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Research article

The Effects of LEDs with different CCT values on growth characteristics of *Triticum aestivum* L. (wheat) and *Hordeum vulgare* L. (barley)

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Abstract

Light Emitting Diode (LED)s are used extensively in almost everywhere in our daily life and they have different color temperatures such as Correlated Color Temperature (CCT) which is represented by ˚K (Kelvin). In this study, wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) were cultivated in laboratory environment under LED with different CCT values (2000, 3000, and 6000˚K). After cultivation, plant height and weight values, the quantity of chlorophyll and carotene, the amount of leakage of electrolyte and element absorption capacity from the soil, POX (Peroxidase) and SOD (Superoxide Dismutase) enzyme activities of cultivated plants were determined. Results were evaluated on Statistical Package for the Social Sciences Program (SPSS 22) and significant differences were obtained on plants which were grown at different color temperatures of light. It was concluded that measurements from plants which were grown under LED light with cold color temperatures (6000˚K) were more consistent than those of plants grown under other lights with different temperatures. It has been deduced that cold color temperatures are closer to the optimum light values required for a plant to grow faster.

Keywords: *Barley; Correlated Color Temperature (CCT); lighting, Light Emitting Diode (LED); plant lighting; wheat*

1. Introduction

LED stands for Light Emitting Diode. LED consists of two elements of a treated substance, which is referred as p-type and n-type semiconductors. LEDs are indeed semiconducting diodes that give out light via photons from p-n junction parts (Dupuis and Krames, 2008). The temperature of a light source which has the same coordinates with the color of luminescence of a black object at a certain temperature is described as "Color Temperature". However, the term "Correlated Color Temperature (CCT)" is used for light sources such as fluorescent lamps whose color values do not exist on black objects. CCT values of this kind of light sources are accepted as the temperature of the luminescence of black object which gives out the closest color to them under the same observation and radiance conditions (Wyszecki and Stiles, 1982). LEDs are produced with CCT values between 1000˚K and 6500˚K that enables LEDs to be used in various application fields. Luminous

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efficacy of LEDs decreases at higher CCT values. CCT values of white power LEDs vary between 3200-9000˚K (Gurbuz, 2012). As given in Figure 1, the temperature between 3200-3300˚K is termed warm white, 3500-4500˚K is termed natural white, 5500-6500˚K is termed pure white or day light and 6500-9000˚K is termed cold white.

The light is an irreplaceable source of energy. Plants need light for the formation of chlorophyll, photosynthesis, the transformation of inorganic substances to organic substances, the formation of shoot, leaf, flower and fruits (Eris, 2007). The source of light which is needed for the growth of plants is either sun or artificial lights (Kim et al., 2005; Ohashi-Kaneko et al., 2007). The light from the sun consists of rays with different wave lengths. About 390 nm and 760 nm of wavelength of the light in the spectrum are termed visible light. Red-orange light in visible light spectrum is the light with the longest wavelength (600-700 nm). The energy of photons of visible wavelength from the electromagnetic rays from the sun is used for the photosynthesis by plants (Eris, 2007; Yang et al., 2012). Light is not just a source of energy for photosynthesis, it also controls different growth processes (Zhu et al., 2008). Several factors related to light such as light density, wavelength have effects on plant growth parameters (differences of node lengths, length of the plant, branch pattern, size of leaves and biomass) (Lee et al., 2014). The use of LED light has recently become widespread for additional lighting before sunrise or after sunset due to its superior advantages (Eris, 2007).

Leaves, which are one of the most important organs of plants, are necessary for photosynthesis. Photosynthesis abilities of leaves i.e. their efficiency of using light is directly proportionate to the chlorophyll concentration which is the pigment of green color (Kirbay and Ozer, 2015). Another parameter that light affects is the substance called carotene. Carotene is the pigment that gives the colors ranging from light yellow to red in plants. Some carotenoids functions as the pre-substance of vitamin A and therefore, they are important for the synthesis of the necessary vitamin A. Beta-carotene has certain beneficial properties such as protecting photons against harmful light during photosynthesis, acting as antioxidants, protecting against cancer, increasing immune response, inhibiting tumor growth (Kahyaoglu and Kivanc, 2007).

Caglayan and Ertekin (2011) analyzed the technological superiorities and differences of LED light in comparison with traditional growth lamps, discussed their effects on plants and concluded that LEDs are preferred in agriculture due to their distinguished properties. Bourget (2008) and Morrow (2008) stated that solid-state light sources are ideal for the designs of plant lighting and they investigated the effects of wave lengths on plant photoreceptors in order to provide optimal production, to effect plant morphology and metabolism. Lee et al. (2014) investigated the effect of different LED lights that used commonly on buckwheat and Tartary wheat, while Koc et al. (2009) analyzed technological properties of the sources of LED type lights and mentioned their properties in terms of plant and animal production. Furthermore, Ozkok et al. (2016) concluded in their studies that, a safe lighting support was obtained through LED lightings, sprout growth was healthier, the growth of plants could be under control and increase in productivity and quality could be achieved. They also stated that a homogeneous radiance could be created and a significant level of energy saving was also possible.

In the study by Wu et al. (2007) where pea seeds were analyzed, sprouts were incubated under different LED lights and in dark for 4 days. There was no difference in stem diameter in sprouts grown under LED lights and in dark; however, they have observed that stem length, leaf extent and sprout weight were affected by the quality of the light to a large extent. Caglayan and Ertekin (2015) compared LEDs with traditional sources of light in their study about plant growth rooms, and they concluded that LEDs are perfect sources of light that can provide benefits for plant growth environments such as plant tissue, growth rooms and cabins. (Chen et al., 2017) investigated the effects of alternative red and blue lights provided by LEDs on growth and nutritional properties of lettuce. In this research, red and blue LED lights were applied at different time periods and in different combinations in order to reveal the effects on red and blue lights on plant. Alternating irradiation of red and blue LEDs was observed to significantly increase the growth rate and biomass of lettuce when applied at varying time intervals. It was also observed that it increases the ascorbic acid content and reduces the nitrate content, leading to higher nutritional value.

There are limited numbers of studies related to the effects of LED lights in plant growth. Distinct from other studies in literature, current study aims to determine the potential effects of white LED lighting systems with 2000-6500˚K CCT value. Within this context, white LED lighting systems with 2000˚K, 3000˚K and 6000˚K color temperature values were designed and their potential effects on barley and wheat grown under this light were studied.

2. Materials and methods

LED Luminaires with 2000˚K, 3000˚K and 6000˚K CCT values were designed to illuminate the environments where the wheat and barley were planted. CCT, CRI and LUX values of these LED elements were determined by spectrometer (Gossen M600A) during designing stage. The light parameters of the LEDs are given in Table 1. LED Luminaires with different CCT values were installed separately on working plane where *T. aestivum* L. and *H. vulgare* L. are planted after all measurements were carried out and the design stage was completed.

Table 1
Light parameters

CCT (Correlated Color Temperature)	2000˚K	3000˚K	6000˚K
CRI (Color-Rending Index)	26.34	71.7	71.4
LUX (Light Intensity Level)	97.73	1426.4	1209.2
Light of Wavelength	595 nm	596 nm	442 nm

The soil used in the study was obtained from a productive, uncontaminated field where agricultural activities have been performed. ½ of the used soil has soil, ¼ has fertilizer and ¼ has pearlite. 750g of soil was placed into plastic pot with a capacity of 1 kg.

At first, 750g of soil was placed into the bottom of the pot, then 7g of wheat and 5g of barley were weighted and planted which then were covered with 100 g of soil. As seen in Fig. 1, three specimens were prepared and watered in accordance with the field capacity. Wheat and barley seeds in pots were exposed to almost 13 hours of light daily under LED luminaires with 2000˚K, 3000˚K and 6000˚K CCT values**.**

The wheat was harvested after 15 days and the barley was harvested after 11 days. First, the wet weight and height of the samples harvested at different color temperatures were determined and consequently, electrolyte leakage, chlorophyll levels, POX, SOD enzyme activities and mineral element

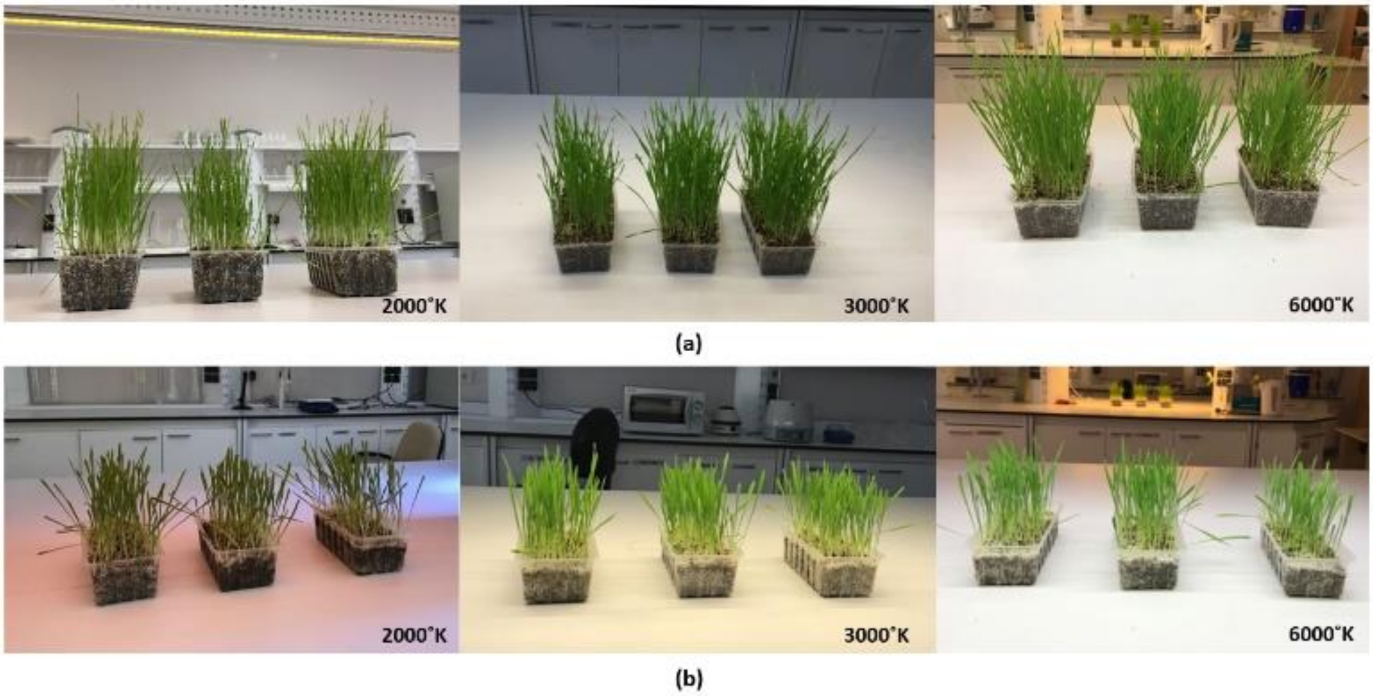

Fig. 1. Wheat (a) and barley (b) plants grown under different color temperature

concentrations were determined.

2.1. Determination of parameter values

0.1 g of rinsed fresh plant sample (leaf) was placed in each of 6 test tubes with 4 ml of pure water and kept at 4˚C for 24 hours. Then the amount of ion passing into the pure water in the tubes was measured with a conductometer. The response level of the plant was determined by setting a parallelism between the electrolyte leakage and the damage on the cell based on the measured value (Osma et al., 2014).

Total chlorophyll and carotenoid content in fresh leaves was estimated by using The Lichtenthaler and Buschmann (2001) method. Fresh leaf tissue with an amount of 0.5 g was grounded in a mortar and pestle which contained 5 ml acetone (80%). The solution had 663 and 646 nm (chlorophyll) and 440 nm (carotenoids) optical densities. Photosynthetic pigments were expressed as mg/g-1 FW (Osma et al., 2018).

The determination of antioxidant enzyme activities was performed on six replicate samples in the following manner. Plant leaves (0.5 g) were blended with 10 mM potassium phosphate buffer (pH = 7.0) which contains 4% (w/v) polyvinylpyrrolidone. The homogenized pulp was centrifuged at 12.000 x g for 30 minutes at 4˚C. Then the extract was isolated to determine the type of enzyme. After adding the plant extract to 50 mM phosphate buffer (pH = 7.0) which contains 1 mM guaiacol and 0.5 mM H_2O_2, POX was determined by monitoring the increase in absorbance at 470 nm. One unit of POX activity was defined as the amount of enzyme that caused an increase in absorbance of 0.01 per min (Osma et al., 2014).

The reduction in absorbance of nitroblue tetrazolium (NBT) dye was monitored and in this way the activity of superoxide dismutase (SOD) was determined (Dhindsa et al., 1981). The reaction consisted of a mixture of 75 µM NBT, 13 mM methionine, 0.1 mM EDTA, 2 µM riboflavin, 50 mM sodium carbonate, 50 mM phosphate buffer (pH = 7.8) and 0.1 mL of plant extract. The reaction was launched by irradiating tubes which contained the mixture using two 30-W fluorescent lamps for 15 minutes and ended by switching off the light. The absorbance of the mixture at 560 nm was measured instantly. The maximum color producing reaction mixture without enzymes was used as control. A mixture of non-irradiated complete reaction was used as a blank. The amount of enzyme, which reduces the absorbance by % compared to the tubes without enzyme, was determined as one unit of activity (Osma et al., 2014).

0.5 g of plant and sediment samples were arranged via precision scale and then put into Teflon cells. 5 ml of 65% HNO_3, 3 ml of 37% HCl and 2 ml of 48% HF (Merck) was added to the milled soil samples, as well as 8 ml of nitric acid (65%) to the milled plant samples (Osma et al., 2018). Samples were put into a microwave oven (Berghof-MWS2). Microwave was heated to 175˚C gradually and held constant for 20 minutes. Samples and chemicals were filtered by using Whattman filters into 50 ml sterile tubes and they were diluted to 50 ml with ultra-pure water to perform ICP-OES analysis. Before performing spectroscopic analysis (Merck), standards were prepared using 1,000 ppm multi element solution. ICP-OES measurements were performed after the calibration by using the standards (Osma et al., 2018).

Various analyses were performed by using the data obtained from our study. In the statistical comparison of obtained data $p \leq 0.05$ value was determined as significant and average values, standard deviation, ANOVA test multiple comparisons of the samples in confidence interval of 95% were performed.

3. Results and discussion

It was observed that the different color temperatures of the light have a significant effect on the plant growth. In this study, the amounts of chlorophyll and carotene, electrolyte leakage, mineral element capacity, catalase and peroxidase enzyme activities were also determined. Significant differences were

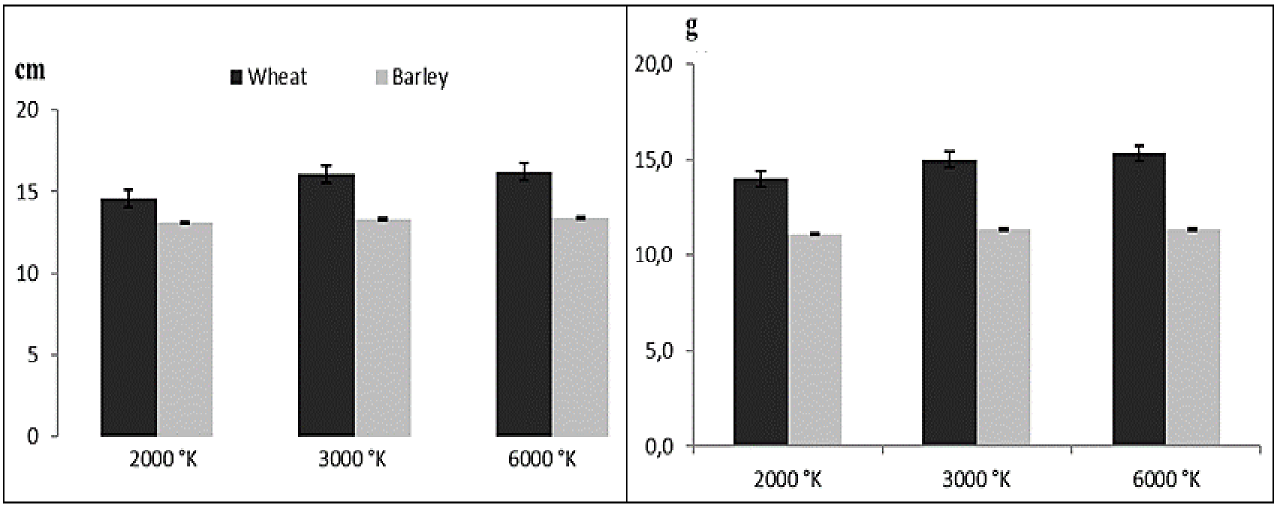

Fig. 2. Length and weights in wheat and barley of growth under LEDs with different color temperature.

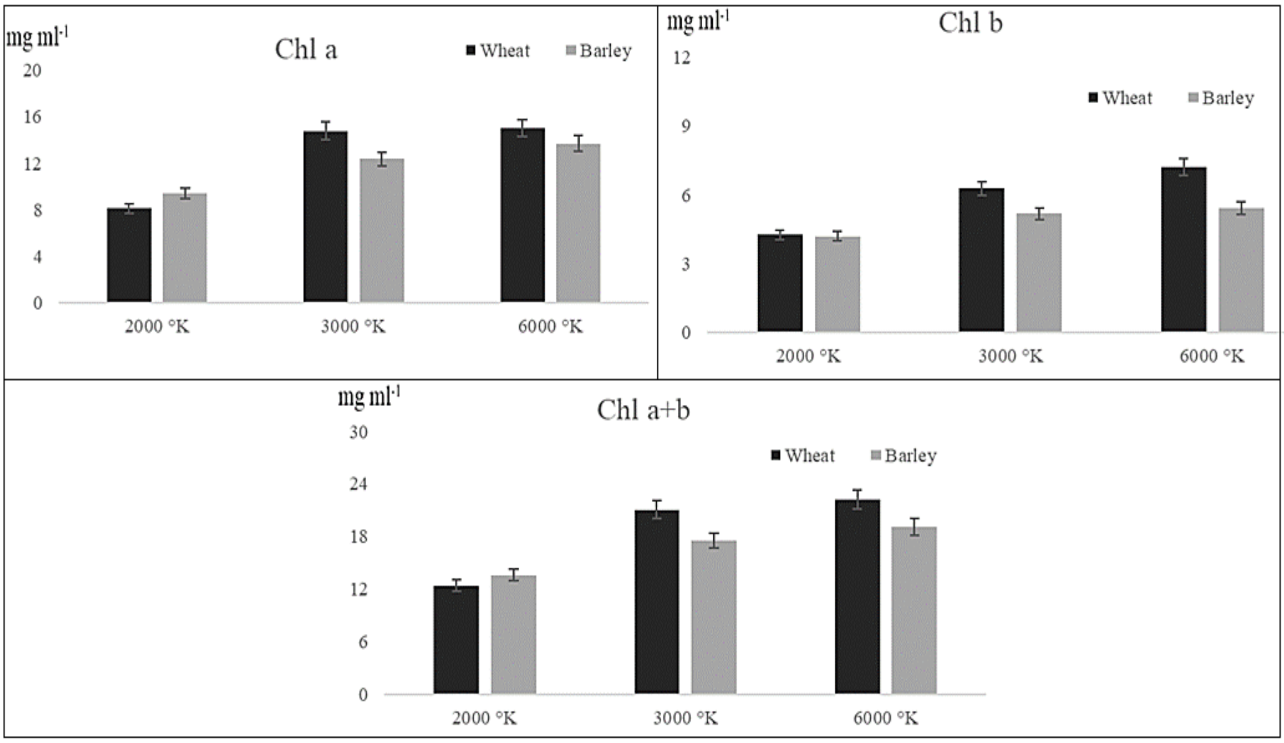

Fig. 3. Chlorophyll a, Chlorophyll b, Chlorophyll a+b in wheat and barley leaves of growth under LEDs with different CCT.

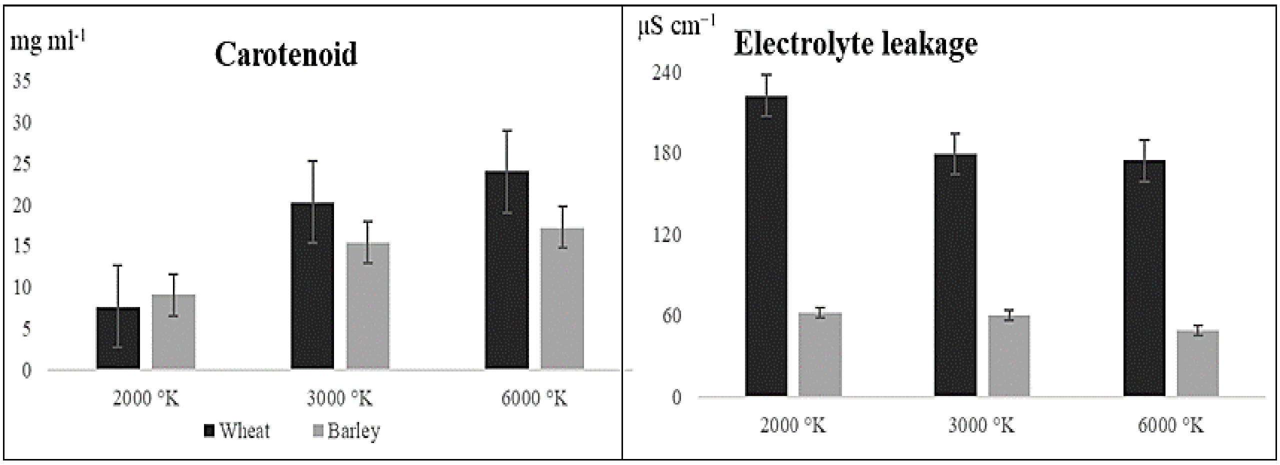

Fig. 4. Carotenoid and electrolyte leakage in wheat and barley leaves of growth under LEDs with different CCT.

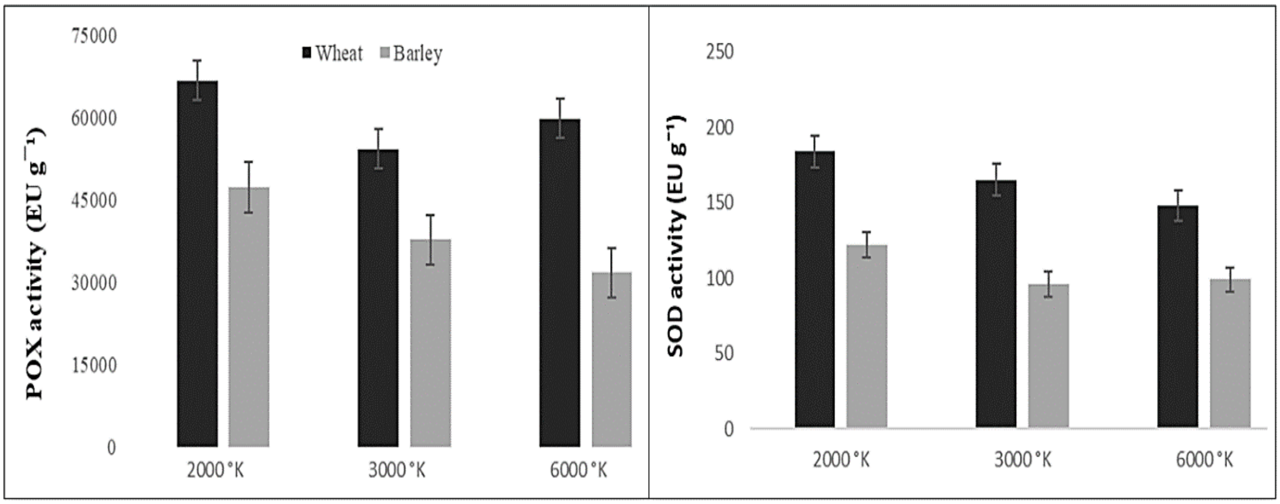

Fig. 5. POX and SOD activity in wheat and barley leaves of growth under LEDs with different CCT.

observed in the parameters that have an effect on wheat and barley in accordance with the color temperature of the light (Table 2). When the average post-harvest height measurement of the plants was examined, it was seen that it varied between 14.6-16.2 cm in wheat and 13.1-13.4 cm in barley. In addition, it was observed that the optimum value of average length was obtained at 6000˚K in both plants. Additionally, the weight of the plants changed between 14-15.3 g in wheat and 11.3-11.4 g in barley after harvesting and 6000˚K was again optimum light value for the maximum weight gain (Fig. 2).

Table 2
Statistical evaluation of data (**p*<0.05; ***p*<0.01; ****p*<0.001 significant).

	Wheat	Barley
Chl a	***	***
Chl b	**	Nd
Chl a+b	***	***
Carotenoid	***	*
Electrolyte leakage	*	**
CAT activity	Nd	Nd
POX activity	***	***

The amount of chlorophyll a varied between 8.15±0.63 - 15±0.2 mg ml^{-1} in wheat and 9.3±0.37 - 13±0.3 mg ml^{-1} in barley after harvesting. The amount of chlorophyll b varied between 4.2±0.3 - 7.2±2.4 mg ml^{-1} in wheat and 4.5±0.6 - 5.4±0.2 mg ml^{-1} in barley. The amount of chlorophyll a+b ranged between 12.4±0.7 - 22.2±0.8 mg ml^{-1} in wheat and 13.8±0.4 - 19.1±0.5 mg ml^{-1} in barley as seen in (Fig. 3).

The amount of carotenoid in wheat was 7.6±0.8 - 23.9±1.4 mg ml^{-1} and it was 10.3±1.6-16.3±1.8 mg ml^{-1} in barley. The amount of chlorophyll and carotenoid was more at 6000˚K (Fig. 4). The amount of electrolyte leakage in wheat was between 74±12.5 - 222±14.2 µS cm^{-1} and it changed between 49±2.4 - 62±3.9 µS cm^{-1} in barley. The loss of electrolyte in wheat and barley grown under the light with 2000˚K color temperature was more (Fig. 4).

SOD enzyme activity in wheat was between 148-184 EU/g, and its POX enzyme activity was between 54320-66711 EU/g. On the other hand, it was determined that SOD enzyme activity in barley was between 96-122 EU/g and its Peroxidase enzyme activity was between 31733-47315 EU/g. It was observed that both of the enzyme activities were pronounced in samples grown at 2000˚K when the obtained data was analyzed statistically. It was also determined that there are significant differences in both wheat and barley with respect to type of light (Fig. 5).

The effect of minerals is undisputable in the growth and developments of all the living creatures that obtain necessary elements form soil. It was observed that 7 nutrition elements i.e. Mg, K, P, Ca, Zn, Cu, Fe have statistically significant differences in terms of element absorption capacity in wheat and barley grown on the different color temperatures of the light. When the data was analyzed, mineral element concentration in the samples grown at 2000˚K appears to be lower than others. Especially, the concentration of Mg element in chlorophyll structure changed depending on the color temperature (Table 3).

Koksal et al. (2013) analyzed the growth parameters of plant length (cm) and it was determined that additional lighting with red-orange LED light created statistical difference in terms of plant length, number of leaves, number of flowers and biomass weight, while in this study, it was determined that LED light with higher color temperature increased plant height and weight compared to LED light with lower color temperature. Lee et al. (2014) found in their study that the levels of phenolic compounds tended to increase when LED was used in growing wheat plants. In our study, it was observed that the amount of chlorophyll and carotene in the plant increased as the color temperature of the used white LED luminaires was increased. Bourget (2008) and Morrow (2008) reported in their work that LED lighting systems have many advantages such as spectral composition, small size, durability, long operating life, wavelength specificity, and the ability to control photon output linearly with electrical input current. They stated that they are ideal for use in plant lighting designs and allow wavelengths to match plant photoreceptors to provide more optimal production and influence plant morphology and metabolism. Our study results showed that as the color temperature of LED luminaires, which has superior properties compared to other luminaires, increases, and the amount of magnesium element that the plant takes from the soil increases. Likewise, as the color temperature of the LED luminaires increased, the electrolyte leakage amount in the cells decreased. The research by Jiang (2021) was mainly conducted with pak choi (*Brassica rapa* L.) to detect the difference between physiological response and gene expression under treatments of varying LED spectra. An attempt has been made to determine the ideal LED lighting "Recipes" (which includes luminous intensity and LED spectrum) for particular species and varieties. In our study, different color temperatures

Table 3
Element concentration in wheat and barley leaves of growth under LEDs with Different CCT. (µg/g dw) (*p<0.05; **p<0.01; ***p<0.001 significant).

Element	CCT	Barley	Significant	Wheat	Significant
	2000°K	2593.2 ± 131.2		2264 ± 87.7	
Mg	3000°K	2751.9 ± 225.3	Nd	2513.3 ± 16.7	*
	6000°K	2740.1 ± 152.2		2488.5 ± 66.4	
	2000°K	5709.9 ± 106.7		10022.9 ± 71.6	
P	3000°K	6259.3 ± 479.7	Nd	10715.2 ± 177.8	***
	6000°K	6343.3 ± 797.8		10115.1 ± 49.9	
	2000°K	13.1 ± 0.3		14.3 ± 0.1	
Cu	3000°K	15.4 ± 0.5	*	14.4 ± 0.2	***
	6000°K	15 ± 0.7		13.5 ± 0.2	
	2000°K	45.8 ± 0.7		44.2 ± 1.2	
Zn	3000°K	49.7 ± 2.2	Nd	41.1 ± 0.8	*
	6000°K	48.1 ± 1.9		41.2 ± 0.6	
	2000°K	35389.2 ± 587.1		61256.7 ± 1171	
K	3000°K	41765.7 ± 2350.8	Nd	61785.2 ± 372.4	Nd
	6000°K	44705.5 ± 4448		61581.9 ± 306.1	
	2000°K	112.1 ± 1.8		91.4 ± 4.9	
Fe	3000°K	106.6 ± 4.8	*	121.8 ± 1.5	***
	6000°K	206.5 ± 40		117.5 ± 2.2	
	2000°K	1566.8 ± 12.7		1527 ± 78.1	
Ca	3000°K	1450.1 ± 109.1	Nd	2034.6 ± 92.5	***
	6000°K	1449.4 ± 45.3		1584 ± 46.3	

of LED luminaires were evaluated and the ideal color temperature for plant growth was tried to be determined.

4. Conclusion

In this study, unlike other studies in literature, the potential effects of white LED lighting systems with 2000-6000˚K CCT values on wheat and barley were determined. Following results can be drawn:

- White LED luminaires which are the most commonly used LEDs in lighting applications were chosen and Color temperature as well as wave length has significant effects on plants.
- Physiological and biochemical effects of light on plants grown in laboratory environment created a significant effect on the enzymes and plant morphology.
- The LED light has various effects on plants such that when color temperature increased, the length and weight values of plants, amounts of chlorophyll, carotene and mineral absorption capacity also increased. However, the amount of electrolyte leakage and antioxidant enzyme activity decreased inversely.
- As a result, it was concluded that CCT values can be directly proportional with the plant productivity.

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Conflict of interest: The authors declare that they have no conflict of interests.

Informed consent: The authors declare that this manuscript did not involve human or animal participants and informed consent was not collected.

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