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EFFECTS OF LIGHT AT DIFFERENT DISTANCES AND POWER ON WHEAT (*Triticum aestivum* L.) AND BARLEY (*Hordeum vulgare* L.) GROWTH

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ABSTRACT

Global population growth increases the need for efficient methods of maintaining a stable food supply. Light is one of the most important influences on plant growth and development. Artificial lighting elements used in agricultural applications have different effects on plants. This study analyzed the effects of metal halide (MH) lamps with a wavelength of 450 nm, at distances of 1, 1.5, and 2.5 m, on barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.) growth. Growing occurred in light magnification rooms without daylight, using 250, 400, and 600 W MH lamps as the only light source. Plants exposed to light for 13–14 h a day were harvested after 18 days. After harvest, the amount of electrolyte leakage, chlorophyll, carotenoid, and B, Cu, Mn, Zn, K, and Ca intake were determined using inductively coupled plasma optical emission spectroscopy (ICP-OES). The data were analyzed with the SPSS 22 Statistical Package program. Wheat and barley grown at different light distances and intensities showed statistically significant changes in mineral element uptake and plant chlorophyll levels. This research contributes to the optimization of agricultural productivity and the understanding of the interaction between light quality and other environmental parameters.

Keywords: artificial light, chlorophyll, ICP-OES, mineral element uptake.

INTRODUCTION

It is an undeniable fact that light affects every living organism. Plants need a great deal of light as well as different environmental conditions. Light affects plant growth, development, and different metabolic functions while also providing energy for photosynthesis (Yeh and Chung, 2009; Li *et al*., 2012; Lee *et al*., 2014). Light could be effective at different levels in all plant developmental stages, such as the germination process. Not only is light necessary for plant development, but the quality of the light is also important (Wu *et al*., 2007).

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Plants require light at specific wavelengths for optimal growth. Increasing the light intensity to a certain degree improves the photosynthesis rate; however, after a certain value, this becomes adverse (Wu *et al*., 2007). When plants photosynthesize, they prefer medium-wavelength beams of blue, yellow, and red. These contribute to the formation of chlorophyll, the development of tissues, and blossoming (Taiz and Zeiger, 2008; Hogewoning *et al*., 2010; Samuolienė *et al*., 2012). Chlorophyll is the foundation of growth by using inorganic chemicals and generating organic substances (Samuolienė *et al*., 2012). Light is a critical signal that induces plastid development and carotenoid biosynthesis in plants. During photoreceptors, photomorphogenesis, or de-etiolation, are activated, initiating the production of molecular factors necessary for the biosynthesis of carotenoids and chlorophyll. In fruits, light absorption by chloroplasts during the early stages of ripening facilitates the gradual synthesis of carotenoids in both the peel and pulp, coinciding with the initiation of chromoplast development (Quian-Ulloa and Stange 2021).

Light requirements are directly related to soil fertility. Plants grown in poor soils contain more chlorophyll in their leaves to increase photosynthesis, enhancing both dry matter accumulation and yields (Long and Bernacci, 2003). Moreover, macro- and micronutrients are essential variables influencing plant growth and metabolism in their natural environments (Kumar et al., 2021). A number of studies suggest that nutrient uptake and utilization by plants is modified by light quality, intensity and photoperiod. In particular, light alters the uptake of multiple elements through changes in light quantity and quality. Furthermore, studies reveal links between light perception and nutrient uptake (Chen et al., 2016; Sakuraba and Yanagisawa, 2018; Lin et al., 2020; Xua et al.,2021). Minerals are vital for normal growth, development, fruiting, flowering, and other plant activities (Broadley *et al*., 2012; Subramanian *et al*., 2022). Although minerals are essential micronutrients responsible for many regular processes in plants, their excess can have detrimental effects and directly affect plant growth, metabolism, physiology, and aging (Ghori *et al*., 2019).

Artificial light sources vary depending on wavelengths, colors, and other characteristics. Differences in the light spectrum cause different photosynthetic and morphogenetic responses for each plant species (Urbonavičiūtė *et al*., 2008). High-pressure sodium steam discharge lamps, incandescent wire lamps, fluorescent lamps, and metal halogen lamps are often used as light sources in plant production, while the usage of LED lamps has lately increased (Lee *et al*., 2017). Artificial light sources in plant cultivation are used both to support sunlight and as an alternative solution in places with no sunlight.

This study aimed to understand the role of metal halide (MH) lamps in plant growth and to investigate the effects of 250, 400, and 600 W MH lights, set at different distances (1, 1.5, and 2.5 m), on the yields of barley (*H. vulgare* L.) and wheat (*T. aestivum* L.). Given the increasing need for effective strategies to maintain a secure food supply due to issues like the growing global population and the ongoing climate crisis, this study may represent an important contribution to the field of sustainable agriculture.

MATERIALS AND METHODS

In the present study, wheat (Bezostaja), and barley (Kral 97) seeds were planted in soil mixed with animal manure taken from agricultural fields. The soil was prepared for 750 g and placed in plastic pots. The seeds were weighted, and 6 g of wheat seeds and 5 g of barley seeds were planted in each pot. Three pots of barley and three pots of wheat seeds were prepared for each light source application. Then, the planted seeds were covered with soil. After germination, the wheat and barley plants were exposed to light at different distances (1 m, 1.5 m and 2.5 m) under 250, 400, and 600 W metal halide (MH) lamps with a wavelength of 450 nm for approximately 13–14 hours a day. Plants were irrigated during the growing process, taking into account field capacity and irrigation methods, and harvested at the end of 18 days.

Electrolyte leakage in the cell

After harvest, 0.1 g of fresh leaf samples were taken and placed in test tubes separately. Each tube was filled with 4 ml of pure water and stored at 4 °C for 24 h. Additionally, to determine cell damage, the amount of ions transferred from the samples to the water was examined using an electric conductometer (Griffith *et al*., 1992; Duman and Koca, 2014).

Chlorophyll and carotenoid concentrations determination

To evaluate the amount of chlorophyll, 0.5 g of the harvested leaves were placed in a porcelain mortar with 20 mL of 80 % acetone. The mixture was homogenized using a pestle, filtered using filter paper, transferred to a 10 mL centrifuge tube, and centrifuged for 10 min. The absorbance values at 663, 646, and 440 nm were determined individually using a spectrophotometer. The amount of chlorophyll (Chl) and carotenoids (Car) was calculated using the equations below. Results were reported in mg g^{-1} FW (fresh biomass weight) (Porra *et al*., 1989; Osma *et al*., 2014; Duman and Koca, 2014).

$$Chl\ a = 12.25\ A663 - 2.55\ A646$$

$$Chl\ b = 20.31\ A646 - 4.91\ A663$$

$$Chl\ a + b = 17.76\ A646 - 7.34\ A663$$

$$Car = 4.69\ A440 - 0.267\ Chl\ a + b$$

Mineral elements determination

Harvested wheat and barley samples were dried in an oven at 80 °C for 24 h, ground into a powder in a mortar, and placed in separate plastic bags for storage. To avoid mixing the powders of the samples during the powdering process, ethyl alcohol was added after each sample was powdered. Following the addition of 10 mL of 65 %

HNO_3, 0.5 g of each plant were weighed into Teflon cells and burned for 20 min at 180 °C using a microwave device at 280 Psi = 1930.5 kPa. The cells were allowed to cool, and the samples inside were adjusted to 50 mL with distilled water. The samples were then filtered using filter paper, and the element concentrate on was determined at the appropriate wavelengths using an inductively coupled plasma optical emission spectroscopy (ICP-OES) instrument (Duman *et al*., 2015; Osma *et al*., 2017; Elveren and Osma, 2022). Results were reported in mg kg^{-1} DW (dry weight).

Statistical Analysis

The data were analyzed with the SPSS 22 Package Statistical program (IBM Statistics) using an ANOVA test with a 95 % confidence interval. The differences between samples in multiple comparisons were determined by S-N-K and Tukey's B test (Elveren and Osma, 2022).

RESULTS AND DISCUSSION

Chlorophyll-*a* concentration ranged from 8.16 to 13.56 mg g^{-1} FW in barley, with the maximum value observed in the group that received light from a 250 W lamp from a 1.5 m distance. In wheat, the amount of chlorophyll-*a* ranged from 9.58 to 17.75 mg g^{-1} FW, and the highest value was found in the group that received light from a 400 W lamp from a 2.5 m distance (Figure 1).

Chlorophyll-*b* concentration ranged between 3.24 and 5.48 mg g^{-1} FW in barley, with the best results obtained using a 600 W lamp from a 1 m distance, whereas in wheat, it ranged between 4.45 and 5.90 mg g^{-1} FW, with the best results obtained using a 600 W lamp from a 1 m distance (Figure 2).

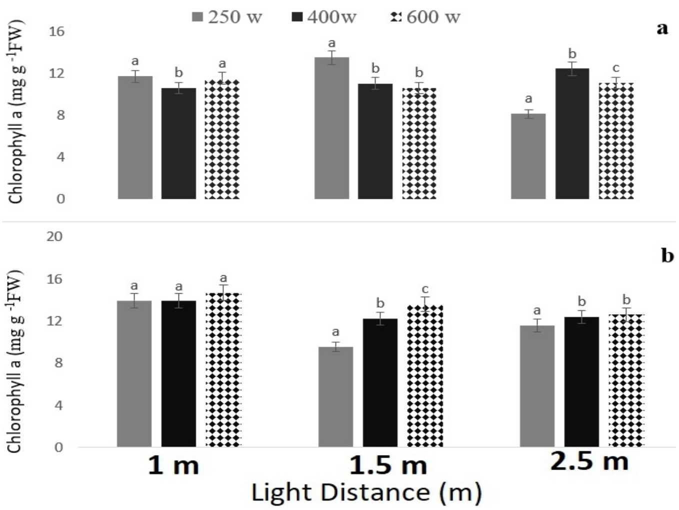

Figure 1. Chlorophyll *a* in leaves of plants cultivated with light at different distances and radiant power values. a: barley; b: wheat.

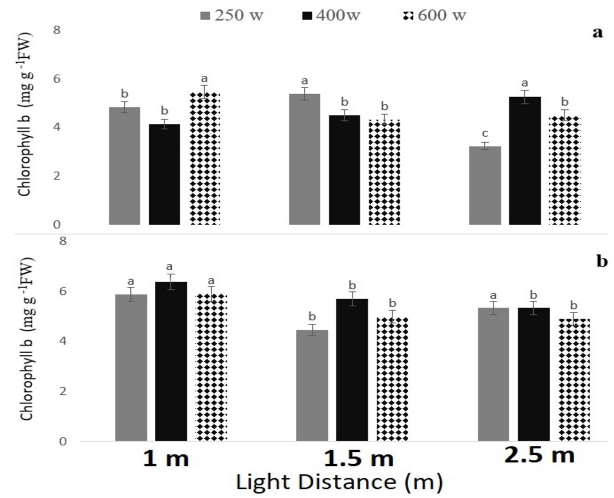

Figure 2. Chlorophyll *b* in leaves of plants cultivated with light at different distances and radiant power values. a: barley; b: wheat.

The total amount of chlorophyll in barley ranged between 11.4 and 18.95 mg g^{-1} FW, with the highest values obtained using a 250 W lamp from a 1.5 m distance. In wheat, it ranged between 14.04 and 20.61 mg g^{-1} FW with a 600 W lamp from a 1 m distance (Figure 3).

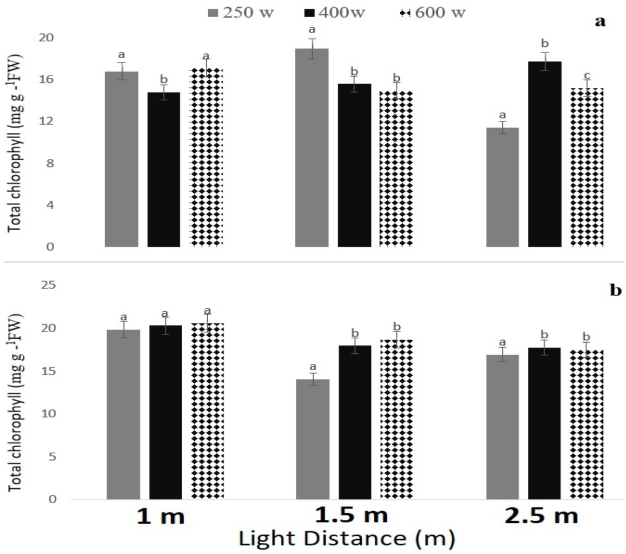

Figure 3. Total chlorophyll in leaves of plants cultivated with light at different distances and radiant power values. a: barley; b: wheat.

The results indicated that there were 1.56–2.70 mg g^{-1} FW of carotenoids in barley, with the highest concentrations observed using a 250 W lamp from a distance of 1.5 m. The optimal results were obtained using a 600 W from a 1 m distance in wheat, with carotenoid levels of 1.81–2.84 mg g^{-1} FW (Figure 4).

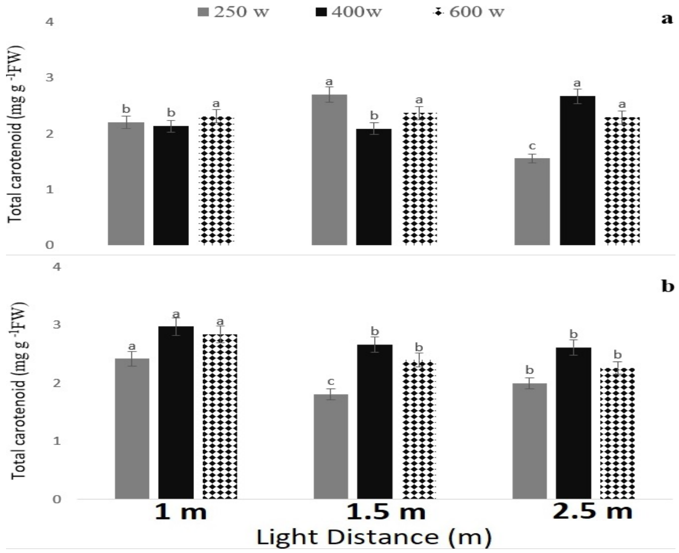

Figure 4. Total carotenoids in leaves of plants cultivated with light at different distances and radiant power values. a: barley; b: wheat.

In this study, it was found that the concentration of electrolyte leakage in wheat and barley plants varied depending on the distance and power of the applied light source. This finding reveals the effects of light intensity and distance on the cellular membrane permeability of plants and provides important clues about plant physiology. In particular, new information has been provided on how different light conditions affect the stress tolerance mechanisms of plants, thus contributing to the development of important strategies for increasing agricultural productivity and protecting plant health (Figure 5).

Statistically significant differences were observed when comparing the chlorophyll levels of plants grown at different light intensities and distances. These results indicate that growing conditions have a determining effect on chlorophyll production. In this study, the amount of chlorophyll in barley was higher in samples grown at 400 W and a distance of 1.5 m. In wheat, in general, the amount of chlorophyll was found to be higher in samples grown with a 400 W light source and at a distance of 1 m.

Given the element concentration data obtained in the present study, in barley, it was found that the values obtained for B (5.11–15.48 mg kg^{-1} DW), Mn (35.79–58.06 mg kg^{-1}

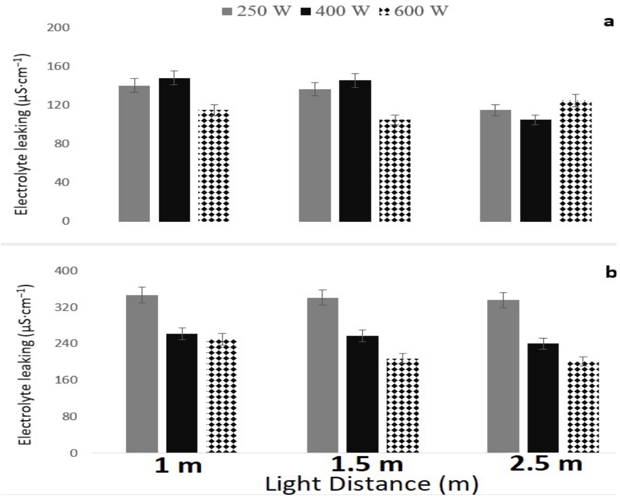

Figure 5. Electrolyte leaking in leaves of plants cultivated with light at different distances and radiant power values. a: barley; b: wheat.

DW), Zn (42.38–61.55 mg kg^{-1} DW) and K (55 399.22–63 472.64 mg kg^{-1} DW), were the highest when using a 250 W light source at a distance of 2.5 m; for Cu, concentration was higher (11.47–14.82.5 mg kg^{-1} DW) with a 600 W lamp at a 2.5 m distance; and for Ca (2 069.43–2 954.47 mg kg^{-1} DW), the highest values were found using a 400 W lamp at a distance of 2.5 m (Table 1).

Table 1. Mineral element concentrations in barley leaves grown with light at different distances and radiant power values (mg kg^{-1} dry weight).

Element	Distance (m)	250 W	400 W	600 W
K	1.0	63 620.09 ± 638.50	57 697.99 ± 790.39	57 353.81 ± 700.23
	1.5	56 474.17 ± 948.92	61 662.83 ± 872.96	55 399.22 ± 880.10
	2.5	63 338.64 ± 795.55	58 022.29 ± 942.19	60 791.34 ± 757.24
Ca	1.0	2 166.38 ± 34.99	2 295.42 ± 48.11	2 085.18 ± 23.61
	1.5	2 069.43 ± 33.88	2 169.52 ± 96.43	2 901.06 ± 17.33
	2.5	2 477.25 ± 25.00	2 954.47 ± 38.33	2 556.94 ± 20.77
B	1.0	7.64 ± 0.04	11.96 ± 0.22	7.41 ± 0.10
	1.5	5.11 ± 0.08	10.96 ± 0.16	11.57 ± 0.12
	2.5	15.48 ± 0.38	15.30 ± 0.11	11.50 ± 0.09
Mn	1.0	51.72 ± 0.34	45.68 ± 0.70	50.36 ± 0.69
	1.5	51.61 ± 0.67	37.72 ± 0.44	55.74 ± 0.92
	2.5	58.06 ± 0.21	35.79 ± 0.78	46.75 ± 0.86
Zn	1.0	51.02 ± 0.43	45.34 ± 1.21	47.10 ± 0.99
	1.5	51.19 ± 0.26	45.08 ± 0.66	42.38 ± 0.30
	2.5	61.55 ± 0.28	46.90 ± 0.62	43.96 ± 0.14
Cu	1.0	13.60 ± 0.48	13.44 ± 0.46	14.81 ± 0.43
	1.5	13.44 ± 0.25	12.79 ± 0.37	13.77 ± 0.25
	2.5	14.10 ± 0.22	11.47 ± 0.47	14.82 ± 0.21

In wheat, it was determined that the concentration of B (10.14–17.46 mg kg^{-1} DW), Cu (14.02–19.22.5 mg kg^{-1} DW), Mn (26.02–79.47 mg kg^{-1} DW), Zn (54.53–95.74 mg kg^{-1} DW), and Ca (2 118.20–4 527.11 mg kg^{-1} DW) was higher in the samples grown using a 250 W light source at a distance of 2.5 m, while and the concentration of K (55 804.74–77 735.07 mg kg^{-1} DW) was higher in the samples grown at a distance of 2.5 m using a 600 W light source (Table 2).

Table 2. Mineral element concentration in wheat leaves grown with light at different distances and radiant power values (mg kg^{-1} dry weight).

Element	Distance(m)	250 W	400 W	600 W
K	1.0	55 804.74 ± 766.65	72 275.60 ± 677.35	66 225.41 ± 1 469.05
	1.5	64 262.84 ± 1 243.47	60 815.29 ± 789.35	66 496.31 ± 590.98
	2.5	62 666.88 ± 762.25	68 985.34 ± 594.97	77 735.07 ± 1 370.60
Ca	1.0	3 237.02 ± 51.52	2 795.42 ± 19.11	2 138.25 ± 21.39
	1.5	3 183.73 ± 26.04	2 501.06 ± 63.81	2 118.20 ± 16.70
	2.5	4 527.11 ± 43.20	2 510.24 ± 18.55	2 482.91 ± 37.63
B	1.0	16.08 ± 0.46	11.44 ± 0.09	12.41 ± 0.25
	1.5	17.46 ± 0.51	10.14 ± 0.43	12.38 ± 0.16
	2.5	14.67 ± 0.12	11.65 ± 0.43	10.55 ± 0.05
Mn	1.0	40.03 ± 0.87	32.42 ± 0.35	26.02 ± 0.57
	1.5	51.81 ± 0.52	34.19 ± 1.30	28.49 ± 0.43
	2.5	79.47 ± 2.56	35.50 ± 0.72	45.89 ± 0.34
Zn	1.0	71.96 ± 0.45	59.94 ± 1.08	62.18 ± 0.66
	1.5	82.88 ± 0.88	54.53 ± 1.72	75.76 ± 1.00
	2.5	95.74 ± 0.73	63.57 ± 0.96	76.37 ± 0.81
Cu	1.0	14.57 ± 0.20	17.17 ± 0.40	14.02 ± 0.24
	1.5	17.32 ± 0.25	15.69 ± 0.46	16.14 ± 0.21
	2.5	19.22 ± 0.42	17.44 ± 0.32	19.14 ± 0.56

It was determined that the concentrations of K, B, Mn, and Zn were generally higher in wheat samples grown at a distance of 2.5 m with a 250 W light source. On the other hand, for barley, it was observed that the concentration of Ca, Mn, Zn, and Cu increased in samples grown at a distance of 2.5 m with a 250 W light source. These results indicate that plants can uptake nutrients in different ways according to environmental conditions and that appropriate cultivation strategies are important in optimizing plant nutrient uptake. Therefore, it is necessary to carefully evaluate the effects of lighting intensity and distance on plant nutrition and growing practices. Previous studies found that there were considerable changes in element concentrations at different light intensities and distances. In a study on pea seeds (*Pisum sativum* L.), Wu *et al*. (2007) found no difference in stem diameter between seedlings produced in the dark and those grown under LED lights, but light quality had a significant impact on stem length, leaf area, and seedling weight. Islam *et al*. (2012) examined LED and classic high-pressure sodium lamps to grow the poinsettia plant (*Euphorbia pulcherrima* Willd. ex Klotzsch), and those growing under LED were found to be 20–34% shorter. Furthermore, Yamaguchi *et al*. (2019) studied the relationship between LED lighting system power usage and lettuce (*Lactuca sativa* L.) leaf development in a hydroponic plant-growing system. The development of lettuce in a growing system with minimum electrical power and a long illumination time was found to be outstanding. Limprasitwong and Thongchaisuratkrul (2018) evaluated shallot plants (*Allium ascalonicum* L.) under daylight, LED light, and in nursery conditions under a grow lamp. In the first seven days, shallots grown under LED light and the growth lamp had a greater germination rate, and the grow lamp performed better than the LED in the first three days. In another study, Hamamoto and Yamazaki (2009) supplemented greenhouse tomatoes (*Solanum lycopersicum* L.) with a 40 W fluorescent lamp for 2 h at sunrise and found that tomato productivity and fruit quality increased by 10 % when conducting trials in the spring-summer and autumn-winter months.

Lin *et al*. (2013) used red-blue (RB) LED, red, blue, white (RBW) LED, and fluorescent lamp (FL) as a control group in their study in Taiwan and evaluated the responses of chlorophyll accumulation, plant biomass, carotenoids, soluble protein, sugar, and nitrate to three different light sources in lettuce leaves. Plants cultivated under RBW LED applications had high soluble sugar and low protein content compared to RB LED combinations. Accordingly, there were no significant differences in chlorophyll, carotenoid, or soluble proteins in lettuce leaves.

It was found that LED lamps can affect the production of phenolic compounds in buckwheat sprouts (*Fagopyrum esculentum* Moench), and certain light intensities and LED burning time could be important in the growth chamber to increase phenolic compounds (Lee *et al*., 2014). It has been observed that external lighting increases seedling growth and quality in vegetable-growing greenhouses. A new approach in greenhouse lighting systems is the strong illumination of tomatoes, peppers, and cucumbers throughout the entire growth cycle (Olle and Viršilė, 2013).

Experiments have been devised to clarify the impact of monochromatic LED light or different combinations on plant morphogenesis and physiology. Significant differences in several parameters were observed when comparing plants under fluorescent light. In a study on *in vitro* banana (*Musa acuminata* Colla) plantlets, a significant increase in chlorophyll-*a*, chlorophyll-*b*, total chlorophyll levels, and a number of stomata was observed under LED illumination compared to fluorescent lamp illumination (Vieira *et al*., 2015).

Both the color temperature and wavelength of commonly used white LED fixtures have significant effects on plants. As the color temperature increased, there were corresponding increases in plant height and weight values, chlorophyll and carotene levels, and mineral absorption capacity (Şahin *et al*., 2022a). In their study, Şahin *et al*. (2022b) analyzed the effects of three commonly used light sources on wheat and barley and found that chlorophyll levels (*a*, *b*, and *a*+*b*) in plants with stress factors differed according to the light sources. Furthermore, in the study, El Haddaji *et al*.

(2023) concluded that producing micro-greens under artificial LED lighting is a very important model to solve the problem of decreasing arable land stocks per capita due to problems such as increasing population, decreasing water resources, urbanization, and climate change.

Miao *et al*. (2023) found that increasing the light intensity had a positive effect on plant height and leaf number in two lettuce varieties (*Lactuca sativa* L.) and one spinach variety (*Spinacia oleracea* L.), which is consistent with previous studies. While Crunchy lettuce plant width was not affected by changing light intensities, Deangelia lettuce width decreased as light intensity increased. However, Shawen spinach width was positively correlated with light intensity. These results highlight the influence of species-specific traits, such as morphological and physiological traits, that make certain varieties more or less suitable for certain environments.

Compared to previous studies investigating the effects of light on plants, this study shows that different applications of light have significant effects on plants. In particular, in parallel with previous studies investigating the effects of different wavelengths and intensities of light on plant growth, development and productivity, this study found that specific light spectra and application methods caused significant differences in photosynthetic activity, biomass production and morphological characteristics of plants. Artificial lighting has an impact on plants in all of the aforementioned investigations. In the present study, unlike the previous studies, it was observed that light affects mineral element uptake and the amount of chlorophyll in plants by considering the light intensity and distance together. Artificial light sources are expected to become more essential in plant growth in the future as the world population increases. The developments in artificial light sources, especially with developing technology today, warrant further research studies, which may lead to innovations in indoor farming, vertical farming, and greenhouse production, where artificial lighting plays a crucial role in providing the necessary light energy for photosynthesis. Additionally, understanding how different light spectra affect plant growth can lead to more efficient and sustainable agricultural practices, potentially reducing the need for chemical inputs and optimizing resource use.

CONCLUSION

This study demonstrates the importance of artificial lighting for agricultural productivity by addressing the effects of light intensity and distance on elemental uptake and chlorophyll content in plants. This approach is important as artificial light sources are becoming increasingly important in indoor plant cultivation and greenhouse production. From this study, researchers and agricultural practitioners can develop more efficient and sustainable practices, potentially reducing the need for chemical inputs and optimizing resource use. This knowledge will contribute to meeting the growing global demand for food and addressing challenges such as limited arable land and climate change.

With the use of artificial light methods in plant cultivation, appropriate lighting should be provided for the plants. In addition to sunshine in agricultural production, the primary goal of using artificial lighting is to boost agricultural productivity by delivering adequate light under economic conditions. Benefiting from light that creates perfect conditions for the plant may be more efficient. The results obtained in this study emphasize that plant species respond differently to various lighting conditions and that cultivation methods should be carefully determined to ensure optimum chlorophyll production. Therefore, careful adjustment of lighting conditions in plant breeding practices can be a decisive factor in plant productivity and quality.

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