different artificial light sources for growing pepper seedlings. Furthermore, they also provide a basis for studies based upon additional lighting. In the future, research should be focused on the effect of choosing the best light source in year-round greenhouse vegetable production with supplemental light when combined with solar radiation.

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## REFERENCES

Balkaya A. Uzun S. Odabas M.S. (2004) Determination of the relationship between the sowing times and plant light interception in red podded bean growing. Asian Journal of Plant Sciences, 3(2): 223-230.

Bozcuk S. (1997) Bitki fizyolojisi: metabolik olaylar. Ankara: Hatiboğlu Yayınevi.

Brazaitytė A. Duchovskis P. Urbonavičiūtė A. Samuolienė G. Jankauskienė J. Sakalauskaitė J. Šabajevienė G. Sirtautas R. Novičkovas A. (2010) The effect of light-emitting diodes lighting on the growth of tomato transplants. Zemdirbyste-Agriculture, 97(2): 89-98.

Brown C.S. Schuerger A.C. Sager J.C. (1995) Growth and photomorphogenesis of pepper plants under red light-emitting diodes with supplemental blue or far-red lighting. Journal of the American Society Horticultural Science, 120 (5): 808-813.

Chia P.L. Kubota C. (2010) End-of-day far-red light quality and dose requirements for tomato rootstock hypocotyl elongation. HortScience, 45: 1501-1506.

Dayıoğlu M.A. Silleli H. (2012) Seralar için yapay aydınlatma sistemi tasarımı: Günlük ışık İntegrali yöntemi. Tarım Makinaları Bilimi Dergisi, 8(2): 233-240.

Demir K. Çakırer G. (2015) Kaliteli fide üretimini etkileyen faktörler. TÜRKTOB Türkiye Tohumcular Birliği Dergisi, 4(13): 12-15.

Demirsoy M. (2016) Investigation of different artificial color and light sources quantitative effects on development, growth and quality of seedlings and adaptation of after planting tomato (*Lycopersicon esculentum* Mill.), pepper (*Capsicum annuum* L.) and eggplant (*Solanum melongena* L.) in greenhouses. Ph.D. Dissertation, University of Ondokuz Mayıs. Turkey.

Demirsoy M. Balkaya A. Uzun S. (2016) Farklı ışık kaynağı ve renk uygulamalarının patlıcan (Solanum melongena L.) fidelerinin büyüme parametreleri üzerine etkileri. Selçuk Tarım Bilimleri Dergisi, 3(2): 238-247.

Deram P. (2013) Light-emitting-diode (LED) lighting for greenhouse tomato production. M.S. Dissertation, University of McGill. Canada.

Gislerød H.R. Mortensen L. Torre S. Pettersen H. Dueck T.S and A. (2012) Light and energy saving in modern greenhouse production. Acta Horticulture, 956: 85-97.

Goto E. (2012) Plant production in a closed plant factory with artificial lighting. Acta Horticulture, 956: 37-49.

Graham H.A.H. Decoteau D.R. (1995) Regulation of bell pepper seedling growth with end-of-day supplemental fluorescent light. Hortscience, 30(3): 487–489.

Hernández R. Kubota C. (2012) Tomato seedling growth and morphological responses to supplemental led lighting red, blue ratios under varied daily solar light integrals. Acta Hortorticulture, 956: 187-194.

Hernández R. (2013) Growth and development of greenhouse vegetable seedlings under supplemental LED lighting. Ph.D. Dissertation, University of Arizona, Arizona.

Kandemir D. (2005) The quantitative effects of temperature and light environment on the growth, development and yield of pepper (*Capsicum annuum* L.) grown in greenhouses Ph.D. Dissertation, University of Ondokuz Mayıs, Turkey.

Kelley W. Boyhan G. Harrison K. Granberry D. Summer P. Langston D. Sparks A. Culpepper A. Hurst W. Fonsah H. (2009) Commercial Pepper Production Handbook. Oxford University Press.

Kim S.J. Hahn E.J. Heo J.W. Paek K.Y. (2004) Effects of LEDs on net photosynthetic rate, growth and leaf stomata of chrysanthemum plantlets in vitro. Scientia Horticulturae, 101: 143–151.

Köksal N. İncesu M. Teke A. (2013) LED aydınlatma sisteminin domates bitkisinin gelişimi üzerine etkileri. Tarım Bilimleri Araştırma Dergisi, 7 (1): 53-57.

Li H. Tang C. Xu Z. Han X. (2012) Effects of different light sources on the growth of non-heading Chinese cabbage (*Brassica campestris*). Journal of Agricultural Science, 4(4): 262 .

Masuda M. Yoshida Y. Murakami K. Nakachi K. Kinoshita T. (2006) Leaf injury and dry mass production in eggplant and pepper plant as affected by overnight supplemental lighting. Environment Control in Biology, 44 (4): 285-291.

McCall D. (1992) Effect of supplementary light on tomato transplant growth, and the after-effects on yield. Scientia Horticulture, 51: 65-70.

Novičkovas A. Brazaitytė A. Duchovskis P. Jankauskienė J. Samuolienė G. Viršilė A. Sirtautas R. Bliznikas Z. Žukauskas A. (2012) Solid-state lamps (LEDs) for the short-wavelength supplementary lighting in greenhouses, experimental results with cucumber. Acta Horticulturae, 927: 723-730.

Özkaraman F. (2004) The quantitative effect of temperature, light and different pruning systems on the growth, development and yield of melon (*Cucumis melo* L.) grown in greenhouses. Ph.D. Dissertation, University of Ondokuz Mayıs, Turkey.

Piszczek P. Glowacka B. (2005) Effect of light quality on growth of cucumber (*Cucumis sativus* L.) transplants. Vegetable Crops Research Bulletin, 63: 77-85.

Samuolienė G. Brazaitytė A. Duchovskis P. Viršilė A. Jankauskienė J. Sirtautas R. Novičkovas A. Sakalauskienė S. Sakalauskaitė J. (2012) Cultivation of vegetable transplants using solid-state lamps for the short-wavelength supplementary lighting in greenhouses. Acta horticulturae, 952: 885-892.

Singh D. Basu C. Meinhardt-Wollweber M. Roth B. (2015) LEDs for energy efficient greenhouse lighting. Renewable and Sustainable Energy Reviews, 49: 139-147

Taiz L. Zeiger E. (2006). Plant physiology ($4^{th}$ ed.).

Uzun S. (1996) The quantitative effects of temperature and light environment on the growth, development and yield of tomato and aubergine. Ph.D. Dissertation, University of Reading. England.

Uzun S. (1997) Sıcaklık ve ışığın bitki büyüme, gelişme ve verimine etkisi (I.Büyüme). OMÜ Ziraat Fakültesi Dergisi, 12(1): 147–156.

Wheeler R.M. (2008) A historical background of plant lighting: an introduction to the workshop. HortScience, 43(7): 1942-1943.