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The Effect of Different Light Spectra on the Morphology and Physiology of Lettuce ((*Lactuca sativa var. Crispa*) Cultivation: A Review

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Abstract
For plants, light is one of the most important environmental factors representing the energy source in photosynthesis. Light is the basic signal that regulates the growth and development processes of the plant throughout its entire life cycle. Light condition (light intensity, light quality, and photoperiod) is one of the most important environmental variables in regulating vegetable growth, development, and photochemical accumulation, especially for vegetables grown in controlled environments. With the development of light-emitting diode (LED) technology, studies have become more common in order to regulate light environments and to provide ideal light quality, intensity, and photoperiod for indoor environments. The aim of this review is to collect the effect of different light spectra on the morphology and physiology of the lettuce grown in a closed system.

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I. Introduction

Of all the environmental conditions affecting the developing plant, light can be considered the most important. Besides its key role in plant metabolism and therefore all life on Earth where it directs the process of photosynthesis, light energy also regulates plant growth and development (Still 2007). Light energy is absorbed by the plants through photosynthesis to convert light energy into adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADPH) in light reactions. Next, CO2 is fixed in the form of carbohydrates, and O2 is produced in light-independent reactions (Zhang et al. 2014).

Photosynthesis is primarily driven by PAR (photosynthetically active radiation) ranging in wavelength from about 400 to 700 nm. However, not all photons in this wavelength range can achieve plant photosynthesis equally. For example, red light (600 to 700 nm) is 25-35% more efficient than blue light (400 to 500 nm) and 5-30% more effective than green light (500 to 600 nm) (Ruangrak and Khummueng 2019).

Certain types of light promote plant growth or affect plant morphology. Red and blue colored lights can generally be considered the most important light zones required for plant development and growth. Red light promotes biomass accumulation, growth, and photosynthesis in lettuce. Blue LED light influences biomass accumulation and biosynthesis of chlorophyll and anthocyanin, as well as stimulating photomorphogenesis and adaptive phenomena such as the stomatal opening/closing regulation mechanism (Loconsole et al. 2019).

Chlorophyll is a plant pigment found in intracellular chloroplasts, they are green in color and are responsible for the green coloring of leaves and stems. Two main types of chlorophyll are found in higher plants; Chlorophyll a and b are slightly different from each other with their light absorption curves. This difference allows them to capture more of the sunlight spectrum, capturing different wavelengths. However, chlorophyll is not the only plant pigment; secondary pigments (carotenoids, xanthophylls, etc.) and phenolic substances (flavonoids, anthocyanins, etc.) only capture wavelengths other than red and blue. Accessory pigments are yellow, red, and purple. These colors attract insects and birds and also protect tissues from environmental stress such as high light irradiation (Bures et al. 2018).

Biomass production is a light-dependent activity in addition to the photosynthesis process that provides energy for flowering, seed development, and other functions such as germination, flowering time, and plant morphology. These actions are highly correlated with the light quality in which the plant perceives the signals of its environment. These responses are mediated by wavelengths within and beyond the PAR domain, including UV and Infrared irradiation (Falciatore and Boler 2005).

Effects of Light on Plants

There are many environmental factors that affect plant growth; light, temperature, humidity, water, nutrients, gravity, etc. Light is indispensable for plant growth and development, as an energy source for photosynthesis, and as an environmental cue for photomorphogenesis.

Photosynthesis

Photosynthesis is a series of processes driven by photons absorbed by plant pigments. Photosynthesis is not very efficient, converting only 4-6% of the energy available in radiation into biomass. Photosynthesis can be intensified by high CO2 concentration; however, an increase in photosynthesis rate does not translate into a linear increase in plant growth or yield increase. Plants control their own development so they do not grow indefinitely. As it is known, photosynthesis is not the only determining factor when looking at good plant growth, other factors are also taken into account. Including UV-B, UV-A (280-380 nm), and infrared irradiation (above 700 nm) are important for plants in/out of the PAR area The combination and ratios between different wavelengths are also important for plants; the blue-green ratio and especially the red-infrared ratio, It also determines how fast or slows the plant grows and when it will start to bloom (Ikeda et al. 2009).

Wavelengths and the relationship between them provide information about the growth medium. For example, changes in the Red: Infrared ratio allow plants to detect neighboring plants and encourage stem elongation, which better competes to capture more light, allowing plant growth. Therefore, when discussing plant lighting, it would be more informative to concentrate on the entire light spectrum rather than the PAR range, which does not only cover UV or infrared wavelengths (Bures et al.2018).

It is well known that plant growth and development are regulated by light quality, light intensity, and photoperiod, and more than three factors are therefore key components of light status. The light requirements of plants are subject to plant species, cultivar, growth-development stages, environmental conditions, and the ultimate goal of yield and quality. Therefore, the need for detailed studies on light-based physiological requirements is increasing rapidly in order to obtain high yield and quality plants in closed-type production systems (Kang et al. 2013).

light intensity

Growing using artificial light in a controlled environment ensures stable vegetable production regardless of weather conditions. Controlling light intensity is useful in controlled environment agricultural facilities to achieve high productivity or high nutritional quality of commercial crops even with limited light intensity, but the effective application of light quality differs depending on the plant species. Light intensity is a limiting factor at higher latitudes in winter (Ohashi-Kaneko et al. 2007).

The insufficient light intensity can limit the assimilation of plant carbon and reduce the activity of carbon assimilation enzymes, thereby reducing the net photosynthetic rate (Pn), and the effective quantum yield of photosystem II photochemistry (FPSII), and electron transport rate (ETH). Although low light intensities increase plant height and specific leaf area, this factor decreases leaf number, leaf thickness, and yield. Plants were grown under high light intensities often cannot use all the energy absorbed by their photosynthetic apparatus, and this excessive energy absorption often decreases the efficiency of photosystems, particularly photosystem II (Zhou et al. 2019).

The combination of 290-9/3 (light intensity-photoperiod) shows the highest plant height and fresh shoot weight. However, plants grown at 290-18/6 showed the greatest root fresh weight, leaf dry weight, and longest root length. The combination of 290-6/2 (light intensity-photoperiod) showed the greatest leaf width, Anthocyanin content, maximum leaf number, and largest root dry weight (Kang et al. 2013). However, the high light intensity of 600 μmolm− 2 s− 1 often results in quality degradation, especially in leafy green vegetables with harder leaves. Light intensity has different effects on fresh weight and dry weight, and it was determined that the dry matter content increased at higher light intensity (Meinen et al. 2018).

Determining the appropriate light intensity is very important because photosynthesis leads to the etiolation of seedlings under low light intensity. On the other hand, the excessive light intensity can generate free oxygen species and cause photoinhibition. In addition, the high light intensity can cumulatively increase the fresh and dry weights of shoots with respect to plant growth rate, number of leaves, tip blight, calcium, and water absorption per plant (Ruangrak and Khummueng 2019).

Plant	Light Intensity	Effects of Light Intensity on Plants	References
leaf salad (*Lactuca sativa* L. Refire)	300 µmolm − 2 s – 1	In blue light, carotenoids and chlorophyll a and b increase.	(Ohashi-Kaneko et al. 2007)
Lettuce (*Lactuca sativa* L.)	300 (250 FL) µmol m-2 s-1.	It increases the photosynthetic rate and production efficiency in red light.	(Shimizu et al. 2011)
Lettuce (*Lactuca sativa* L.)	Range of 400 µmol m-2 s-1 to 600 µmol m-2 s-1	It is a recommended light intensity for lettuce production.	(Weiguo et al. 2012)
Lettuce (*Lactuca sativa* L.)	Four light intensity applications; 200, 230, 260 and 290 µmolm − 2 s − 1	Its high light intensity (290 µmolm -2 s -1) and low photoperiod (6/2 (light/dark) result in good plant growth and lettuce development. 230 or 260 µmol m in light intensity with longer photoperiods18/6 and 9/3 (light/dark) -2 s -1, iyi bir results in growth and higher photosynthetic capacity.	(Kang et al. 2013)
Lettuce (*Lactuca sativa* L.)	200 to 600 µmolm−2 s−1	Increasing the light intensity from 200 to 600 µmolm − 2 s − 1 results in a significant increase in fresh biomass production.	(Meinen et al. 2018).
Lettuce(*Lactuca sativa* L.)	100 ve 300 µmol • m − 2 • s − 1).	It increased the biomass, and the production of secondary metabolites.	(Kitazaki et al. 2018).
Lettuce (*Lactuca sativa* L.)	150 µmol / m2 • s	A 1:2 ratio of red and blue light increases the nitrate content of lettuce.	(Zhang et al. 2018).
	300 µmol / m2 • s	A 2:2 ratio of red and blue light increases the lettuce's vitamin C and soluble sugar content.	
Lettuce (Lactuca *sativa* L.)	200, mmol·mL2·sL1	The nitrate content in lettuce leaves decreases in red and blue light.	(Zhou et al. 2019).
	350, mmol·mL2·sL1	It increases the Net photosynthetic rate (Pn), and Stomatal conductivity (gs),	
	500, mmol·mL2·sL1	Yaprak sayısı, yaprak alanı ve marul bitkilerinin taze ağırlığını artırmaktadır.	
	600, mmol·mL2·sL1	Bitki kuru ağırlığına artırmaktadır.	
Lettuce (*Lactuca sativa* L.)	200- 300 µmol • m − 2 • s − 1).	Fresh and dry weight in red and blue light increases the specific leaf area.	(Zha et al. 2019).
Lettuce (*Lactuca sativa* L.)	220 µmolm − 2 s − 1 red and blue light.	It reduces the nitrate content in lettuce leaves and increases the its quality.	(Ruangrak and Khummueng 2019).
Lettuce (*Lactuca sativa* L.)	130 µmol m-2s-1) White light.	It increases the fresh fresh weight, the plant height and the number of leaves.	(Matysiak and Kowalski 2019).

Table 1.1 Effects of different light intensities on yield and quality of lettuce

light quality

Light quality, also called spectral composition and spectral energy distribution (SED), expresses the composition of light according to wavelengths that are effective in photosynthesis and other plant growth and development processes. Wavelengths of primary importance in photobiology are UV, visible light, and infrared (Hopkins 1999). Integrated optimization of light intensity and light spectrum in the daily light integral is important for optimum plant growth and development. Light intensity and daily light integral mainly affect plant photosynthesis, while the light spectrum induces many photomorphogenic responses within a plant. Changes in the light spectrum affect shoot elongation, lateral shoot formation, leaf area, leaf thickness, germination processes, tropism, flowering promotion and development, and the color of flowers and leaves (Hemming 2009).

Plants absorb the light spectrum in a similar range to the human eye, but unlike humans, red and blue light absorption is higher. Specifically, the light spectrum also influences the vernalization process. It has been determined that some species or cultivars require a shorter vernalization time under artificial growing conditions when the plant is given a simultaneous low light spectrum. It has also been determined that photoperiods that are longer than or shortly after the vernalization period accelerate the flowering period (Bures et al. 2018).

Spectral quality can have a profound effect on the growth, development and physiology of plants. The yield and quality of products can be improved by controlling the light quality in a controlled environment. For example: long-term irradiation with a low ratio of red light to infrared light causes an increase or decrease in leaf area and an increase in stem dry weight. Most of the studies on the effect of light quality on vegetables, biomass production, leaf area, and branching and internal quality; focused on both external quality and internal quality, including parameters such as vitamins, minerals, carotenoids, and phenolic compounds (Smith 1982).

Light quality influences all aspects of plant biology and also guides the photobiological processes by which plants perceive and respond to the light environment. Optimal lighting regimens have the potential to increase yield and plant quality and increase nutritional value and palatability. Light quality affects stoma development. In addition, light quality affects the regulation of plant metabolism and morphology, as well as many other factors necessary for healthy plant growth (Davis and Burns 2016).

Table 1.2 Effects of light quality or spectral quality on lettuce quality and yield

Plants	**Light Qualities**	**Effects of Light Quality on Plants**	**References**
Lettuce (Lactuca sativa L)	White Light	It increases the dry weight of the shoot, leaf area, number of leaves and chlorophyll a and b.	(Ohashi-Kaneko et al. 2007).
Lettuce (Lactuca sativa L)	Red+Blue+White	The light intensity-photoperiod (290-9/3) combination showed the highest plant height and fresh shoot weight, while plants grown at 290-18/6 exhibited the greatest root fresh weight, leaf dry weight, and longest root length.	(Kang et. 2013).
Lettuce (Lactuca sativa L.)	As a spectral percentage of red, green, blue, and light far-red. 1- 88+1.0+10.6+0.4%+8.3 2- 81.6+0.6+17.8+1. +4.6 3-81.4+0.6+18+11.6+4.5	1- The plant increases leaf length. 2- The length between shoot and internode of the lettuce plant is decreasing. 3- It increases the leaf number and the dry weight of the plant.	(Pinho et al. 2017).
Lettuce *(Lactuca sativa* L)	Red and blue light were applied at a ratio of 1:2 and 2:2.	The nitrate, leaf fresh weight, and root fresh weight content increase the red and blue in a 2:2 ratio. Red and blue in a 1:2 ratio increase the vitamin C content.	(Zhang et al. 2018).
Lettuce (Lactuca sativa L)	Red and Blue 1- %83 K +%17 M, 2- %91 K +%9 M,	1- 83% R +17% B; increases the number of plant leaves, 2- 91% R + 9% B Increases Chl a an b, carotenoids, Plant fresh and dry weight.	(Naznin et al. 2019).
Lettuce (*Lactuca sativa* L)	It applies five red: blue (K:M) ratios (0.5-1-2-3-4).	RB: ratio 2 increases the flavonoid content, RB: ratio 3 increases the chlorophyll content, wet weight, dry weight and dry matter of the plant.	(Pennisi et al. 2019).
Romaine Lettuce	Red, green, yellow, blue. Four loops are used; Cycle 1: ratio; 69.9:17.0:13.1. Cycle 2: ratio; 73.0: 20.1: 6.9 Cycle 4; rate; 79.1:16.6:4.3	Cycle 1; Plant fresh weight, chl a and b were increased. Cycle 2; Increase root fresh weight, leaf dry mass, total carotenoid content. Cycle 4; The nitrate content is reduced.	(Loconsole et al. 2019).
Letuce *(Lactuca sativa* L)	Light intensity of white with light (130 μmol m-2 s-1).	Increases plant fresh weight, plant height and number of leaves.	(Matysiak and Koalski 2019).
Lettuce	Blue light	It was determined that the fresh weight increased up to 53%.	(Shimokawa et al. 2014, Demir & Çakırer, 2017).

Photoperiod

Photoperiodism is the plant's ability to perceive and respond to different lengths of dark and light periods, that is, to distinguish between short days and long days, which is essential for the plant's life cycle (Jackson and Thomas 1999). Photoperiodism is one of the most important and complex aspects of the interaction between plants and their environment. The word photoperiod come from the Greek roots for 'light' and 'duration of time' and can be defined as responses to the length of the day that enable living organisms to adapt to seasonal changes in their environment (Vince-Prue 1975).

Plants are divided into three groups according to their photoperiodism characteristics. These; are short-day plants, long-day plants, and day-neutral plants. Short-day plants require a long period of darkness (12 hours or longer) to initiate flowering. On the other hand, a photoperiod of 16-18 hours is sufficient for flowering induction for long-day plants. Neutral-day plants bloom independently of the photoperiod, and generally, flowering induction is related to plant size rather than a fixed photoperiod. Chrysanthemums, some types of strawberries, beans, camellias, primroses, and poinsettia are examples of short-day types. Long-day species include lettuce, spinach, and other leafy vegetables (Adams and Langton 2005).

Short-day plants bloom rapidly in short-day conditions (short light-long dark). However, if the dark period is broken by a short exposure, the plant perceives the dark period as two darks instead of perpetual darkness, and therefore flowering is inhibited (Bures et al. 2018).

Table 1.3 Effects of different photoperiods on lettuce quality and yield

Plant	**Photoperiod**	**Photoperiod Effects on Plants**	**References**
Lettuce (*Lactuca sativa* L.Redfire)	12-hour photoperiod with white light.	The plant increases the dry weight of the shoot, leaf area, number of leaves, and Chl a, b.	(Ohashi-Kaneko et al. 2007).
lettuce (*Lactuca sativa*)	Photoperiod of 16 hours with red and UV light.	It increases the fresh weight of the plant, the number of leaves and the leaf area.	(Urbonavičiūt ė et al. 2007).

lettuce (*Lactuca sativa "Greenwave"*.)	Red light with 16 hours of photo period.	It increases the Dry, fresh weight and photosynthetic rate of the plant.	(Shimizu et al. 2011).
lettuce (*Lactuca sativa L.*)	A photoperiod (light / dark) of 14/10 hours.	It increases the nitrate content of the leaf.	(Weiguo et al. 2012).
lettuce (*Lactuca sativa* L.)	Photoperiod with light intensity of (290-9/3).	Plant height and plant fresh weight increase.	(Kang et al. 2013).
	light intensity-photoperiod of (290-18/6).	Root fresh weight, leaf dry weight and root length are exhibited.	
	Light intensity-photoperiod (290-6 / 2.).	It increases Leaf width, leaf number and root dry weight indicate leaf anthocyanin content.	
lettuce (Lactuca sativa)	Photo period of 16 hours with blue, red, white.	It increases leaf area, number of leaves and fresh weight.	(Chinchilla et al. 2018).
lettuce (*Lactuca sativa* L.)	Photoperiod of 16/8 hours +light intensity (300 μmol • m − 2 • s – 1 red and blue.	It increases dry and fresh weight of plants.	(Zha et al. 2019).
lettuce (Lactuca sativa)	A 16 hour photoperiod with different ratio percentage of Red and Blue light.	83% K + 17% M light increases the height of the plant, the number of leaves, and decreases the dry weight.	(Naznin et al. 2019).

Photomorphogenesis

Light is one of the most important environmental factors affecting plant growth. All higher plants develop in the light differently than in the dark. The development in light is called photomorphogenesis, the development in the dark or etiolation is called etiolation. All aspects of plant development, including germination, plant height, leaf shape, chloroplast development, chlorophyll biosynthesis, and apical dormancy, can be affected by growing the plant in light or darkness (Jackson and Thomas 1990).

Photomorphogenesis is understood to mean that light can control a plant's growth and differentiation independent of photosynthesis. To grasp the full significance of this, we need to know that the specific development of a living system depends on the genetic information of a particular system and its environment. The environmental factor is less effective in all higher plants. However, light can be viewed as a "selective" factor influencing the way these genes present in the particular organism are used. In this sense, the study of photomorphogenesis has been part of a worldwide program to investigate the influence of the environment on the development of higher organisms (Mohr 2012).

Photomorphogenesis is the process that causes plant morphology and pigmentation to change after plants are exposed to light. In this process, several photoreceptors are activated and controlled. There are other particles that have the ability to absorb light and these are called photoreceptors (Davis and Burns 2016).

Photoreceptors and light absorption

Ultraviolet: UV-B light is absorbed by the UVR8 photoreceptor. A large dose is harmful to plants, as it breaks down DNA. However, in small doses, both UV-B and UV-A increase the stress tolerance of plants. In general, plants grown under ultraviolet light have thick leaves and short stems (Flesch 2006).

Blue light: Blue light is detected by its photoreceptors, phototropin, and cryptochromes. Cryptochromes regulate many photo-morphological responses such as inhibition of stem elongation. Plants grown under high blue irradiation have short internodes, high dry matter content, and low leaf temperature. Blue light modulates a variety of plant responses, including phototropism, root growth inhibition, leaf expansion, chloroplast development, stomatal opening, anthocyanin accumulation, and changes in the expression of various genes (Khurana and Poff 1999).

Greenlight: Greenlight is partially detected by phototropin and cryptochromes (blue light receptors). The greenest light is reflected or penetrating from the canopy. However, the green light contains valuable information about the plant's environment and guides growth accordingly. Plants grown under green light have long stem internodes and high leaf temperatures (Chaves et al. 2011).

Red light: Red light is detected by phytochromes (Pr). Phytochromes absorb both red and infrared light and are key regulators of shadow avoidance syndrome. Red light converts phytochromes to their inactive state, Pr, which has an absorption peak at 660 nm. The Pr form of phytochrome is synthesized under dark or infrared light conditions. When Pr absorbs red light, the absorption changes to the infrared absorbing form Pfr, whose peak is at 730 nm. The conversion from Pr to Pfr can be reversed by excessive red light or darkness (Falciatore and Bowler 2005).

Far-red: absorbed by phytochromes. Phytochromes absorb both red and infrared light and are key regulators of shadow avoidance syndrome. High infrared irradiation causes early flowering and elongation of roots and petioles in many species (Possart et al. 2014).

Plants reaction to the light spectra

Urbonavičiūtė et al. (2007), reported that the use of Red, blue and ultraviolet lights (K-640+ M-460nm, near-UV-365nm+K-640 increases total plant height, hypocotyl height, number of leaves, leaf area and plant fresh weight of lettuce. The anthocyanin concentration of lettuce plants grown under UV-A and M light increased by 11% and 31%, respectively (Li and Kubota 2009). According to (Baek et al 2013), the application of blue and red (69: 31 K:M oranı ve 163 -182μmolm – 2 s – 1) light on lettuce increases the rate of anthocyanin in lettuce. Lettuce (*Lactuca sativa* L. var. *capitata*) plants treated with red + blue + white and fluorescent lamps showed an increase in shoot and root fresh and dry weight, shape, soluble sugar and nitrate content (Lin et al. 2013). Fu et al. (2017), reported that the use of 220 mol m − 2s – 1 of light intensity increases plant dry weight, vitamin C accumulation, nitrate content in the leaf of the lettuce plant decreased. According to the results obtained in the study, lettuce grown under red + green + blue + far-red showed the greatest leaf growth and total shoot biomass (Micken et al. 2018). It has been determined that green light supplementation under red and blue light is highly effective in increasing nutritional values while maintaining high net photosynthetic rates and maximum photochemical efficiency (Bian et al. 2018). Yan et al. (2019), reported that Seedlings grown under red and blue LEDs with a ratio of 1.2 showed lower plant vitamin C content. According to the results obtained at the end of this study, leaf salad plants applied with the combination M:90K:90FR:30 increased the plant leaf length and shoot fresh weight, and the amount of chlorophyll decreased at the same time (Meng and Runkle 2019). According to the results obtained in this study, under red + blue light, lettuce plant fresh weight, stomatal conductivity, antioxidant capacity, phenolics and flavonoids increased which were applied 250 μmolm − 2 s − 1 light intensity (Pennisi et al. 2020).

II. Conclusion

With indoor hydroponic system, production can be carried out anywhere and all year round, regardless of climate or soil. In countries where the growing season is limited, this technique is a good option for the year-round production of fresh vegetables and herbs. One of the benefits of hydroponics in urban settings is the ability to produce where crops are consumed and the reduced need for transportation. By using a lighting system compatible with vegetable production in hydroponics, the growth period can be shortened, the yield can be increased by using more than one shelf, continuity in production can be ensured, the density of plants can be increased and waste control can be made.Plants has the ability to sense changes in light composition, duration, and growing environment and initiate the physiological and morphological changes necessary to survive existing environmental conditions. The ability of light to control plant morphology is known as photomorphogenesis, and the blue, red and infrared regions of the light spectrum play a key role in this process. If we use suitable light spectra, light intensity and photoperiod, vegetable production in closed system will provide the best result for yield and quality of vegetable in this system.

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