Erzincan Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
2022, 15(3), 916-930
ISSN: 1307-9085, e-ISSN: 2149-4584
Araştırma Makalesi

Erzincan University
Journal of Science and Technology
2022, 15(3), 916-930
DOI: 10.18185/erzifbed.1093191
Research Article

The Effects of Light Produced in Different Ways on *Triticum aestivum* L. (Wheat) and *Hordeum vulgare* L. (Barley)

Mustafa ŞAHİN[1]*, Elçin KILIÇ[2], Etem OSMA[3]

[1]Hamidiye Vocational School of Health Services, University of Health Sciences, İstanbul, Turkey
[2] Department of Electrical & Electronics Engineering, Graduate School of Natural and Applied Science, Erzincan University, Erzincan, Turkey
[3]Department of Biology, Faculty of Science and Arts, Erzincan Binali Yıldırım University, Erzincan, Turkey

Received:25/03/2022, **Revised:** 20/06/2022, **Accepted:** 27/07/2022, **Published:** 30/12/2022

Abstract

It produces lights of different qualities with different lighting elements used in agricultural practice. This situation creates different effects on living things. In this study, the effect of incandescence, electric discharge and electroluminescence light, which is the most used light production method in lighting applications, on *Triticum aestivum* L. (Wheat) and *Hordeum vulgare* L. (Barley) was investigated. For this purpose, different lighting environments where sources of light with LED, incandescence, sodium vapor, mercury vapor and metal halide discharge were used were created, and all variables except for the sources of light were kept the same. Wheat and barley plants were grown in these environments, and harvested after 15 days. After the harvesting processes had been completed, wet weight, height, amounts of electrolyte leakage, chlorophyll and carotene amounts, SOD (superoxide dismutase) and (CAT) Catalase enzyme activities were determined. Differences between the plants grown under the light parameters were determined by evaluating the data with SPSS. There were statistically significant differences between the data obtained from wheat and barley grown under different lamps.

Keywords: Artificial light sources, agriculture, *Triticum aestivum* L., *Hordeum vulgare* L.

Farklı Şekillerde Üretilen Işığın *Triticum aestivum* L. (Buğday) ve *Hordeum vulgare* L. (Arpa) Üzerindeki Etkileri

Öz

Tarımsal uygulamada kullanılan farklı aydınlatma elemanları ile farklı niteliklerde ışıklar üretmektedir. Bu durum canlılar üzerinde farklı etkiler oluşturmaktadır. Bu çalışmada, aydınlatma uygulamalarında ışık üretim yöntemlerinden en fazla kullanılan termik, deşarja dayanan ve elektrolüminesans yol ile üretilen ışığın *Triticum aestivum* L. (Buğday) ve *Hordeum vulgare* L. (Arpa) üzerindeki etkisi incelenmiştir. Bu amaçla, LED, enkandesan, sodyum buharlı, civa buharlı ve metal halojenli deşarj ışık kaynaklarının kullanıldığı farklı aydınlatma ortamları oluşturulmuş ve ışık kaynağı haricinde diğer tüm değişkenlerin aynı olması sağlanmıştır. Sonrasında bu ortamlarda buğday ve arpa bitkileri yetiştirilmiş ve 15 gün sonunda hasat edilmiştir. Hasat işlemleri tamamlandıktan sonra bitkilerin yaş ağırlıkları, boyları, elektrolit sızıntı, klorofil ile karoten miktarları, Süperoksit dismutaz (SOD) ve Katalaz (CAT) enzim aktiviteleri belirlenmiştir. Elde edilen veriler SPSS İstatistik Paket Programı'nda değerlendirilerek çalışılan ışık parametreleri altında yetiştirilen bitkiler arasındaki farklılıklar belirlenmiştir. Farklı lambalar altında yetiştirilen buğday ve arpalarda elde edilen veriler arasında istatistiksel olarak anlamlı farklılıklar olduğu gözlenmiştir.

Anahtar Kelimeler: Yapay ışık kaynakları, tarım, *Triticum aestivum* L., *Hordeum vulgare* L..

***Corresponding Autho**r: mustafa.sahin4@sbu.edu.tr

Mustafa ŞAHİN, https://orcid.org/00000-0003-2284-8507
Elçin KILIÇ, https://orcid.org/0000-0002-2873-1564
Etem OSMA, https://orcid.org/0000-0002-5250-8194

1. Introduction

Light has been an irreplaceable source of energy since the existence of humanity, and the need for light increases daily. In order to provide sustainable light sources when the sun was not enough for lighting, people invented artificial sources of light [1]. Artificial light sources are used for many purposes. Venue design, environmental luminance, plant growth rooms, among others are examples of intended uses with different purposes and functions [2]. Artificial light is generally produced via three different light production methods. These are produced via incandescence, an electrical discharge [3] and electroluminescence [4]. The foundation for light production methods is based on the principle of conversion of electric energy to light. Since each of these light production methods differs from one another, each source of light has different physical and structural properties [5].

Producing light via the incandescence method is the oldest known method. Electrical current is conducted through a metal wire in the lamp and light is obtained when the metal wire becomes incandescent in this method of production [6]. The first incandescent lamp was researched by H. Goebel in 1854, and T. Edison invented lightbulbs in 1879, which have been technologically improved until the present day [7].

In the method based on electrical discharge, the gas between the two plates in the lamp starts to ionise by interacting, and light is produced. Radiation for this production method occurs in two ways: in the visible wavelength zone or in the ultraviolet radiation zone. Discharge lamps are described as low-pressure lamps or high-pressure lamps in accordance with the pressure of the gas in the tube. Discharge lamps need auxiliary sources during operation. Therefore, they are operated with ballast and ignitor [8]. The purpose of the ballasts used in discharge lamps is to prevent the current from short-circuiting by limiting ionization, in other words, discharge current [9]. It is quite important for a discharge lamp to be suitable for the ballast and it is preferred for ballasts to be electronic and electromagnetic [10]. If the current provided by the ballast is less than it should be, it causes inefficient current to be conveyed to the lamp. This leads the lamp to illuminate inefficient luminous flux and causes it not to reach the necessary brightness [11]. Therefore, it is important to pay attention to the compatibility of lamps and ballast. These blasters, called starters or ignitors, are electronic devices, which provide suitable voltage and energy to start and maintain luminescence discharge [12].

Light production with the electroluminescence method was developed in recent years as solid-state semiconductor-based devices. This method is where electric energy is converted into direct luminous energy [13]. LEDs, which produce light through this method, are small and durable. LED, which means light-emitting diode, is a semiconductor-based lighting equipment

consisting of semiconductor equipment, called n-types or p-types, which have undergone some processes. The property that distinguishes LEDs from other diodes is that they emit light through photons in p-n joint parts [14].

In addition to other environmental parameters, plants need substantial amounts of light. Light affects the physiological development of plants as well as the formation of blooming and floral organs and the morphology of organs. Briefly stated, plants need light for growth, development and various metabolic purposes. Applying insufficient light has some negative impacts on plants as does having excess light [15]. The sources of light that are needed for plant development can be the sun or artificial lights [16].

The beams emitted by the sun to the earth have various wavelengths. The light spectrum contains a wide range of wavelengths including infrared, visible light and ultraviolet [17]. The range that plants use for photosynthesis includes the 390–760 nm wavelengths [18]. Besides being a source of energy for plants used for photosynthesis, light is a factor that affects various developmental processes [19]. Photosynthesis, a photochemical process, is a function of wavelength of the light source. The speed of photosynthesis depends on both wavelengths and the addition of light sources with different wavelengths can cause photosynthesis speed to increase. Consequently, this situation is an important aspect when it comes to artificial lighting [20].

The lives of all living creatures depend on green plants that photosynthesise. Therefore, plants form the basic level of most food chains. Leaves are the main organ of plants that have an effective part in photosynthesis [21]. The most important pigment of plants that is used in photosynthesis is chlorophyll [22]. Chlorophyll generates the carbohydrates, which have the most significant role in the growth and development of plants using sunlight [23]. There are eight different chlorophylls in plants, and the most important ones are chlorophyll a and chlorophyll b. Light is a basic need for these coloured pigments to function. Chlorophylls absorb photons at certain wavelengths of 430 nm (blue) and 662 nm (red) while the green color is reflected strongly [24].

In this study, the effects of the placement of artificial sources of light and light production methods on agricultural production and the effects of light on plants were analysed. The lengths, wet weights, electrolyte leakage, chlorophyll and the activities of CAT and SOD enzyme plants were investigated and analysed.

2. Material and Methods

Fertile soil mixed with manure from the fields where agriculture activities have been performed and seeds of wheat (*T. aestivum* L.) and barley (*H. vulgare* L.) that can be easily grown in a laboratory environment were used in the study. Soil, consisting of 25% of pearlite, and 25% of manure, was prepared. Then 750 g of this mixture was put into 1kg plastic pots. Three pots each were prepared with seeds of barley and wheat for each source of light application. After the seeds to be planted had been weighed, 7 g of wheat or 5 g of barley were planted in each pot. Next, the seeds were covered with 100 g of soil. The pots were placed under incandescent lamps, LEDs, metal halide discharge lamps, sodium vapour lamps or mercury vapour discharge lamps (Table 1). Since wheat and barley are long-day plants, they were subjected to 13–14 hours of light exposure [25]. After germination, the plants were grown and harvested, barley after 11 days and wheat after 15 days, by being cut at the soil surface. The lengths of the plants, which had been grown under five different lighting mechanisms, were determined and their wet weight values were measured. Then, samples were collected from harvested plants, and amounts of electrolyte leakage, chlorophyll, carotene, CAT and SOD enzyme activities values were determined.

Table 1. Lamp Parameters

Lamp Types	Lamp Power (W)	Color correlated temperature - CCT (˚K)	Illumination level (Lux)
SodiumVapor	70	2003	1548
Incandescent	42	2759	279
Metal Halogen	400	5767	6082
LED	18	6729	475
Mercury Vapor	125	3985	3076

Determination of Electrolyte Leakage

First, each of the 12 test tubes received 0.1 g of fresh plant material taken from plant leaves. The tubes were then filled with 4 mL of distilled water and stored at 4 °C for 1 day. An electrical conductivity meter was then used to quantify the levels of ions in distilled water from the samples collected to determine cell damage [26].

Determination of Chlorophyll and Carotenoid

First, 0.5 g of harvested leaves was placed in a porcelain mortar and ground in the porcelain mortar to homogenize in 20 mL of 80% acetone. The mixture was filtered through filter paper

and placed in a centrifuge tube that was filled up to 10 mL. The solution was then centrifuged for 10 minutes. Finally, the absorbance values of the resulting combination at 663, 646, and 440 nm were determined individually using a spectrophotometer.

The following formulas were used to calculate the amount of chlorophyll:

$Chl_a = 12.25\ A_{663} - 2.55\ A_{646}$

$Chl_b = 20.31\ A_{646} - 4.91\ A_{663}$

$Chl_a + Chl_b = 17.76\ A_{646} + 7.34\ A_{663}$

$Carotenoid\ (Car) = 4.69\ A_{440} - 0.267\ Chl_{a+b}$

The results were obtained as mg mL^{-1} [27, 28].

Antioxidant Activity

After weighing 0.5 g of tissue and placing it in the porcelain mortar, 5 mL of cold homogenate buffer (0.1 M KH_2PO_4 at pH 7.0 with 1% PVP and 1 mM EDTA) was added. The mixture was transferred to a centrifuge tube and centrifuged for 15 minutes at 15000 g and 4 °C. The supernatant antioxidant produced from centrifugation was employed as a source for enzyme activity deaths [29]. Whether the plants were under stress physiologically was assessed by measuring antioxidant enzyme (superoxide dismutase, catalase, and peroxidase) activities in response to increases in reactive oxygen species during watering and soil stress conditions. Each antioxidant enzyme had its own set of substances and methodologies [30].

Catalase Enzyme Activity

The method was used to determine the activity of Catalase (CAT). This method of measuring activity is based on the premise of seeing a drop in absorbance in a CAT activity measurement setting when H_2O_2 is transformed into O_2 and H_2O at 240 nm [31]. A 5 mM H_2O_2 solution was used to assess catalase activity in the extraction solution derived from plant samples. Following the addition of 103.5 mM of KH_2PO_4 buffer and 40 mM of H_2O_2 substrate solution to 3 mL quartz vials, 20 L of enzyme extract from leaves and 50 L of enzyme extract from roots were added. The absorbance of the vial against a blank was observed at 240 nm for 3 minutes at 1 minute intervals after it was placed in the spectrophotometer. The absorbance per minute was estimated from the point where the absorbance dropped linearly. A standard curve was used to convert these average absorbance values into mol H_2O_2. One enzyme unit was identified as the amount of enzyme that reduced absorbance by 1 mol at 25 °C in 1 minute, and the results are provided as enzyme units per gram of tissue (EU g^{-1} tissue) [31, 32].

Superoxide Dismutase Enzyme Activity

The inhibition of the photochemical reduction of nitro blue tetrazolium (NBT) by superoxide dismutase (SOD) activity was determined spectrophotometrically [33]. 3.84 mL

spectrophotometer vials were filled with a reduction mixture containing 50 mM of KH_2PO_4 (pH 7.8), 13 mM of methionine, 75 M of NBT, 2 M of riboflavin, and 0.1 mM of EDTA or 2.84 mL of a comparable reduction mixture that did not contain riboflavin. The mixture was then pipetted with 100 mL of enzyme extract. After pipetting and mixing 60 mL of 100 m of riboflavin solution into the tube, the reaction was begun by placing the tube under a white light source. The color fading density of NBT was measured in 15 minutes against a blank at 560 nm. The blank was an enzyme-free sample that went through the same procedure. The amount of enzyme producing 50% inhibition of NBT reduction detected at 560 nm was recognized as one enzyme unit in this analysis, and values were determined as EU g^{-1} tissue [32].

Statistical evaluations were then performed using data obtained from this study. Average values of data and standard errors were calculated using SPSS 22 at a 95% confidence interval.

3. Result and Discussion

Significant data was obtained for wheat and barley are grown under five different lighting mechanisms. When the data were evaluated, the average weight measurement was 13.5–19 g in barley, and 13–18 g in wheat. The weight was at its lowest under the metal halide lamp for both of the plants (Fig. 1). When length data was evaluated, it was 12.2–13.7 cm in barley, and 13–18 cm in wheat (Fig. 1). Plant length was also at its shortest under the metal halide lamp for both of the plants. Electrolyte leakage from barley was 63.63 ± 6.5 μS cm^{-1} to 115 ± 7.7 μS cm^{-1}. This value was 53.33 ± 3.1 μS cm^{-1} to 82.27 ± 3.65 μS cm^{-1} in wheat (Fig. 1).

Chlorophyll a values of barley were 7.68 ± 0.21 mg mL^{-1} to 13.54 ± 0.06 mg mL^{-1}, and the values of wheat were 9.73 ± 0.24 mg mL^{-1} to 14.49 ± 0.4 mg mL^{-1} (Fig. 2). Chlorophyll b values of barley were 4.56 ± 0.44 mg mL^{-1} to 6.28 ± 0.12 mg mL^{-1}, and the values for wheat were 4.41 ± 0.13 mg mL^{-1} to 6.41 ± 0.26 mg mL^{-1} (Fig. 2). When chlorophyll a + b values were evaluated, these values were 12.25 ± 0.64 mg mL^{-1} to 19.83 ± 0.18 mg mL^{-1} for barley and 14.06 ± 0.50 mg mL^{-1} to 20.75 ± 0.86 mg mL^{-1} for wheat (Fig. 2). Regarding carotene values, they were 8.40 ± 0.99 mg mL^{-1} to 19.8 ± 0.45 mg mL^{-1} for barley and 10.12 ± 0.87 mg $mL^{-1}$and 20.22 ± 0.82 mg mL^{-1} for wheat (Fig. 3).

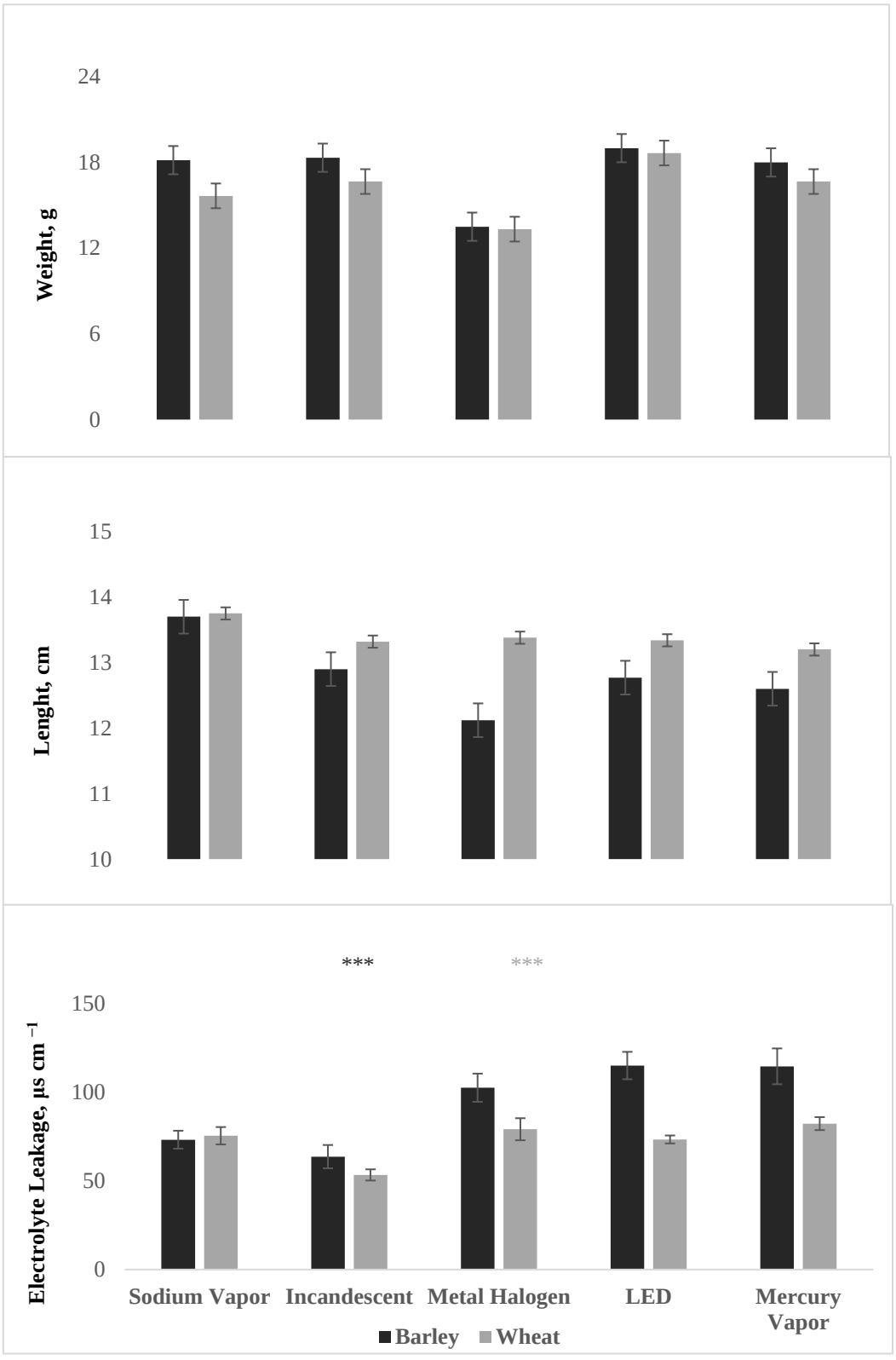

Figure 1. Weights, length and amount of electrolyte leakage barley and wheat plants grown under different light sources (*p<0,05; **p<0,01; ***p<0,001 significant).

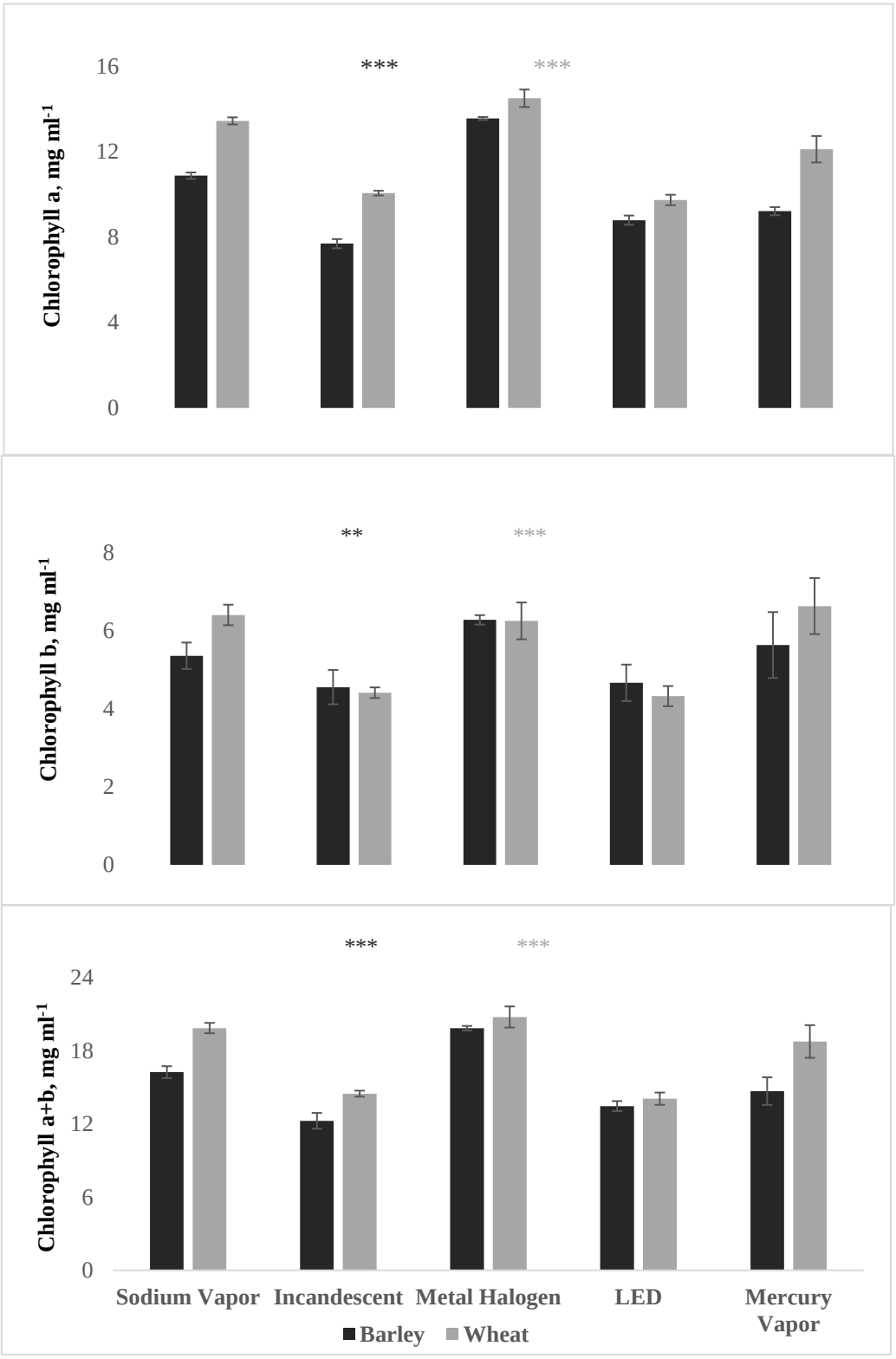

Figure 2. Chlorophyll a, chlorophyll b, chlorophyll a + b amounts of barley and wheat plants grown under different light sources (*p<0,05; **p<0,01; ***p<0,001 significant).

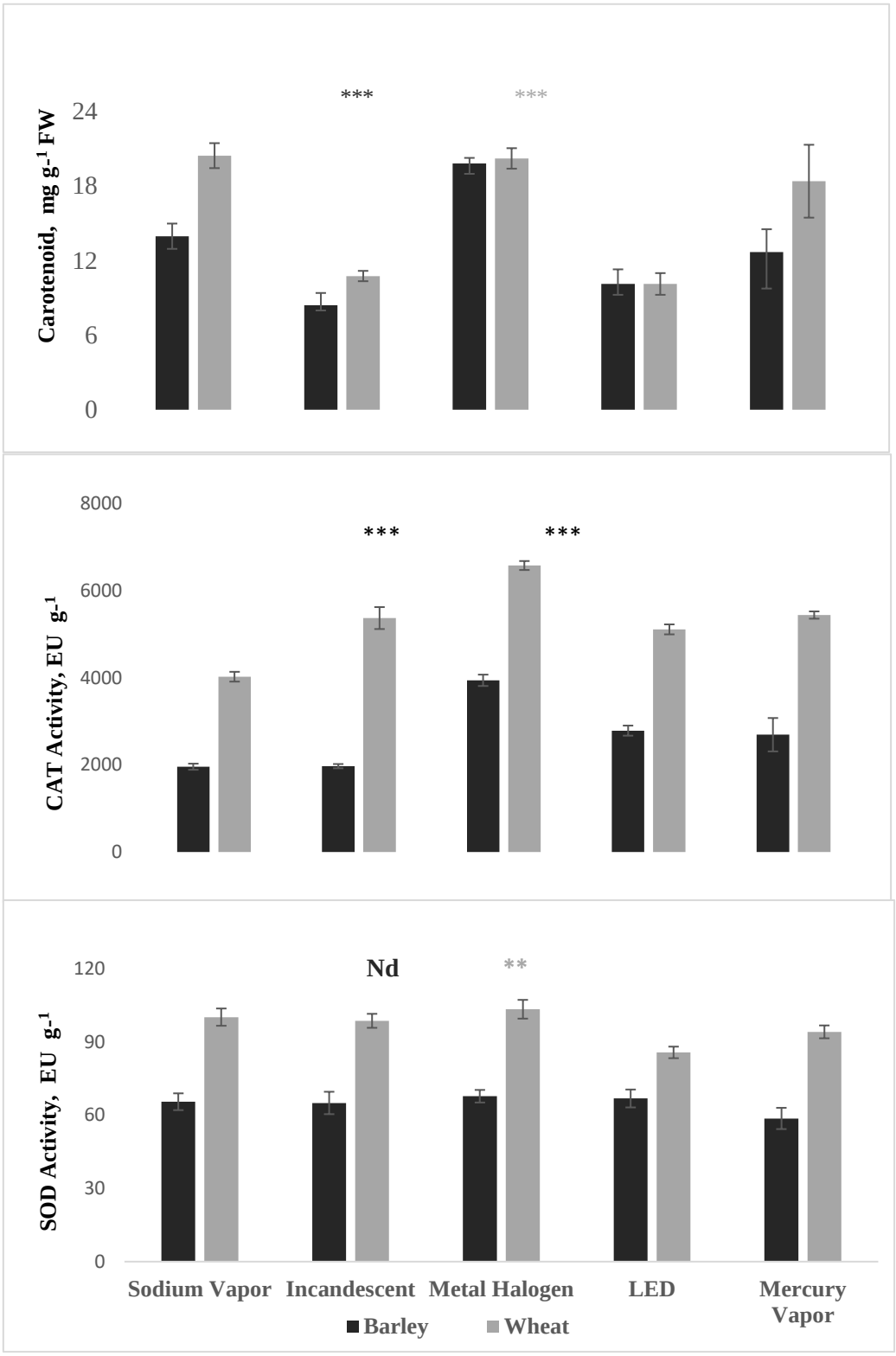

Figure 3. Caretenoid, CAT and SOD enzyme activity of barley and wheat plants grown under different light sources (*p<0,05; **p<0,01; ***p<0,001 significant).

Catalase data for the barley was 1960–3945 EU g^{-1} and 4028–6583 EU g^{-1} for wheat. SOD enzyme activity for the barley was 58.62–67.73 EU g^{-1}, and for wheat 85.6675–103.3397 EU

g^{-1} for wheat (Fig. 3). When the length and weight data of the plants grown under the lamps were compared, the values for plants grown under metal halide lamps were lower than those of plants grown under other light sources. The amounts of chlorophyll a and b and carotene were at their highest under metal halide lamps and they were at their lowest under incandescent lamps.

The amount of electrolyte leakage was lower under incandescent lamps compared to other sources of light. CAT and SOD enzyme activities were higher in barley and wheat that were grown under metal halide lamps. In conclusion, since the light intensity of metal halide lamps was higher, the amount of chlorophyll in plants was also higher. In addition, the increase in the temperature of the environment due to the intensity of the light caused negative impacts on the development of plants. Therefore, it is necessary to consider the distance of lighting while using artificial lights for growing plants.

Unlike other studies in the literature that were based on different production methods of light, this study has examined the effects of the light produced by various methods, on barley and wheat. Aydınşakir (2005) [34] analysed the development of goldenrod under incandescent and sodium vapour lamps and determined that the use of sodium vapour lamps led to the best results in yield, length of the stalk and bunch, stem diameter, flower offshoot and wet weight values of the plants. Demirsoy et al. (2016) [35] analysed proportional leaf weight, proportional stem weight, proportional root weight, leaf zone, leaf thickness, specific leaf zone and proportional leaf zone parameters of eggplant (*Solanum melongena* L.) seedlings during two different periods (autumn and spring) with three different sources of light (high-pressure sodium vapour lamp (HPS), incandescence lamp (IL) and light-emitting diode (LED). They determined that artificial lighting applications increased the proportional stem weights and proportional leaf weights of eggplant seedlings. When lengths of eggplant seedlings were compared, those grown under incandescent lamps had the shortest length for both periods. Uzun (1996) [36] stated that change in eggplant plant length increased linearly with heat and curvilinearly with light. Kandemir (2005) [37] confirmed that when the intensity of the light increased, the plants became shorter and stem diameter increased, and they determined that the formation of plants with thin stems occurred in low light. Islam et al. (2012) [38] compared LED and traditional high-pressure sodium vapour lamps while growing *Euphorbia pulcherrima*. Plants grown both in greenhouses and in plant growth rooms were compared in terms of both high-pressure sodium vapour lamp and LEDs; plants grown under LEDs were 20–34% shorter. Mitchell et al. (2015) [39] analysed a number of characteristics and effects related to incandescence lamps, metal halide lamps, fluorescent lamps, high-pressure sodium vapour discharge lamps and LED

sources of light that are commonly used on garden plants, on plants under separate titles in his collection. They concluded that high-pressure sodium vapour lamp increased the yield and quality of tomatoes and increased the numbers and zones of leaves per seedling of tomatoes, pepper, cucumber and eggplant. Sumarni et al. (2022) [40] investigated the effects of red-blue LED and white fluorescent lamps on the growth and yield of aroponic potato seeds grown in the highlands. Artificial lighting was applied to on the plant at 110 cm, 120 cm and 130 cm distances. As a result of the experiments, it was observed that the red-blue LED lamp combination with a height of 110 cm had the highest efficiency. Yeh and Chung (2009) [41] mentioned that fluorescent, high-pressure sodium vapor, metal halogen lamps and incandescent lamps have long been used in tissue culture and growth chambers. And with that, they examined the potential of LEDs in indoor plant growing. As a result, they suggested that LEDs, which provide higher energy efficiency, are the primary light source. Köksal (2013) [42] used artificial lighting with red-orange LED light and determined that there were statistical differences in terms of plant height, biomass weight, number of flowers and leaves.

With the help of technology currently under development, the technological progress in artificial lights has enabled more opportunities for studies in the field of plant biology. Applying lower light intensity to plants has a limiting impact on photosynthesis as does apply applying high amounts of light above critical value. A suitable lighting source should be provided through artificial lighting for plant growth. In this way, the technical properties of light sources are quite important. In order to utilise productivity in agricultural production ideally, studies need to be continued to understand the interaction of the quality of light and other environmental parameters.

4. Conclusion

In this study, the effects of three commonly used sources of light on wheat and barley were analysed, and the data obtained corresponded with previous literature. The following results can be withdrawn from this study:

The effect of lower intensity light on plants has a limiting impact on photosynthesis as does apply high amounts of light above a critical light intensity value. Suitable lighting source should be provided through artificial lighting methods for improved growth in wheat and barley plants. For the maximum weight and length of wheat and barley plants, sodium vapour, incandescent lamps and LEDs perform better than those of other sources of lighting, respectively. Carotenoid levels and SOD activity in both plants are mainly improved with sodium vapour lamps whereas CAT activity was dominantly influenced by metal halogen lights especially effective on wheat

plant. Chlorophyll levels (i.e. a, b and a+b) improve mainly with sodium vapour and metal halogen lamps irrespective of the type of plant.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

References

[1] Şahin M., Oguz Y., Buyuktumturk F., (2015). Approximate and Three-Dimensional Modeling of Brightness Levels in Interior Spaces by Using Artificial Neural Networks, Journal of Electrical Engineering and Technology, 10, 1822-1829.

[2] Nikoudel, F., Mahdavinejad, M., Vazifehdan, J., (2018). Nocturnal architecture of buildings: interaction of exterior lighting and visual beauty, Light & Engineering, 26(1).

[3] Lister, G. 2018. Gas discharge lamps–a requiem.

[4] Karlicek, R., Sun, C. C., Zissis, G., Ma, R. (Eds.)., (2017). Handbook of advanced lighting technology, Springer.

[5] Craver, J. K., Boldt, J. K., Lopez, R. G., (2019). Comparison of supplemental lighting provided by high-pressure sodium lamps or light-emitting diodes for the propagation and finishing of bedding plants in a commercial greenhouse, Hortscience, 54(1), 52–59.

[6] Cole, L., Hoggatt, L. R., Sterrenberg, J. A., Suttmiller, D. R., Penney, W. R., Clausen, E. C., (2018). A Transient experiment to determine the heat transfer characteristics of a 100 W incandescent light bulb, operating at 48 W. Fluid Mechanics and Heat Transfer: Inexpensive Demonstrations and Laboratory Exercises, 179.

[7] Habich, N., Homeyer, I. K., (2018). Untersuchung zur vermeidung der blaulichtanteile bei der hintergrundbeleuchtung von displays unter einsatz von LED-Clustern mit steuerbarem farbspektrum (Doctoral dissertation, Universität Hildesheim).

[8] Ponce-Silva, M., Aqui, J. A., Osorio, R., & Lozoya-Ponce, R. E., (2018). Starting circuit adapted to stabilize hid lamps and reducing the acoustic resonances, IEEE Transactions on Power Electronics.

[9] Gavrilov, S. A., Gavrish, S. V., Puchnina, S. V., (2019). Investigation of processes in glass-ceramic solders of sapphire-niobium seals in gas-discharge lamps, Glass and Ceramics, 1-5.

[10] Shahzad K., Čuček, L., Sagir, M., Ali, N., Rashid, M.I., Nazir, R., Nizami, A.S., Al-Turaif, H.A., Ismail, I.M.I., (2018). An ecological feasibility study for developing sustainable street lighting system, Journal of Cleaner Production, 175, 683-695.

[11] Pena-Garcia, A., & Sędziwy, A., (2019). Optimizing lighting of rural roads and protected areas with white light: a compromise among light pollution, energy savings, and visibility, Leukos, 1-10.

[12] Kwok, K.F., Cheng, K.W.E., Ping, D., (2006). General study for design the HID ballasts, 2nd International Conference on Power Electronics Systems and Applications, 182-184.

[13] Cox, G., (2019). Fundamentals of fluorescence imaging, Pan Stanford.

[14] Dupuis, R. D., Krames, M. R., (2008). History, development, and applications of high-brightness visible light-emitting diodes. Journal of Lightwave Technology, 26(9), 1154-1171.

[15] Vialet-Chabrand, S., Matthews, J.S.A., Simkin, A.J., Raines, C.A., Lawson, T., (2017). Importance of fluctuations in light on plant photosynthetic acclimation, Plant Physiology, 173(4), 2163-2179.

[16] Ohasi-Kaneko K., Takase M., Kon N., Fujiwara K., Kurata K., (2007). Effect of light quality on growth and vegetable quality in leaf lettuce, spinach and komatsuna, Environmental Control in Biology, 45, 189-198.

[17] McCree, K.J., (1973). A Rational approach to light measurements in plant ecology. Current Advances in Plant Science, 3(4), 39-43.

[18] Zhu, XG., Long, S.P., Ort, D.R., (2008). What is the maximum efficiency with which photosynthesis can convert solar energy into biomas?, Current Opinion in Biotechnology, 19(2), 153-159.

[19] Galvao, V. C., Fankhauser, C., (2015). Sensing the light environment in plants: photoreceptors and early signaling steps, Current Opinion in Neurobiology, 34, 46-53.

[20] Van Iersel, M.W. Weaver, G. Martin, M.T. Ferrarezi, R.S. Mattos, E. Haidekker, M., (2016). A chlorophyll fluorescence-based biofeedback system to control photosynthetic lighting in controlled environment agriculture, Journal of the American Society for Horticultural Science, 141, 169–176.

[21] Taiz, L., Zeiger, E., (2008). Plant Physiology, Palme Yayıncılık, Ankara.

[22] Çetin, M., (2016). Changes in the amount of chlorophyll in some plants of landscape studies, Kastamonu Univ. Journal of Forestry Faculty, 16(1), 239-245.

[23] Tanaka, Y., Sasaki, N. and Ohmiya, A. (2008) Biosynthesis of Plant Pigments: Anthocyanins, Betalains and Carotenoids, Plant Journal, 54, 733-749.

[24] Demirtaş, M.N., Kırnak H., (2009). Effects of different irrigation systems and intervals on physiological parameters in apricot, Yuzuncu Yıl University Journal of Agricultural Sciences, 19(2), 79-83.

[25] Keddy, P. A., (2017). Plant ecology, Cambridge University Press.

[26] Griffith M., Ala P., Yang DS., Hon WC., Moffatt BA., (1992). Antifreeze protein produced endogenously in winter rye leaves, Plant Physiology, 100(2), 593-596.

[27] Porra, R.J., Thompson W.A., Kriedemann P.E., (1989). Determination of accurate extinction coefficients and simultaneous equations for assaying chlorophylls a and bextracted with four different solvents: verification of the concentration of chlorophyll standards by atomic absorption spectroscopy, Biochimica et Biophysica Acta (BBA)-Bioenergetics, 975(3), 384-394.

[28] Osma, E., İlhan, V., Yalçın, İ.E., (2014). Heavy metals accumulation causes toxicological effects in aquatic *Typha domingensis* Pers, Brazilian Journal of Botany, 37, 461–467

[29] Angelini, R., Federico, R., (1989). Histochemical evidence of polyamine oxidation and generation of hydrogen peroxide in the cell wall. Journal of Plant Physiology, 135, 212-217.

[30] Osma, E., Cigir, Y., Karnjanapiboonwong, A., Anderson, TA., (2018). Evaluation of selected pharmaceuticals on plant stress markers in wheat, International Journal of Environmental Research, 12, 179–188.

[31] Havir, E. A., & McHale, N. A., (1987). Biochemical and developmental characterization of multiple forms of catalase in tobacco leaves, Plant Physiology, 84(2), 450-455.

[32] Osma, E., Cigir, Y., Karnjanapiboonwong, A., Anderson, TA. 2018. Evaluation of selected pharmaceuticals on plant stress markers in wheat, International Journal of Environmental Research, 12, 179–188.

[33] Agarwal, S., Pandey, V., (2004). Antioxidant enzyme responses to NaCl stress in Cassia angustifolia. *Biologia Plantarum*, 48(4), 555-560.

[34] Aydınşakir, K., Özkan, H., Karagüzel, Ö., Kaya, A., (2005). The effects of different artificial light sources on yield and quality characteristics of goldenrod (Solidago x hybrida ‘tara’), Akdeniz University Journal of the Faculty of Agriculture, 18(3), 377-384.

[35] Demirsoy, M., Balkaya, A., Uzun, S., (2016). The Effect of different light sources and artificial colour treatments on eggplant (*Solanum melongena* L.) seedling growth parameters, Selcuk. Journal of Agricultural Sciences, 3(2), 238-247.

[36] Uzun, S., (1996). The quantitative effects of temperature and light environment on the growth, development and yield of tomato and aubergine. PhD Thesis, The University of Reading (Unpublished), England.

[37] 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. PhD Thesis, Ondokuz Mayıs University, Institute of Science and Technology, Samsun.

[38] Islam, M. A., Kuwar, G., Clarke, J. L., Blystad, D. R., Gislerød, H. R., Olsen, J. E., & Torre, S,. (2012). Artificial light from light emitting diodes (LEDs) with a high portion of blue light results in shorter poinsettias compared to high pressure sodium (HPS) lamps, Scientia Horticulturae, 147, 136-143

[39] Mitchell, C. A., Dzakovich, M. P., Gomez, C., Lopez, R., Burr, J. F., Hernández, R., Bourget, C. M., (2015). Light-emitting diodes in horticulture, Horticultural Reviews, 43, 1-87.

[40] Sumarni, E., Soesanto, L., Purnomo, W.H., Priswanto., (2022). The effect of light distance on aeroponic potato seed production in tropical high land, Jurnal Teknik Pertanian Lampung, 11(1), 99-109.

[41] Yeh, N., Chung, J., (2009). High-brightness LEDs energy efficient lighting sources and their potential in indoor plant cultivation, Renewable and Sustainable Energy Reviews, 13(8), 2175-2180.

[42] Köksal, N., İncesu, M., Teke A., (2013). Effects of LED Lighting on Plant Development of Tomato, Research Journal of Agricultural Sciences, 6(2), 71-75.