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Original paper

The Effects of Different Light Spectrums on the Growth and Mineral Nutrition of Hydroponically Grown Barley Grass (*Hordeum vulgare L.*)

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Abstract

Background and aim: The effects of different light spectrum on the growth and nutrient content of hydroponically grown Barley grass (*Hordeum vulgare* L.) in indoor climate conditions were studied.

Materials and methods: In the experiment, under three different LED-based lightings defined by the peak wavelengths of red (625-675 nm), blue (425-475 nm), and green (490-550 nm) light and at a photosynthetic photon flux density of 200-250 μmol m−2 s. were studied. Plant biometric parameters and mineral nutrient concentration of Barley grass were determined. The highest height, fresh weight, dry matter ratio and plant yield per unit area in Barley grass were achieved by the combination of red, blue and green light wavelengths. Lower height and fresh weight values were obtained in the combination of blue and green light.

Results: The highest concentrations of plant nutrients in terms of mineral contents are in combinations of red, blue and green light; and the highest N content was determined under blue light. Fe content of Barley grass was higher under blue light; Zn, Mn, Cu and B nutrients were determined higher under red light.

Conclusion: The results showed that in indoor plant artificial lighting, selected light spectrums can be used to optimize plant growth and mineral nutrition.

Keywords: *LED lighting, Light Spectra, Hydroponic fodder, Barley, Mineral Content*

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Introduction

The developments in recent lighting technologies, the widespread use of LED lighting lamps have become an economical and effective lighting alternative in soilless agriculture and vertical farming cultures in indoor environments or in areas where the light is insufficient for plant cultures. Especially in animal production, in the seasons when green forage is insufficient, the need for lighting is very important for the growth of forage plants produced in soilless culture in a closed environment within a short vegetation period.

The reactions of light to different wavelengths in the development of plants have been known for many years. The absorption of light by chlorophyll pigments in plants occurs mostly in the red (625-675 nm) and blue (425-475 nm) wavelength regions. In addition to primary photosynthetic chlorophyll pigments, other plant pigments such as carotenoids and anthocyanins can also harvest light and use mostly blue wavelength light [1], [2]. The wavelength of the light has an effect on the size, color, texture and aroma of the grown plant [3], as well as on the concentrations of various pigments and metabolites such as chlorophyll, carotenoid, anthocyanin, ascorbic acid and sugars [4].

In the light spectra, red and orange light photons have the highest efficiency for photosynthesis, while green photons have lower efficiency than red and blue [5]. Red light generally forms the basis of the lighting spectrums, and it has been reported that red (640-660 nm) LED light alone can be used in the cultivation of vegetables [6], [7]. In addition, red LED light is generally used in combination with certain proportions of blue light to increase yield and quality in greenhouses and indoor plant growing rooms [3]. It has been reported that different wavelengths of light also have important effects on the mineral nutrition of plants, and when infrared light is used together with red and blue LEDs, potassium, calcium and magnesium intakes increase in plants grown hydroponically [8].

A good understanding of the response of plants to different light spectrums in crop production can provide important information in the selection of the light intensity and wavelength, determining the ligthing time and duration, and thus enable the farmers to control more effectively production timing and plant productivity [9].

It is seen that many and quite different results have been obtained so far in researches on the most suitable light wavelength combinations for plant growth and photosynthesis in various plants, and a significant part of them show methodological differences. Although LEDs are an important alternative that directs existing additional lighting technologies with their constant energy efficiency and improvements in light distribution, there are important problems on how to optimize their spectral quality effects on plant growth, development, nutrition and metabolism [10].

Hydroponic green fodder production in animal nutrition is an important animal feeding culture in seasonal periods when natural feeds are insufficient. Hydroponic Barley Grass is obtained by germinating and sprouting Barley seeds in pans for 6-8 days after pre-soaking, and the roots and green shoots of the plant are used as animal feed. At the end of sprouting, there is a significant weight gain in Barley grains, and with germination, starch, protein and fat compounds in the grain are transformed into simple forms such as sugar, amino acids and fatty acids, and these are used in animal nutrition. The effect of light, which is one of the plant growth factors, on the germination of various forage plant seeds in the indoor environment and the yield and quality of the forage material obtained in the short growing period is extremely important. In this study, the effects of LED light of different wavelengths applied to the Barley plant grown in the indoor hydroponic feed production culture, which has become rapidly widespread in green feed production in recent years, on the growth and mineral nutrient contents of the plant were investigated.

Material and Methods

The experiment was carried out in a temperature and ventilation controlled air-conditioning room, in a hydroponic feeding environment. In the experiment, seeds were sieved, disinfected with 5 % hypochlorite solution and rinsed with distilled water. Barley seeds were placed in trays 40 x 60 cm^2 and 7 cm deep at the rate of 4 kg m^{2-1} dry seeds and soaked with distilled water until germination. Immediately after germination of seeds, classical Hoagland nutrient solution was applied and grown under different light spectrums for 10 days. Ambient humidity in the trial cabinet is set at the level of 50-60%. The plants were harvested at the end of the 10-day growing period after germination and the measurement values were taken.

LED lamps were used as the light source in the experiment. In the study, the light wavelengths of LED lamps were used in the frequency range of red (625-675 nm), blue (425-475 nm) and green (490-550 nm), and white fluorescent light was used as a control application. Light treatments used in the experiment are given in Table 1. In all treatments photosynthetic photon flux density (PPFD) was kept at the level of 200-250 µmol m-2s-1 levels. In the experiment, the lighting time was limited to 12 hours per day. In the growth chamber, light isolation is provided between treatments to prevent different light wavelengths from mixing with each other. All treatments were carried out with 10 replications.

Table 1. Proportional distribution of light frequencies in lighting treatments

	Proportional Distribution of Treatments (%)		
Treatments	Red (625-675 nm)	Blue (425-475 nm)	Green (490-550 nm)
Red	100	0	0
Blue	50	50	0
Green	100	0	0
Red + Blue	50	50	0
Red + Green	50	0	50
Green + Blue	0	50	50
Red + Green + Blue	50	25	25
Control (Fluorescent)	25 ± 10	25 ± 10	50 ± 10

Plant Biometric Parameters and Plant Analysis:

Plant height (cm), root length (cm) and fresh biomass weight (g m^2-1) were determined in Barley plants after 10 days of development. After the plant samples taken from the unit area of the treatments were washed in pure water, they were dried in an oven at 65±5 °C until they reached a constant weight, and the total leaf + root dry matter value was determined. Dry matter ratio (%), dry matter yield (g $m^{2\ -1}$), dry matter proportional change and plant/seed ratio were calculated in plant samples. Dried plant samples were ashed at 500±50 °C and total ash values were determined. For plant nutrient analysis, fresh plant samples were washed throughly with tap water and rinsed with deionized water. Plant samples were dried at 70 ºC in a forced-air oven, ground a porcelain mortar. Total N ratio in dried and ground plant samples was determined by Kjeldahl analysis method. For other mineral analysis dried and ground samples were digested in aqua regia (1:3, HNO_3/HCl) according to the international standard [11]. After cooling to the room temperature, residue was diluted with deionized water and analysed by using ICP-MS under optimised measurement conditions, and values were adjusted for oven dried (12 h at 105 °C) material.

Results and Discussions

Plant Growth Characteristics

Different light wavelengths and their various combinations made statistically significant changes on the sprout (leaf+stem) and root development of Barley plant (Figure 1). The highest sprout length of the Barley plant was determined in the red light wavelength spectrum, and the highest root length was determined in the blue wavelength spectrum. In general, low sprout and root lengths were determined in the blue and green wavelength spectrums, while higher sprout and root values were determined in other wavelengths and their combinations. In the combination of red + green + blue light, the highest total sprout and root length was achieved compared to control and other treatments. In this regard, red photons have the highest efficiency in the lighting spectrums for Photosynthesis; It has been reported that green photons have lower efficiency than red and blue photons [5].

The fresh yield and dry matter values of Barley plant grown in different light spectrums are given in Table 2. The highest fresh weight (sprout + root) value was obtained in combination of red + green + blue light spectrums. The lowest fresh weight value was obtained in green light spectrum in Barley plant. Compared to the control application, higher fresh weight was determined in the combination of red, red + blue, green + blue. Dry matter values, dry matter ratios and dry matter/seed ratios per unit area followed the same trend. It is seen that the lighting treatments also follow this trend on the total ash content of the Barley plant. However, based on the Control application, there were remarkable changes in the relative changes of the applied light spectrums on the dry values (Figure 2).

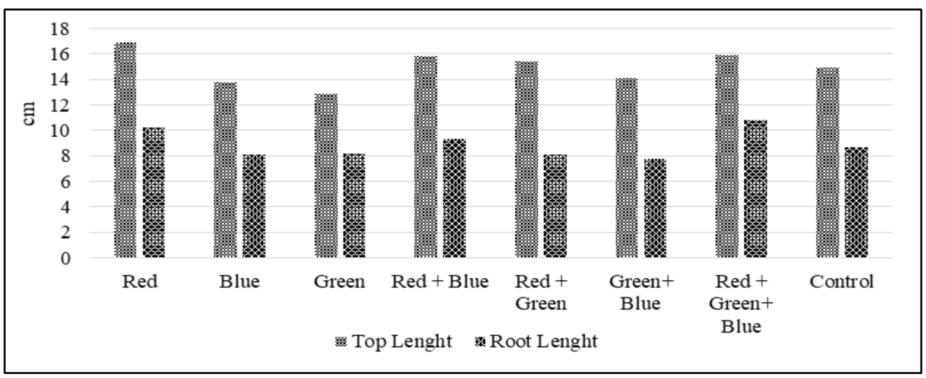

Figure 1. The effects of different light spectrums and their combinations on the crown and root development of Barley plant

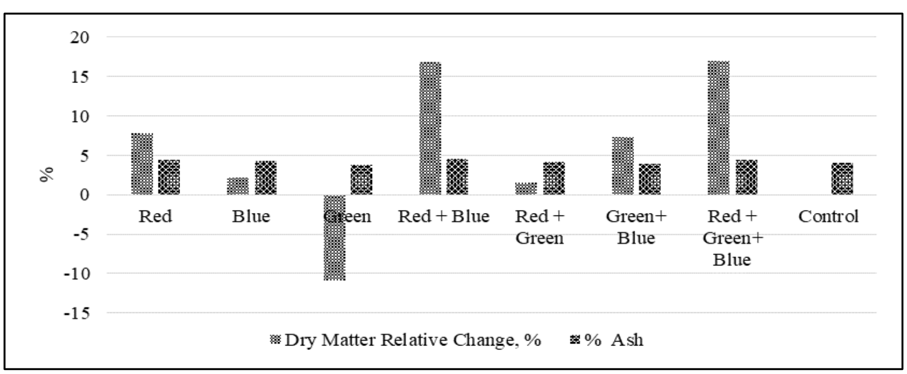

Figure 2. The effects of different light spectrums on total ash ratio and relative dry matter change in Barley plant

According to the control application, it was determined that the total dry matter value of the Barley plant grown at blue wavelength was proportionally negative, and the highest relative changes were achieved in the combinations of red + blue and red + green + blue wavelengths. In many plant lighting studies, it has been determined that photosynthesis and plant biomass increase with the use of blue photons in addition to red photons [12], [13], [14], [15]. In addition, unlike most sources, green light also has important physiological effects on plants [16] and in various studies, it has been determined that the use of green light together with blue and red lights supports plant growth compared to the use of green light alone [17], [18]. These results suggest that the application of light combinations of different wavelengths is an important criterion to be considered in lighting in order to increase productivity in short vegetation period, especially in soilless fodder production.

Table 2. The effects of different light spectrums and their combinations on some biometric parameters of Barley plant

	Fresh Weight, kg m^{2-1}	Dry Matter Yield g m^{2-1}, %	Dry Matter, %	Plant/Seed Rate, kg m^{2-1}
Red	15,93	456	9,54	5,31
Blue	15,4	432	9,35	5,13
Green	14,17	377	8,88	4,72
Red + Blue	16,6	494	9,93	5,53
Red + Green	15,47	430	9,26	5,16
Green+ Blue	16,53	454	9,15	5,51
Red + Green+ Blue	16,73	495	9,86	5,58
Control	15,5	423	9,1	5,17

Plant Mineral Contents

Different light wavelengths and their various combinations made statistically significant changes on the macro and micronutrient contents of the Barley plant (Figure 3; Figure 4). The highest N content was determined in combinations of blue light wavelength and blue light, and the lowest N content was determined at red and green wavelengths. Phosphorus, Ca and Mg contents were determined at the highest red and red+blue wavelengths, and the lowest P content was determined at blue wavelengths. The highest potassium content was determined in the combination of red+green+blue wavelengths, and the lowest values were determined in the blue and green wavelengths. The values obtained in the control process generally gave similar results with the combinations of red, blue and green light.

Micronutrient contents of Barley plant followed the order of Fe>Mn>Zn>B>Cu in all treatments. This is an expected result and can be seen related to the nutrient absorption capacity of the plant. The Fe content of the Barley plant was determined at the highest in the blue wavelength and the lowest in the red wavelength. On the other hand, Mn, Zn and Cu contents of Barley plant were determined at the lowest blue wavelength. Generally, higher Fe, Mn, Zn, Cu and B values were determined in combinations of red, blue and green light. In the control application, the micronutrient contents were determined lower than the combinations of red, blue and green light. It has been reported that calcium accumulation in plants is lowest under blue light and highest under red light, and this is related to the fact that high calcium accumulation under red light reduces iron absorption due to the antagonism between calcium and iron during ion interactions [19]. Studies have shown that total N, total P and total K contents in leaves and pseudostems of garlic (*Allium sativum* L.) seedlings are at the highest level under blue light conditions [20]. In addition, when compared with white light, it was reported that the spinach plant (*Spinacia oleracea* L.) had the lowest K and Mg content and the highest N content under blue light [21]. It has been reported that Ca, Mg, P, S, B, Cu, Fe, Mn, Mo and Zn levels are highest in plants (Brassica oleacea var. italica) given a mixed red and blue light [22], [23]. The fact that the mineral contents of Barley plants differ in different light spectrums is considered to be an important criterion to be taken into account, especially in the mineral nutrition of plants grown in soilless culture.

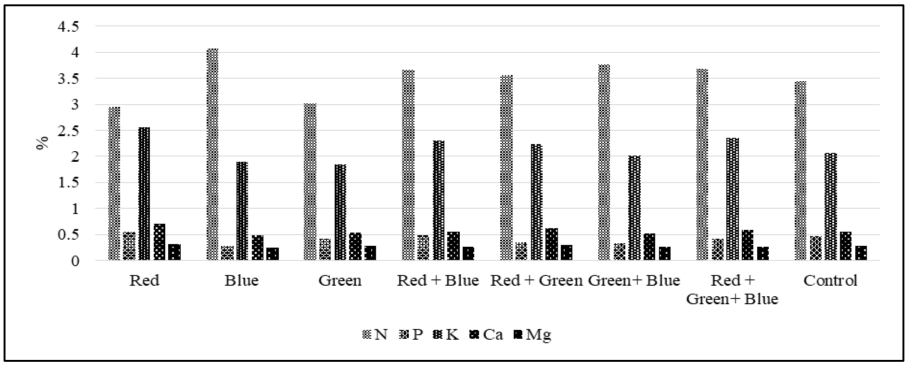

Figure 3. The effects of different light spectrums on the macronutrient contents of Barley plant

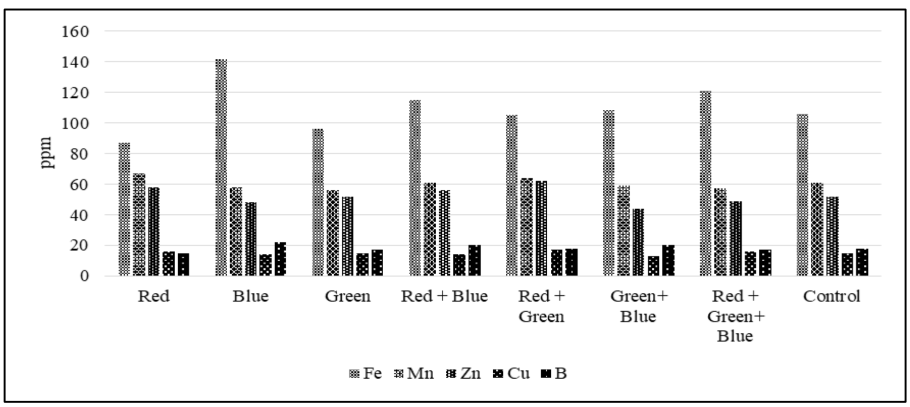

Figure 4. Effects of different light spectrums on the micronutrient contents of Barley plant

Conclusion

Different wavelengths and combinations of LED light used in indoor hydroponic green fodder production had significant effects on green forage yield, plant dry matter ratio and nutrient content of Barley plant. Fresh plant yield, dry matter value, and mineral plant nutrient contents of the light in red+blue and red+blue+green wavelength combinations applied to Barley plant grown in hydroponic culture increased compared to other single wavelength light treatments. The results showed that different wavelength options in LED lighting are effective and applicable in short vegetation period hydroponic Barleygrass production. In hydroponic culture feed production, there is a need to develop fully automated and effective lighting guides by trying different lighting wavelength combinations at different photon flux densities and temporally for forage crops to be examined in future long-term studies.

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Conflict of interests
The author declares that there are no competing interests.

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