INVESTIGATING THE PHYSIOLOGICAL EFFECTS OF LEDS WITH COMBINED SPECTRAL EMITTANCES IN FLORICULTURE

GANESH, S.[1*] – JAWAHARLAL, M.[2] – RAJAMANI, K.[1] – VISALAKSHI, M.[1] – KARTHIKEYAN, S.[1] – GANGA, M.[1] – THAMARAISELVI, S. P.[3] – EEVERA, T.[4]

[1]*Floriculture and Landscape Architecture, Tamil Nadu Agricultural University, Coimbatore, India*

[2]*SRM College of Agricultural Sciences, SRM Institute of Science & Technology, Chennai, India*

[3]*Krishi Vigyan Kendra, TNAU, The Nilgiris, India*

[4]*Seed Science and Technology, TNAU, Coimbatore, India*

**Corresponding author*
e-mail: ganes4u@gmail.com; phone: +91-986-5736-866

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Abstract. The management of plant architecture is important for the promotion of year-round production of quality flowers under controlled environment. Besides temperature, the manipulation of light and its intensity are very essential in greenhouses. Light has a significant impact on how plants grow and develop. The energy from light is used by plants for photosynthesis as well as signalling in several assimilation processes. Natural light levels frequently restrict crop output during specific times under intensive horticulture production systems. Numerous blooming species get artificial lighting to promote photosynthesis, induce an inductive photoperiod, or both. Light intensity, spectrum, and photoperiodic adaptability are urgently needed to boost plant growth and product quality. Plant physiology and biochemistry are affected by changes in light intensity, duration, and quality, which has an impact on their morphology and functionality. The use of LEDs in floriculture enables increased light use efficiency in greenhouse production among the use of various artificial light sources in the horticultural industry. It is understood that monochromatic wavelengths or their mixtures can be used with LED technology to enhance plant development. The replacement of High-Pressure Sodium Lamps (HPS) by a LED lighting system is currently under investigation in greenhouses. Integrating the current growing system with advanced techniques paves full attention. To attain a sustainable and economical production system, a different spectrum of light has to be tested, integrated, and optimized within the horticultural production system.
Keywords: *Greenhouse chrysanthemum, lighting fixtures that are currently in use, light emitting diodes, the spectral quality of the light (red, blue, white, and far-red LEDs), photosynthesis, physiological implications, soilless culture*

Introduction

Light Emitting Diodes (LEDs) are recent innovations in the light industry for the past decade. Horticulture Lighting is gaining importance under protected conditions in improving the plant morphogenesis. LEDs have more technical advantages over traditional lighting. LED is a unique kind of semiconductor diode. The type/details of the semiconductor material used determine the wavelength of the light emitted from the LED source. Morrow (2008) reported that LED is the first light source capable of true spectral control and the wavelengths can be matched with the plant photoreceptors and influence plant morphology and composition. Recently, the LED technology has to gain importance mainly in the industrial and domestic applications. The only thing holding

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back the use of LED technology in horticultural lighting is the expensive cost of the light source. Also, the farm holdings of most of the farmers under protected cultivation are marginal, so the investment in light management systems for flower cultivation is limited. Despite this, it is anticipated that the capital and operating costs of LED lighting systems will decrease as technology advances (Vanninen et al., 2010; Olle and Virsile, 2013; Yeh and Chung, 2009). Initial research on the application of LED was done in space (Massa et al., 2008; Yorio et al., 2001) and these projects served as the impetus for the creation of a horticultural LED-based photoperiod management system. During the early part of the 20th century only red 660 nm LEDs were available. This is widely used for the cultivation of vegetables like *Lactuca sativa*, *Solanum tuberosum*, *Spinacia oleracea*, *Raphanus sativus* and *Triticum aestivum* since the wavelength is very near to the chlorophyll and Pr phytochrome absorption (Bula et al., 1991). The ability to focus lighting spectrums on a particular wavelength that is physiologically active and the ability to conserve energy without using green or yellow or other spectral regions that are underutilised are two of LEDs' most significant advantages. Even then these spectral colour parts have proven their physiological significance on plant growth (Olle and Virsile, 2013). In this review, we briefly outline the importance of supplemental light, history of the development of lighting sources, its uses on plants and respond to photoperiodic requirement, the photomorphogenic response of a plant to light and insight on how LEDs are used for changing in flowering behaviour and to improve greenhouse cultivation of flower crops. Trivellini et al. (2023) reported that potential advantages of LED technology for the floriculture sector go beyond the aesthetic and financial worth of the final product; LEDs offer a reliable, sustainable alternative for lowering inputs of agrochemicals (pesticides and plant growth regulators) and energy (power energy).

Cut flowers: photosynthesis, growth and yield

All plants have the ability to photosynthesize because it is essential to their survival since it uses sugar molecules as both energy and building blocks. However, it is the exact wavelength of light that causes the plants to respond to light. These reactions, which have no bearing on the process of photosynthesis, enable flowering plants to adapt to their surroundings and promote growth. There are some species whose seeds will not sprout until they receive an adequate amount and type of light.

Plants respond to light by having specific molecules called photoreceptors, which are composed of a protein bound to a pigment that absorbs light and is known as a chromophore or phytochrome. If this protein pigment absorbs light, it changes the protein's structure, which changes the protein's function and initiates a signalling cascade. The change in photosynthetic activity, gene expression, growth, or hormone induction is caused by the signalling system. The economic flowering species, which are grown as horticulture crops, are particularly sensitive to the lengths of day or night that they need in order to flower and enter the reproductive stage of their life cycle. Short-day plants are those that only blossom when exposed to light periods that are less than a specific threshold length. A typical illustration of a short-day plant is the *Dendranthema grandiflora Tzvelev*. And certain plants, such as *Dianthus caryophyllus*, only produce flowers when the length of the day exceeds a certain threshold. Not all plants have long or short days. There are plants that do not depend on the length of the day to flower, known as day-neutral plants. The day neutral plants include *Pelargonium*

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x hortorum, *Impatiens balsamina*, *Taraxacum erythrospermum* and *Begonia rex.* Added lighting is used at night to extend the photoperiod or during the day to increase light intensity (Ibaraki, 2017).

Light activates morphogenesis, a wide spectrum of light signals, and other physiological processes (Chen et al., 2004). Plant growth and development can be influenced by the many spectral components of light, such as wavelength of light, intensity, duration, and direction. The way that plants react to different wavelengths of light varies on numerous factors, including the season, genotype, cultivation techniques, and lighting conditions (Kozai, 2016; Bayat et al., 2018). Recently, the canopy lighting has been employed to encourage the middle and lower plants' ability to photosynthesis. Its distribution is uneven both in the horizontal and vertical planes. A more uniform light distribution in the canopy may be beneficial because the curvilinear response of leaf photosynthesis to light intensity (Li et al., 2014). The lower-lying leaves will, on average, receive a higher light intensity when the light is diffuse since it will diffuse light will penetrate deeper into the canopy. The canopy's nitrogen distribution adapts as a result of the increased light intensity (Johnson et al., 2010; Li et al., 2014).

It has been demonstrated that more lighting enhances floral and ornamental development and quality when grown in greenhouses (Zheng and Van Labeke, 2017b). The primary plant pigments *viz*, chlorophyll, carotenoids, and anthocyanins absorb the blue and red wavelengths of the spectrum more efficiently and hence were the prime selection for the producers. The carotenoid and anthocyanins pigments work along with chlorophyll in the transfer of light to the photosystems and scatter the excess light (or) impart antioxidant. The absorption peaks of blue and red spectra by chl a and chl b have been at 430 nm/665 nm and 458 nm/642 nm respectively. As discussed above the non-chlorophyll pigments viz. anthocyanins and carotenoids also absorb and disperse light to the atmosphere.

The range of the absorption spectrum widened and a larger range of the spectrum is absorbed by the plants as a result of the different absorption spectra of chlorophyll and non-chlorophyll pigments (Davies, 2004). Numerous investigations on photomorphogenesis concentrated on the spectral properties of phytochrome and their sensitivity to the red/far-red ratio of the visible spectrum utilizing narrowband filters and fluorescent lights. These studies have recently increased our understanding of the role that phytochromes play in seed germination, stem lengthening, and flowering.

Horticultural lighting for controlling morphogenesis

The photoperiod of many cut flowers can be altered with supplemental lighting, which enables flower growers to regulate flowering in accordance with market demand. In short-day plants, night interruption with additional lighting prevents floral differentiation, but in long-day plants, it encourages the production of flower buds. Red/or far-red light irradiation is crucial for regulating flowering because phytochrome, a hormone that causes plants to respond to light, has two versions that primarily absorb red and far-red light, respectively (Ibaraki, 2017). Studies have shown that different chrysanthemum cultivars require different spectral characteristics of supplemental lighting to manipulate flowering (Liao et al., 2014b; Ochiai et al., 2015). According to Higuchi et al. (2012), the effectiveness of the light needed during the night break may depend on the quality of the supplemental lighting that is provided. Plant growth inhibitors, on the other hand, are frequently employed to control morphogenesis and,

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ideally, reduce their possible adverse impacts on human wellness and the natural environment (Islam et al., 2014). Consequently, environmental control is a possible substitute strategy for morphogenesis control. In addition to using supplemental lighting regimes and different photoreceptors (phototropin and cryptochromes for blue, and phytochromes for red and far-red), alternative techniques include controlling the difference in temperature between day and night (DIF), controlling the spectral properties of light being irradiated on plants, and using LED lights (Ibaraki, 2017). In a study done on greenhouse chrysanthemum, physiological functions like crop growth rate, net assimilation rate, relative growth rate, and IAA oxidase activity were improved at all crucial stages with 10 min of continuous light every 30 min cycle for 8 h (4 h extended light) and 13 h short day regime. (Ganesh et al., 2014, 2016).

Traditional lighting and its implications

The greenhouse industry is an overwhelming history of disruptive change over the time and perspective regarding time and change. This implies with the harnessing the principle of photoperiodism in flower crops and it was transformative. It improves the year-round production of flowers and allows precision control over the flowering. It sets the table for other flowers and ornamentals were photoperiodism is of prime importance and to improve floriculture status. According to Wheeler (2008), electric lamps have been used for plant growth for about 150 years. Some of the oldest references to this may be found in the works of Mangon (1861) and Prilleux (1869) (quoted in Pfeiffer, 1926). The use of light technology for plant growth followed three broad paths of development and was comparable to those of similar illumination (Murdoch, 1985; Withrow and Withrow, 1947): There are three main types of lighting: enclosed gaseous discharge lamps, which were first created with mercury vapour in the late 1800s, open arc lighting, which typically uses carbon rods, and incandescent lighting, which was improved by Edison's invention of the incandescent filament lamp in 1879 (Murdoch, 1985). Siemens (1880) claimed that carbon arcs were possibly the first lamp used for plant growth, a practise he called "*electro horticulture*." It offers a light source with a wide, bluish spectrum but necessitated routine carbon replacement and produced risks from its UV emissions and exhaust byproducts (Parker and Borthwick, 1949; Siemens, 1880) (*Fig. 1*).

Figure 1. *Flowers under incandescent bulb (A) and metal halide lamps (B)*

Incandescent lamps were employed instead of carbon arcs because they were safer to run, had a simpler construction, and could last up to 3000 h (Harvey, 1922). The Mazda lamps were chosen for controlled environment plant research because they emit a lot of

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far-red and infrared light, which produced heat and caused extended stem elongation (Arthur and Stewart, 1935). CFLs release about 80% of their energy as heat compared to incandescent bulbs, which produce light by heating a wire filament and release 90% of their energy as heat. Until 1977, this kind of bulb was used with other lamps in plant growing chambers. This idea was further expanded to incorporate other elements such as sodium, neon, and argon during the testing of low-pressure discharge lamps employing mercury vapour (Murdoch, 1985). High-pressure mercury lamps, followed by metal halide and high-pressure sodium (HPS) lamps, were created as a result of additional testing with gaseous discharge lighting (Murdoch, 1985). These high-pressure lamps gained popularity for use in growth chambers because of their excellent electrical efficiency, lengthy operational lives, and ability to give a somewhat broad-spectrum light that was suitable for a variety of species of plants (Cathey and Campbell, 1980).

Due to more energy-efficient conversion and total photon emission within the PAR, depending on the correlated colour temperature (CCT) of the lamps, fluorescent lamps (FL) are used more frequently in plant growth applications than incandescent lamps (Simpson, 2003). The traditional lighting sources, however, are neither spectrally nor energetically efficient for the various photoperiodic responses of ornamental crops. In particular, when the lamps are placed close to the crops, the stress caused by the light causes damage to the leaf tissue (Nelson, 2014; Gupta and Jatothu, 2013). Continuous conventional lighting is thought to result in higher electricity costs. Interrupted lighting should only be utilised when it significantly affects growth, according to economic theory. In such cases, it is critical to understand how growth is affected by the level of intermittent light in comparison to continuous lighting. In order to reduce electricity consumption under a non-continuous regime, it is vital to determine a set point for managing the switching of the continuous illumination (Ganesh, 2013). In the future, light-emitting diodes (LED) may be able to meet this criterion.

Innovativeness in horticultural lighting

High-pressure sodium (HPS) lamps were first used in the latter half of the 20th century. Over the past ten years, research and development on new technologies in the 1990s led to the introduction of LEDs, which were first tested for their effects on plant growth for food during space travel at the University of Wisconsin, Purdue University, and NASA’s Kennedy Space Centre (Massa et al., 2008). According to Ouzounis et al. (2015), HPS lamps do not offer the option of spectrum modulation or even dimming. Numerous research has shown that Light Emitting Diodes have produced technologies that LED modules are versatile as lighting systems and energetically efficient (Bantis et al., 2018; Gupta, 2017). It is acknowledged that the usage of LEDs in closed systems (growth chambers), greenhouses, multilayer vertical farming, and post-harvest management is constantly expanding. Since the 1990s, there has been a lot of study being done on horticulture using LEDs (Massa and Norrie, 2015; Kozai et al., 2016).

Monochromatic wavelengths emitted by Light Emitting Diodes result in photomorphogenic responses second only to photosynthetic effects. Since infrared radiation raises crop temperature, it does not release any of it. The functioning of light-emitting diodes is fundamentally different because they do not have filaments. Compared to incandescent bulbs, it uses less energy and produces less heat, making it more energy-efficient. With half-peak bandwidths ranging from 25 to 50 nm, LEDs are available in a variety of wavebands, from the ultraviolet (UV)-C range (about 250 nm)

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to the near-infrared region (around 1000 nm). In contrast to conventional lamps, it does not emit heat directly, but it still produces a sizable quantity of heat, and this heat has been channelled outside the fixture to prevent early failure (Mitchell et al., 2015). LED affects how much water, nutrients, and transpiration are taken in. The lighting systems can be precisely engineered to activate particular plant photoreceptors and achieve desired effects thanks to the narrow emission spectra of LEDs (Davis and Burns, 2016). The technology has the benefits of improved food quality and food security along with reduced consumption of energy.

Light emitting diodes in controlled environment

Flowering is regulated by the change in length of light and dark periods in various ornamentals including agronomics and flowering species (Runkle and Heins, 2003; Mattson and Erwin, 2005; Mitchell et al., 2015). According to Thomas and Vince-Prue (1997), the length of the critical night, also known as the dark phase, plays a major role in determining the light responses. Based on how the essential night length affects flowering, flowering plants are frequently divided into response groups. In all specialised fields where the flowering of commercial flower crops is altered by various light sources under protected settings like polyhouses, shade net culture, indoor gardening, and soilless cultivation, supplemental lighting in a regulated system has grown in significance. In this sector, significant advances have been made in photoperiod regulation over two and a half decades. Large amounts of growing media, structures, inputs, pesticides, fertilisers, environment control systems, irrigation systems, plant protection, harvesting, grading, and packing are used in production systems under controlled environments. *Chrysanthemum morifolium*, *Dendrobium nobile* orchid, *Rosa hybrida*, and other economically significant cut flowers and greens production systems, in particular, require the use of extra lighting for the growth of the crops. Growers and scientists concentrate on energy conservation for greenhouse production. The growers want to find lighting for horticulture that is energy-efficient.

Advantages of LED lights in greenhouse

The following are the advantages of Light Emitting Diodes (LEDs) over the conventional horticultural lighting (https://finolex.com/the-advantages-of-led-lights-for-the-environment/).

Durability

LED lights are highly durable with an average life span of 15 years and intense brightness throughout their life. They also last up to six times longer than other light sources.

Energy-efficient

As LEDs are monochromatic and focused on a single direction, better quality of distribution is ensured. This makes the LED lights more economical and energy-efficient in comparison with fluorescents and incandescent lights. High-Pressure Sodium (HPS) and Metal Halide (MH) lamps have the highest luminous efficacies of all the artificial light sources. However, because the red and blue zones are only taken into

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account during the application, the value is greatly diminished in terms of lumens used by the plants (Gupta and Agarwal, 2017). It is also possible to use LEDs with luminous efficacy of 80–150 lm/W to create specific spectra that are fully absorbed by plants, giving them a useful light output equal to the entire luminous output. The efficiency of different lamps used for horticultural lighting is indicated in *Table 1*.

Table 1. *Efficiency of various horticulture lighting lamps*

Lamp type	Spectral output	Luminous efficacy (lm/W)	Power requirement (W)	Life span (h)
Incandescent	Broad-spectrum	20	15-1000	1000
Fluorescent	Broad-spectrum	100-120	5-125	1000-30,000
High-pressure mercury	Broad-spectrum	60	100-250	10,000-20,000
High-pressure sodium	Broad-spectrum	80-125	35-1000	10,000-30,0000
Metal halide	Broad-spectrum	100-120	35-400	10,000-20,000
Light emitting diode	Specific wavelengths	80-150	0.1-5	>50,0000

Source: Gupta and Agarwal (2017)

Spectral quality

The use of high-quality lighting is crucial for the growth of plants. The two crucial primary variables that enhance growth and development in response to illumination conditions are the spectrum and photon flux density (PFD). In order to carry out photosynthesis and control a variety of developmental and adaptation processes, plants often use the far-red, red, and blue regions of the incident spectrum (Gupta and Agrawal, 2017). The chlorophyll pigment absorbs photons and utilizes the energy for photosynthesis (Anderson, 1995). This pigment has an absorption peak at 625-675 nm (red) and 425-475 nm (blue). By using phytochromes, cryptochromes, and phototropins, the axillary receptor of the chlorophyll pigment, carotenoids, controls germination, phototropism, leaf expansion, flowering, stomatal development, chloroplast movement, and shade avoidance (Smith, 1995; Sancar, 2003; Briggs and Christie, 2002; Gupta and Agarwal, 2017).

No toxic element

LEDs do not contain mercury and do not emit traces of this poisonous gas, and thus there is very little environmental impact than incandescent bulbs. LEDs maintain a cold temperature inside the greenhouse and when compared with old fluorescent lamps, LED does not emit UV radiation and does not heat up. Moreover, increased level of biotic and abiotic stress is noticed in those lights which emit heat and UV radiation.

Rapid cycling

Recycling of LEDs does not harm the environment as they are made of recyclable and non-hazardous materials.

Plant morphological and yield influence by different spectral range

Light is a fundamental and significant component that affects several stages of a plant’s life cycle, from seed germination to seed production. According to earlier research, only the PAR with an absorbance range of 400–700 nm is seen by the plant for

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the photosynthetic activities; light from the sun or any other light source is not completely absorbed. The influence of varied spectral ranges on plant growth is depicted in *Table 2*.

Table 2. *Effects of various wavelengths on plant growth*

Wavelength (nm)	Absorption	Influence on plant growth
200-280	Completely absorbed by the ozone layer and it is highly toxic	Radiations are unavailable to the plants
280-315	Mostly absorbed in the ozone layer	Less effect on the growth of plants
315-400	Called as black light. Minimally absorbed by the plant pigments. Not absorbed by the ozone layer	Photoperiodic effect on plants
400-520	Visible spectrum. Highly absorbed by the plant pigments	Has a strong influence on photosynthesis
520-610	The plant pigments absorb less energy	Diminished effect on growth
610-720	Reduced absorption	Significantly affect plant development and flowering
720-1000	Less absorption	Essential for flowering and seed germination
>1000	No absorption	Transformed into heat

Source: Rehman et al. (2017), Deram et al. (2014), Singh et al. (2015) and ISO (2007)

With the advancements made in the recent past, the researchers are conducting quite a lot of experiments to find out the influence of monochromatic wavelengths or in combinations on physiological response and morphogenesis. The preliminary findings from several research showed that significant differences were found for numerous parameters at various wavelengths. For example, in *Tagetes* spp., red spectrum (R) has increased the dry weight of the seedling while blue (B) has increased the stem length (Heo et al., 2002). Zheng and Van Labeke (2017a) reported that blue light is essential for the normal anatomical leaf development which also has an impact on photosynthetic efficiency in *Cordyline australis*, *Ficus benjamina*, and *Sinningia speciosa*. It is assumed that different wavelengths in the PAR spectrum elicit distinct responses in plants. In *Pinus sylvestris* and *Sorghum vulgare*, the combination of blue and red light improves seedling morphology (Mohr, 1986), and it is crucial for preserving a functional photosynthetic process (Ouzounis et al., 2014b). When compared to a High-Pressure Sodium lamp, the net photosynthetic rate (PN) and stomatal conductance (GS) of leaves of Paeonia lactiflora increased under supplemental lighting of 200–220 mol m^{-2} s^{-1} at 5 h per day. The quantity of flowers, pace of flowering, size of the flowers, and inflorescence are all increased in both types (Wan et al., 2020). The physiological functions of a specific spectrum in flowering are discussed below.

Influence of white LEDs on plant growth and development

It becomes crucial to choose the right light source for supplemental lighting when growing flowers. White LEDs are blue (B; 400 to 500 nm) LEDs that have a coating or cover that emits the majority of the blue light as a variety of colours, such as green and red, so that the combination of colours results in white. White LEDs come in a variety of colours, including cool white (also known as daylight), neutral, and warm white. On

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the Kelvin (K) scale, the colour temperature will match the variances. The term “colour temperature” refers to the temperature of a black-body radiator, whose colour is perceived by humans as having a similar hue to that of a lamp but which is not actually a lamp (Meng and Runkle, 2014b).

The colour of a lamp seems cooler as the colour temperature rises. For instance, warm colours are indicated by a low colour temperature of 2,700 to 3,000 K (a softer, redder light), whereas cold colours are indicated by a high colour temperature of 4,000 to 5,000 K (a bluer light). As a result, the cool-white and warm-white LEDs’ spectral distributions are typical of light with high and low B:R ratios, respectively. This process results in the loss of 20–40% of the light produced by a blue LED, making these white LEDs less effective at producing light than a pure colour LED.

The CRI values of LED fixtures influence the plant growth. White LEDs with values of < 60 on a scale up to 100 have less significance on plant growth when compared to red + blue LED fixtures which have negative values. Plants can develop well under lights with low CRI (Runkle, 2018). The balance of short and long waves, which is correlated with colour temperature, the degree of spectrum occupancy, which is correlated with colour rendering, and the perceptible differences in the spectrum of white diodes with identical colour rendering and colour temperature all contribute to the characteristic feature of the white LED spectrum. Therefore, we can estimate the spectro-dependent parameters only by colour temperature, colour rendering, and light efficiency.

Red and blue wavelengths are more readily absorbed by plants. The spectrum that white LEDs emit comes in a variety of spectra that the plant primarily does not employ. Lower ambient temperatures are needed to maintain the ideal surface temperatures because the crop’s canopy’s unused light is converted to heat inside the leaves (Sharakshane, 2017). *Table 3* shows the influence of white light emitting diodes on plant development.

Table 3. *Effect of white LED lighting on plant growth*

Crop	LED radiation	Effect on plant growth	Reference
Cannabis sativa L.	White light (WL)	Affects plant growth and development better than blue-red (BR) light. Quantum yield of photosystem II indicated non-stressed plants	Lalge et al. (2017)
Seedlings of *Begonia rex, Pelargonium hortorum, Petunia hybrida* and *Antirrhinum majus*	100% Mint white LEDs (MW100)	Seedling height, total leaf area, fresh and dry weight remains favour under MW 100. *Petunia hybrida* seedlings grown longer and early flower initiation under MW100	Park and Runkle (2018a)

The mean flower number and flowering percentage in dahlia have been greatly influenced by the sole LED lighting and plants under gibberellic acid treatments had significant effects on growth and glowering measurements (Mills-Ibibofori et al., 2019).

Influence of blue LEDs on plant growth and development

The blue photoreceptors, phototropins, and cryptochromes all detect the blue spectrum. While cryptochromes control numerous light-related responses, including the inhibition of stem elongation, these phototropins regulate stomatal regulation and plant motions towards light. According to Urrestarazu et al. (2018), plants cultivated in

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environments with high blue intensity have short internodes, a lot of dry matter, and cool leaves (efficient transpiration).

Certain findings have also reported the effect of blue light on plant height stomatal opening and synthesis of chlorophyll (Urbonavičiūtė et al., 2007; Jao et al., 2005; Heo et al., 2002). It also encourages a positive effect on vegetative growth in terms of strong root growth and high photosynthetic activity (Rehman et al., 2017). In a study on Dendranthema × grandiflorum 'White Reagan,' daylight filtered with blue polythene films in a greenhouse inhibited stem elongation, reduced dry weight, and increased the pigment content (Oyaert et al., 1999). There are a variety of and poorly understood impacts of monochromatic blue light on blooming behaviour and responses treated by phytochromes and maybe cryptochromes. In certain flowering plants, the blue light interruption during the night has no effect on flowering and inhibits flowering in some SDPs. Quantum yield, or the amount of carbon fixed for every mole of photons absorbed, is a measure of photosynthetic efficiency. Blue light treatment diminishes leaf area by preventing cell division and growth (Dougher and Bugbee, 2004; Bugbee, 2017). Photon capture is decreased by reduced leaf area. The decrease in photon capture by blue light is what causes the growth to slow down. On the efficiency of photosynthetic reaction, there is frequently little direct spectrum effect. It modifies secondary metabolism and offers defense against biotic and abiotic stress (Bugbee, 2017). Blue light can interact with photosynthetic photon flux (PPF), and the response can alter depending on the developmental stage (Cope and Bugbee, 2013; Cope et al., 2014; Chen et al., 2014). *Table 4* illustrates the impact of blue light emitting diodes on plant growth and development.

Table 4. *Effect of blue light on growth and development*

Crop	LED radiation	Effect on plant growth	Reference
Dendranthema × grandiflorum `White Reagan'	Daylight filtered with blue polythene films in a greenhouse	Inhibited stem elongation, decreased leaf area, reduced dry weight and improved pigment content	Oyaert et al. (1999)
	Blue (450 nm)	Increased photosynthetic rate and root development	Kurilcik et al. (2008)
	Four hours daily extension blue (PPF 7 μmol m^{-2} s^{-1})	Flowering was not prevented	Jeong et al. (2012)
Paphiopedilum insigne	Lighting using blue LEDs in growth chambers	Compact plants, shorter leaf length and width	Lee et al. (2009)
Anthurium andreanum	Blue (NA)	Increased shoot formation	Budiarto (2010)
Zantedeschia jucunla	Blue (NA)	Height and chlorophyll content of plants have increased	Jao et al. (2005)
Tagetes erecta cv. Orange Boy, Salvia splendens F. Sello ex Ruem & Schult.cv. Red Vista	Monochromatic blue	Threefold increase in marigold stem length No flower buds formed in salvia	Heo et al. (2002)
Petunia x hybrida	Monochromatic Blue (400 to 500 nm, Peak 450 nm)	Promoted stem elongation, more upright shoot orientation, increased plant height and induced flowering	Gautam et al. (2015)
Eustoma grandiflorum	5 h night interruption with blue light (5 μ mol m^{-2} s^{-1})	Induced early flowering	Yamada et al. (2009)

Influence of red LEDs on plant growth and development

The phytochromes are able to perceive the red spectrum. According to Urrestarazu et al. (2018), phytochromes, a hormone that absorbs both red and far-red light, is the

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primary regulator of the shade avoidance syndrome. PHYA, PHYB, PHYC, PHYD, and PHYE are just a few of the many phytochrome proteins found in angiosperms (Sharrock and Quail, 1989; Clack et al., 1994). According to Mitchell et al. (2015) and Sharrock and Clack (2004), each phytochrome contains two versions, Pfr and Pr, which can coexist in plant cells as homodimers and heterodimers. The inactive form of phytochromes, Pr, which has an absorption peak at 660 nm, is created by red light. In the absence of light or under conditions of far-red light, phytochrome is converted into its Pr form. When the Pr absorbs red light, it changes into the Pfr form, which absorbs far-red light with a peak at 730 nm. With far-red light or complete darkness, the conversion from Pr to Pfr can be undone. Red light is clearly important for the growth of photosynthetic systems and influences morphological development through light-induced changes in the photosynthetic system (Urbonaviit et al., 2007; Rehman et al., 2017). These wavelengths promoted early flowering, greater stem growth, and higher yield. In response to the R: FR, flowering mechanisms and pathways may differ between SDPs and LDPs. Studying this application of red LEDs can improve knowledge of how the red spectrum in photoperiodic lighting controls flowering without interference from other spectra, which could be confusing (Mitchell et al., 2015). *Table 5* reveals plant growth in response to red light emitting diode lighting.

According to Wang et al. (2022), R90B10 boosted the biomass of the bulbs, leaves, and flowers. The R90B10 LEDs delayed flowering by 2.30 and 3.26 days, respectively, in comparison to the control and R10B90 groups. The accumulation of carbohydrates and early flowering were encouraged by optimal red and blue light intensity, which also lengthened the *H. hybrid* plant’s flowering time. Therefore, it is generally necessary to combine several spectral wavebands in order to control the flowering of a variety of horticulture crops that require light.

Influence of far-red LEDs on plant growth and development

The phytochromes absorb far-red light. It is one of the primary regulators of shade avoidance syndrome and absorbs both red and far-red light. Premature flowering, stem and petiole lengthening are all effects of high far-red radiation (Urrestarazu et al., 2018). The majority of LED grow lights are made to emit the lightest spectrum possible between the wavelengths of 400 and 700 nm, which corresponds to the photosynthetically active region of the spectrum (van Iersel, 2017). The phosphor coating of the LEDs determines how much far-red is contained in the white LED. The addition of far-red light to the fixture consistently enhanced the net photosynthetic rate of lettuce exposed to red/blue light, according to Zhen and van Iersel’s (2017) observations of the interactions between the emission of the spectrum by red/blue LEDs and far-red light (peak at 735 nm). The addition of far-red also enhanced ϕPSII, showing that the addition of far-red has led to a more effective use of the light delivered in the light reactions of photosynthesis (van Iersel, 2017). The improvement in net photosynthesis was not only attributable to the addition of far-red light levels. Additionally, it was found in their tests that activating photosystem I with far-red light boosted electron transport, which sped up the reoxidation of the plastoquinone pool in the thylakoid membrane. According to Zhen and van Iersel (2017), this makes it easier for electrons to transfer from Photosystem II to the plastoquinone pool, reopening the reaction centre and improving how effectively photosystem II uses excitation energy. The tiny amount of far-red found in LED lamps may hasten the greater net photosynthesis rates and ϕPSII values (*Fig. 2*).

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Table 5. *Plant growth in response to red LED lighting*

Crop	LED radiation	Effect on plant growth	Reference
Tagetes erecta cv. Orange Boy	R	An increase in the dry weight of marigold seedlings	Heo et al. (2002) and Yihe and Lieth (2019)
Petunia multiflora 'Easy Wave White'	R + Fr	Promoted flowering	Craig and Runkle (2012)
Euphorbia milii	R + Fr	Stimulated flowering	Hahn et al. (2006)
Begonia rex cv. Olympia red, *Pelargonium x hortorum* cv. Deep Rose, *Petunia hybrida* cv Wavelength and *Antirrhinum majus* cv. Liberty Classic Yellow	$W_{75} + R_{25}$	Primary stem elongated and early flowering	Park and Runkle (2018a)
Dendranthema grandiflorum cv. Cheonsu	Monochromatic R	RB: Decreasing the number of stomata while increasing photosynthetic rate and stomata size RFR: Longer stems overall	Kim et al. (2004) and Bantis et al. (2018)
Oncidium cv. Gower Ramsey	RBFR LEDs	Compared to monochromatic R and B, RBFR has increased leaf area, leaf quantity, chlorophyll concentration, and fresh and dry weight	Chung et al. (2010) and Bantis et al. (2018)
	B (10%-30%) and R LEDs	BR: Higher dry weight and protein accumulation compared to FL	Mengxi et al. (2011)
Rosa x hybrida cv. Toril	RB (80% R: 630 nm, 20%B: 465 nm) LED	RB: Improved leaf weight, Reduced leaf area and shoot weight, Not influence flowering	Terfa et al. (2013)
Ageratum houstonianum, *Tagetes erecta, Salvia splendens*	RFR (1:1)	Increased shoot length compared to BR	Hao et al. (2016)
Perlargonium x hortorum, *Petunia x hybrida*, *Antirrhinum majus*, and *Impatiens walleriana*	RFR	Each species: Growing R causes a linear decrease in plant height: FR	Park and Runkle (2017)
Rosa hybrida, *Chrysanthemum morifolium* and *Campunala portenschlagiana*	R (650-670 nm)	R: Curled leaves and other morphological abnormalities	Ouzounis et al. (2014b)
Chrysanthemum morifolium	Red (100%), Blue (100%), 75% red with 25% blue, White	Red light reduced leaf area, White light have high Chlorophyll content and Chl a/b, total flavonoids and carotenoids, Blue registered high proline biosynthesis	Zheng and Van Labeke (2017b)
Impatiens balsamina, *Zinnia elegans*, *Petunia x hybrida* and V*erbena aubletia*	Red, Blue, Red + Blue (25% + 75%), Fluorescent lamps	In all four species, seedlings exposed to red light displayed the highest emergence percentage, pace, and value	Akbarian et al. (2016)
Euphorbia milii	Red (620-720 nm)	Reduction in flowering percentage	Dewir et al. (2006)
Chrysanthemum x morifolium and *Euphorbia pulcherrima*	Red 660 nm of 8 h	Euphorbia plants have shorter stems, although Chrysanthemum plants have not	Bergstrand et al. (2016)

Though far-red light has a significant effect on plant morphology, its considerable impact given horticultural applications has been found in the control of flowering duration. Runkle and Heins (2001) had shown that the presence or absence of far-red light might promote or hinder flowering in a number of long-day ornamental plants. Plant light responses were studied using the light filters. Flowering can either be delayed or advanced using even more extremes red: far-red ratios of LED spectral treatments for plant growth. For instance, earlier induction from up to two weeks was found in plants grown under red, blue, and far-red light when compared to the growing without far-red light in the case of Petunias and Pansies (Davis et al., 2015). The addition of a red-blue and a far-red light emitting diode resulted in an increase in plant

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dry weight (46-77%), leaf area (58-75%), radiation use efficiency (17-42%), incident light use efficiency (46-77%), and intercepted light use efficiency (8-23%), all of which improved after four weeks, according to Jin et al. (2021). Plant dry weights of far-red plants are more resilient at low planting densities than at high planting densities. *Table 6* shows how far-red light emitting diode lighting affects plant development.

Figure 2. *Different spectral illuminations of light emitting diodes in controlled environment*

Table 6. *Effect of Far-red LED lighting on plant growth*

Crop	LED irradiation	Effect on plant growth	Reference
Antirrhinum majus	Far-red	Increasing flowering with increasing FR	Park and Runkle (2017)
Chrysanthemum morifolium	Far-red (735 nm)	When applied during night-break, the FR-containing treatments lengthened shoots more than the non-FR-containing treatments did	Liao et al. (2014)
Pharbitis nil (Ipomea morning glory)	Far-red	Inhibit flowering	Takimoto and Hamner (1965)
Gypsophila paniculata	Far-red	Monochromatic FR produces no flowering	Nishidate et al. (2012)
Cyclamen persicum	Blue + Red + Far-red	Accelerate flowering in LDPs	Shin et al. (2010)
Petunia hybrida	Far-red 700-740 nm	Increased shoot length, promoted higher flowering	Park et al. (2016a)

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Combination of spectral emittances and its influence on plant growth

For the growing of flowers, the combination of various LED regimens can offer enhanced influence and tailored wavelengths (Monotsori et al., 2018). According to Shen et al. (2014), combined red and blue light may enhance photosynthetic activity and control morphogenesis. Improvement in horticultural traits by mixed LED spectrum has been studied and reported in a large number of crops like *Lactuca sativa*, *Gossypium hirsutum*, *Piper nigrum*, *Stevia rebaudiana*, *Fagopyrum esculentum* Moench, *Fragaria x ananassa*, etc. Park and Runkle (2018b) compared the sole source lighting with blue plus red combination in *Begonia rex*, *Petunia hybrida* and *Pelargonium x hortorum* and have revealed that *petunia hybrida* grown under sole-source lighting had improved stem length, early flower buds. Previous research on the Lilium oriental hybrid 'Pesaro' suggested that altering the light's quality has an impact on the hybrid's growth throughout the crop growing stage in vitro (Lian et al., 2002). In contrast to only red and blue LEDs, Olschowski et al. (2016) found that root and shoot development of Calibrachoa cuttings was best under a wider spectrum of white LEDs or a combination of white, blue, and red LEDs. With minimal leaf and stem development, far-red to red and blue radiation irradiation of snapdragon enhanced photosynthetic efficiency and dry matter production (Park and Runkle, 2016b; Virsile et al., 2017). According to a study comparing HPS and SSL on seedling growth, the majority of species had generally higher root and shoot dry mass, stem diameter, relative chlorophyll content, and the quality index (a quantitative measurement of quality) under SSL and SL than under AL (Randall and Lopez, 2015). Endogenous phytohormone balance is unaffected by monochromatic or mixed spectral emissions, which also decrease stress more effectively than fluorescent lights in in vitro-grown *Gerbera jamesonii* plants (Cioc et al., 2022). The combined effect of light quality in various ornamental crops are discussed in *Table 7*.

Table 7. *Combined effect of different spectrum on morphology of flower and ornamentals*

Crop	LED radiation	Effect on plant growth	Reference
Ficus benjamina cv. Exotica, Cordyline australis cv. Red star, and Sinningia speciosa cv. Sonata Red	B (460 nm): RB (75% R-25% B)	B and RB: All species had higher Fv/Fm and ϕPSII. Additionally, they made S. speciose's palisade parenchyma larger	Zheng and Van Lebeke (2017a)
Oncidium cv. Gower Ramsey	RBFR LEDs	Compared to monochromatic R and B, RBFR exhibits greater leaf growth, quantity, chlorophyll content, and fresh and dry weight	Chung et al. (2010) and Bantis et al. (2018)
Ageratum houstanianum, *Calibrachoa x hybrid*, *Dahlia x hybrid*, *Dianthus chinensis*, *Petunia hybrida*, *Antirrhinum majus* and *Verbena x hybrid*	R + W + FR 4h of night interruption (NI)	Under NI as opposed to SD, ageratum, dianthus, petunia, snapdragon, and verbena all blossomed earlier	Meng and Runkle (2014a)
Phalaenopsis hybrids (cv. Vivien) and cv. Purple star	Emission from 40% B/60% R LEDs was 200 mol m^{-2} s^{-1}.	40% B/60% R: Decreased electron transport rate in cv and increased non-photochemical quenching. Vivien	Ouzounis et al. (2015a)
Rosa hybrida, *Chrysanthemum morifolium* and *Campunal portenschlagiana*	40% B/60% R	Reduction in plant height and leaf count in campunals compared to 20% B/80% R for roses and chrysanthemums	Ouzounis et al. (2014b)

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Crop	LED radiation	Effect on plant growth	Reference
Pelargonium x hortorum, *Petunia x hybrid*, *Antirrhinum majus* cv. Montego Yellow	(737 nm, 12 mol m-2 s-1) 12% B 10% G 68% R + FR	Snapdragon: B12G20R68 + FR improved plant height and leaf area, and they accelerated flowering by an average of 7 days. B45R55 and B12G20R68 + FR geraniums blossomed seven to nine days early	Poel and Runkle (2017)
Pelargonium x hortorum, *Pennisetum x advena*	50:50 R: B and B:	14 days after production ended, when the greenhouse DLI was low (9 mol $m^{-2}d^{-1}$), the foliage colour was intensified	Owen and Lopez (2017)
Rosa hybrida	Blue (20%) and Red (80%)	Increase leaf weight. Reduction in leaf area, shoot weight and has no influence on flowering	Terfa et al. (2012)
Chrysanthemum morifolium	Blue light with a higher red: far-red ratio	Reductions in plant height, leaf area, and dry weight	Mortensen and Stromme (1987) and Ouzounis et al. (2015)
	Blue with far-red LED	Decreased photosynthetic rate, increased number of stomata with decreased size	Kim et al. (2004)
Begonia× hiemalis Fotsch., *Campanula isophylla* Moretti	Blue light with a higher red: far-red ratio	Reduction in plant dry weight, shoot length, and diameter. No flowering effect on begonia but delayed flowering in campanula	Mortensen (1990)
Oncidium Gower Ramsey	Blue (10% to 30%) and red LEDs	Protein accumulation and increased dry weight	Mengxi et al. (2011)
Cymbidium aloifolium	Blue + red LEDs in growth chambers	Reduction in leaf growth and increased chlorophyll content. Red showed a reverse effect	Tanaka et al. (1998)
Euphorbia milii	Far-red plus either Red or Blue	Enhanced flowering	Dewir et al. (2006)
Dendrobium officinale	Red (660 nm) + Blue (450 nm)	Enhanced shooting	Lin et al. (2010)
Ageratum houstonianum, *Verbena x hybrida*, *Calibrachoa hybrida*, *Dahlia x hybrida*, *Dianthus chinensis*, *Petunia x hybrida*,	Red + White + Far-red	Effective at controlling flowering of photoperiodic plants	Meng and Runkle (2014b)
Gypsophila paniculata	FR: R	Promotion of flowering and flower budding was increased	Nishidate et al. (2012)
Antirrhinum majus, *Catharanthus roseus*, *Celosia argentea*, *Impatiens walleriana*, Hook, *Pelargonium hortorum*, *Petunia hybrida*, *Salvia splendens*, *Tagetes patula* and *Viola wittrockiana*	Various combinations of 660 nm red and 470 nm blue light; R: B, 85:15	Reduction in seedling height. Larger stem caliper of seedlings grown under 85:15 red: blue LEDs	Randall and Lopez (2015) and Virsile et al. 2017
Impatiens hawker, *Pelargonium hortorum* and *Petunia hybrid*	R: B 70:30	Increased leaf dry mass, root dry mass, root mass ratios, and root: shoot ratio of cuttings	Currey and Lopez (2013)

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Irradiating polyhouse chrysanthemums var Salvador and var Pusa Centenary with single wavelengths from different spectral bands or combination wavelengths promoted growth and yield. A single wavelength altered photomorphogenic chrysanthemum characteristics such as increased total leaf area, stem girth, early blooming, flower production, and colour. (Ganesh et al., 2021). Under red and RGB light, cut flower length and internode length were found to be shorter, according to Roh and Yoo (2023). In Tulip cv. “Lagergame,” the ratio of leaf length to width was larger under green and blue light than under other treatments.

Physiological implications of distinct and intermittent application of LEDS

LEDs have a significant impact on the growth and development of plants. Epidermal flavonoids have been shown to improve under a single wavelength of blue light (Hoffman et al., 2014). According to Ranade and Gil (2016), blue wavelength is crucial for the development of chloroplasts, the synthesis of chlorophyll, photomorphogenesis, stomatal opening, and the creation of the red pigment anthocyanin. However, Ngilah (2018) has found that combining blue light with different wavelengths might boost the phenolic contents, antioxidants, vitamins, tannins, and other secondary metabolites. According to Ma et al. (2021), the impact of LED on plant growth and quality features varied depending on the species and the farmed conditions.

Similar to how conventional lights can, plants exhibit physiological abnormalities in response to their environment of LED lighting. According to Mitchell et al. (2015), this may be a result of unfavourable reactions to light quality, high-intensity damage, and aberrant photoperiod effects (Morrow and Wheeler, 1997). But compared to HPS and HID lighting, LED lighting has different fundamental properties (short waveband, high light output, and low heat generation). The common physiological disorder caused by differences in light quality is known as intumescence injury (called edema) which occurs in different plant species under a protected environment (Morrow and Tibbitts, 1988; Mitchell et al., 2015). The disorder has a greater impact on growth and productivity, leads to plant death. The physiology of disorder is may be due to the lack of UV light in the spectrum seems to triggers this response, causing abnormal development. The capacity of LEDs to provide high light intensities when placed closer to the plants in the greenhouse causes tissue damage resulted in photobleached spots in the side of leaves (Morrow, 2008). LED activity has been linked to gene activation or suppression in a range of processes, including the production of bioactive chemicals and the stimulation or inhibition of flowering, among others. To improve crop yield and quality under different LED illuminations, the processes behind these interactions between LED wavelengths and genes must be elucidated (Al Murad et al., 2022). Only then will these genes be able to be changed or manipulated.

Conclusion

The application of LEDs in the floriculture sector has created its way under increasing climate change over the last two decades. LEDs use in sustaining the horticultural production system under changing climate led to the utilization of cost-effective and energy-efficient light sources for supplemental lighting in indoor and protected environments. The floriculture species are diverse, countless varieties, and cultivars, as well as varied climatic zones, cultivation systems have resulted and

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necessitates the production of flowers during the offseason and increasing the productivity of the crop per unit area. The review has indicated the need for innovative inventions such as extended lighting research in the commercial flower production system. The findings from past studies on the production of decorative plants appear to be more complex than those on vegetable illumination. Various studies indicated that LEDs could have control over both light spectrum and Photosynthetic Photon Flux Density (PPFD), still there exists a knowledge gap on understanding the distinct spectral effects on photosynthetic responses, as well as photobiological conclusions for many whole physiological processes that control light capture and its efficiency. The response of the sole source spectrum at varied spectral range and its interaction with other sources on plant growth and development are still poorly understood and deserves more study. The smart lighting under a protected environment would be highly beneficial to the greenhouse growers when light-induced responses of short day and long day flowering species were studied and lighting controlling systems at greater economy. Moreover, it encourages young researchers to take up research and development projects in the future.

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REFERENCES

[1] Akbarian, B., Matloobi, M., Mahna, N. (2016): Effects of LED light on seed emergence and seedling quality of four bedding flowers. – Journal of Ornamental Plants 6(2): 115-123.

[2] Al Murad, M., Razi, K., Jeong, B. R., Samy, P. M. A., Muneer, S. (2021): Light emitting diodes (LEDs) as agricultural lighting: impact and its potential on improving physiology, flowering, and secondary metabolites of crops. – Sustainability 13: 1985. https://doi.org/10.3390/su13041985.

[3] Anderson, J. M., Chow, W. S., Park, Y. I. (1995): The grand design of photosynthesis: acclimation of the photosynthetic apparatus to environmental cues. – Photosynthesis Research 46: 129-139.

[4] Arthur, J. M., Stewart, W. D. (1935): Relative growth and dry weight production of plant tissue under Mazda, neon, sodium, and mercury vapor lamps. – Contr. Boyce Thompson Inst 7: 119-130.

[5] Bantis, F., Smirnakou, S., Ouzounis, T., Koukounaras, A., Ntagkas, N., Radoglou, K. (2018): Current status and recent achievements in the field of horticulture with the use of light-emitting diodes (LEDs). – Scientia Horticulturae 235: 437-451.

[6] Bayat, L., Arab, M., Aliniaeifard, S., Seif, M., Lastochkina, O., Li, T. (2018): Effects of growth under different light spectra on the subsequent high light tolerance in rose plants. – AoB Plants 10(5): ply052.

[7] Bergstrand, K. J., Asp, H., Schüssler, H. K. (2016): Growth control of ornamental and bedding plants by manipulation of photoperiod and light quality. – VIII International Symposium on Light in Horticulture 1134: 33-40.

[8] Briggs, W. R., Christie, J. M. (2002): Phototropins 1 and 2: versatile plant blue-light receptors. – Trends in Plant Science 7(5): 204-210.

[9] Budiarto, K. (2010): Spectral quality affects morphogenesis on Anthurium plantlet during in vitro culture. – AGRIVITA, Journal of Agricultural Science 32(3): 234-240.

[10] Bugbee, B. (2017): Economics of LED Lighting. – In: Datta Gupta, S. (ed.) Light Emitting Diodes for Agriculture: Smart Lighting. Springer Nature, Singapore, pp. 81-99.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_017040

[11] Bula, R. J., Morrow, R. C., Tibbitts, T. W., Barta, D. J., Ignatius, R. W., Martin, T. S. (1991): Light-emitting diodes as a radiation source for plants. – HortScience 26(2): 203-205.
[12] Cathey, H. M., Campbell, L. E. (1980): Light and lighting systems for horticultural plants. – Horticultural Reviews 2: 491-537.
[13] Chen, M., Chory, J., Fankhauser, C. (2004): Light signal transduction in higher plants. – Annu. Rev. Genet. 38: 87-117.
[14] Chen, X. L., Guo, W. Z., Xue, X. Z., Wang, L. C., Qiao, X. J. (2014): Growth and quality responses of ‘Green Oak Leaf’ lettuce as affected by monochromic or mixed radiation provided by fluorescent lamp (FL) and light-emitting diode (LED). – Scientia Horticulturae 172: 168-175.
[15] Chung, J. P., Huang, C. Y., Dai, T. E. (2010): Spectral effects on embryogenesis and plantlet growth of Oncidium ‘Gower Ramsey’. – Scientia Horticulturae 124(4): 511-516.
[16] Cio´c, M., Dziurka, M., Pawłowska, B. (2022): Changes in endogenous phytohormones of Gerbera jamesonii axillary shoots multiplied under different light emitting diodes light quality. – Molecules 27: 1804. https://doi.org/10.3390/molecules27061804.
[17] Clack, T., Mathews, S., Sharrock, R. A. (1994): The phytochrome apoprotein family in Arabidopsis is encoded by five genes: the sequences and expression of PHYD and PHYE. – Plant Molecular Biology 25: 413-427.
[18] Cope, K. R., Bugbee, B. (2013): Spectral effects of three types of white light-emitting diodes on plant growth and development: absolute versus relative amounts of blue light. – HortScience 48(4): 504-509.
[19] Cope, K. R., Snowden, M. C., Bugbee, B. (2014): Photobiological interactions of blue light and photosynthetic photon flux: Effects of monochromatic and broad-spectrum light sources. – Photochemistry and Photobiology 90(3): 574-584.
[20] Craig, D. S., Runkle, E. S. (2012): Using LEDs to quantify the effect of the red to far-red ratio of night-interruption lighting on flowering of photoperiodic crops. – VII International Symposium on Light in Horticultural Systems 956: 179-186.
[21] Currey, C. J., Lopez, R. G. (2013): Cuttings of Impatiens, Pelargonium, and Petunia propagated under light-emitting diodes and high-pressure sodium lamps have comparable growth, morphology, gas exchange, and post-transplant performance. – HortScience 48: 428-434.
[22] Davies, K. (2004): Plant Pigments and Their Manipulation. – Ann. Plant Rev. 14 Blackwell Publishing, Oxford, UK.
[23] Davis, P. A., Burns, C. (2016): Photobiology in protected horticulture. – Food and Energy Security 5(4): 223-238.
[24] Davis, P. A., Beynon-Davies, R., Mcpherson, G. M., Banfield-Zanin, J., George, D., Ottosen, C. O. (2015): Understanding crop and pest responses to LED lighting to maximise horticultural crop quality and reduce the use of PGRs. – AHDB Project CP125 Year One Report.
[25] Deram, P., Lefsrud, M. G., Orsat, V. (2014): Supplemental lighting orientation and red-to-blue ratio of light-emitting diodes for greenhouse tomato production. – HortScience 49(4): 448-452.
[26] Dewir, Y. H., Chakrabarty, D., Hahn, E. J., Paek, K. Y. (2006): The effects of paclobutrazol, light emitting diodes (LEDs) and sucrose on flowering of *Euphorbia millii* plantlets in vitro. – European Journal of Horticultural Science 71(6): 240.
[27] Dougher, T. A., Bugbee, B. (2004): Long-term blue light effects on the histology of lettuce and soybean leaves and stems. – Journal of the American Society for Horticultural Science 129(4): 467-472.
[28] Dutta Gupta, S., Jatothu, B. (2013): Fundamentals and applications of light-emitting diodes (LEDs) in in vitro plant growth and morphogenesis. – Plant Biotechnology Reports 7: 211-220.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_017040

[29] Ganesh, S. (2013): Standardization of precision production technologies of greenhouse chrysanthemum under sub-tropical conditions. – Thesis submitted to Tamil Nadu Agricultural University, Coimbatore.

[30] Ganesh, S., Kannan, M., Jawaharlal, M. (2014): Standardization of light regime to optimize growth and yield of spray chrysanthemum for winter under sub-tropical conditions. – Trends in Biosciences 7(18): 2680-2683.

[31] Ganesh, S., Kannan, M., Jawaharlal, M., Arulmozhiyan, R. (2016): Plant growth analysis of greenhouse chrysanthemum on interrupted photoperiodic regime. – International Journal of Agriculture Sciences. 8(23): 1470-1473.

[32] Ganesh, S., Jawaharlal, M., Rajamani, K., Thamaraiselvi, S. P. (2021): Responses of mixed light-emitting diode ratios on vegetative, flower regulation, and stalk elongation of cut chrysanthemum (*Dendranthema grandiflora* Tzvelev). – Journal of Applied and Natural Science 13(2): 496 – 503.

[33] Gautam, P., Terfa, M. T., Olsen, J. E., Torre, S. (2015): Red and blue light effects on morphology and flowering of Petunia× hybrida. – Scientia Horticulturae 184: 171-178.

[34] Gupta, S. D. (2017): Light Emitting Diodes for Agriculture: Smart Lighting. 1st Ed. – Springer Nature, Singapore.

[35] Gupta, S. D., Agarwal, A. (2017): Artificial Lighting System for Plant Growth and Development: Chronological Advancement, Working Principles, and Comparative Assessment. – Datta Gupta, S. (ed.) Light Emitting Diodes for Agriculture: Smart Lighting. Springer Nature, Singapore, pp. 16-17.

[36] Hahn, E. J., Paek, K. Y., Dewir, Y. H. Chakrabarty, D. (2006): Flowering of *Euphorbia milii* plantlets *in vitro* as affected by paclobutrazol, light-emitting diodes (LEDs), and sucrose. – XXVII International Horticultural Congress - IHC 2006: International Symposium on Plant Biotechnology: From Bench to 764, pp. 169-174.

[37] Hao, X., Little, C., Zheng, J. M., Cao, R. (2016): Far-red LEDs improve fruit production in greenhouse tomato grown under high-pressure sodium lighting. – VIII International Symposium on Light in Horticulture 1134 95-102.

[38] Harvey, R. B. (1922): Growth of plants in artificial light. – Botanical Gazette 74(4): 447-451.

[39] Heo, J., Lee, C., Chakrabarty, D., Paek, K. (2002): Growth responses of marigold and salvia bedding plants as affected by monochromic, or mixture radiation provided by a light-emitting diode (LED). – Plant Growth Regulation 38: 225-230.

[40] Higuchi, Y., Sumitomo, K., Oda, A., Shimizu, H., Hisamatsu, T. (2012): Day light quality affects the night-break response in the short-day plant chrysanthemum, suggesting differential phytochrome-mediated regulation of flowering. – Journal of Plant Physiology 169(18): 1789-1796.

[41] Hoffmann, A. M., Noga, G., Hunsche, M. (2015): High blue light improves acclimation and photosynthetic recovery of pepper plants exposed to UV stress. – Environmental and Experimental Botany 109: 254-263.

[42] Ibaraki, Y. (2017): LED Supplementary Lighting. – Datta Gupta, S. (ed.) Light Emitting Diodes for Agriculture: Smart Lighting. Springer Nature, Singapore, pp. 6-17.

[43] Islam, M. A., Gislerød, H. R., Torre, S., Olsen, J. E. (2014): Control of shoot elongation and hormone physiology in poinsettia by light quality provided by light emitting diodes–a minireview. – XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014) 1104: 131-136.

[44] ISO (2007): Space environment (natural and artificial). Process for determining solar irradiances. – ISO 21348:2007.

[45] Jao, R. C., Lai, C. C., Fang, W., Chang, S. F. (2005): Effects of red light on the growth of Zantedeschia plantlets in vitro and tuber formation using light-emitting diodes. – HortScience 40(2): 436-438.

[46] Jeong, S. W., Park, S., Jin, J. S., Seo, O. N., Kim, G. S., Kim, Y. H., Shin, S. C. (2012): Influences of four different light-emitting diode lights on flowering and polyphenol

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_017040

variations in the leaves of chrysanthemum (*Chrysanthemum morifolium*). – Journal of Agricultural and Food Chemistry 60(39): 9793-9800.
[47] Jin, W., Urbina, J. L., Heuvelink, E., Marcelis, L. F. M. (2021): Adding far-red to red-blue light-emitting diode light promotes yield of lettuce at different planting densities. – Front. Plant Sci. 11: 609977. DOI: 10.3389/fpls.2020.609977.
[48] Johnson, I. R., Thornley, J. H., Frantz, J. M., Bugbee, B. (2010): A model of canopy photosynthesis incorporating protein distribution through the canopy and its acclimation to light, temperature and CO2. – Annals of Botany 106(5): 735-749.
[49] Kim, S. J., Hahn, E. J., Heo, J. W., Paek, K. Y. (2004): Effects of LEDs on net photosynthetic rate, growth and leaf stomata of chrysanthemum plantlets in vitro. – Scientia Horticulturae 101(1-2): 143-151.
[50] Kozai, T., Fujiwara, K., Runkle, E. S. (2016): LED Lighting for Urban Agriculture. – Springer Science-Business Media, Singapore.
[51] Kurilčik, A., Miklušytė-Čanova, R., Dapkūnienė, S., Žilinskaitė, S., Kurilčik, G., Tamulaitis, G., Žukauskas, A. (2008): In vitro culture of Chrysanthemum plantlets using light-emitting diodes. – Open Life Sciences 3(2): 161-167.
[52] Lalge, A., Cerny, P., Trojan, V., Vyhnanek, T. (2017): The effects of red, blue and white light on the growth and development of Cannabis sativa L. – Mendel Net 8(9): 646-651.
[53] Lee, Y. I., Fang, W., Chen, C. C. (2009): Effect of six different LED light qualities on the seedling growth of Paphiopedilum orchid in vitro. – VI International Symposium on Light in Horticulture 907: 389-391.
[54] Li, T., Heuvelink, E., Dueck, T. A., Janse, J., Gort, G., Marcelis, L. F. M. (2014): Enhancement of crop photosynthesis by diffuse light: quantifying the contributing factors. – Annals of Botany 114(1): 145-156.
[55] Lian, M. L., Murthy, H. N., Paek, K. Y. (2002): Effects of light emitting diodes (LEDs) on the in vitro induction and growth of bulblets of Lilium oriental hybrid ‘Pesaro’. – Scientia Horticulturae 94(3-4): 365-370.
[56] Liao, Y., Suzuki, K., Yu, W., Zhuang, D., Takai, Y., Ogasawara, R., Fukui, H. (2014a): Night-break effect of LED light with different wavelengths on shoot elongation of Chrysanthemum morifolium Ramat ‘Jimba’and ‘Iwa no hakusen’. – Environmental Control in Biology 52(1): 51-55.
[57] Liao, Y., Suzuki, K., Yu, W., Zhuang, D., Takai, Y., Ogasawara, R., Fukui, H. (2014b): Night break effect of LED light with different wavelengths on floral bud differentiation of chrysanthemum morifolium Ramat ‘Jimba’and Iwa no hakusen. – Environmental Control in Biology 52(1): 45-50.
[58] Lin, Y., Li, J., Li, B., He, T., Chun, Z. (2011): Effects of light quality on growth and development of protocorm-like bodies of Dendrobium officinale in vitro. – Plant Cell, Tissue and Organ Culture (PCTOC) 105: 329-335.
[59] Ma, Y., Xu, A., Cheng, Z. M. M. (2021): Effects of light emitting diode lights on plant growth, development and traits a meta-analysis. – Horticultural Plant Journal 7(6): 552-564.
[60] Mangon, H. (1861): Production de la matière verte des feuilles sous l’influence de la lumière électrique Compt. – Rend. Acad. Sci. Paris. 53243244.
[61] Massa, G. D., Kim, H. H., Wheeler, R. M., Mitchell, C. A. (2008): Plant productivity in response to LED lighting. – HortScience 43(7): 1951-1956.
[62] Massa, G. D., Norrie, J. (2015): LEDs electrifying horticultural science: proceedings from the 2014 Colloquium and Workshop. – HortScience 50(9): 1272-1273.
[63] Mattson, N. S., Erwin, J. E. (2005): The impact of photoperiod and irradiance on flowering of several herbaceous ornamentals. – Scientia horticulturae 104(3): 275-292.
[64] Meng, Q., Runkle, E. S. (2014a): Controlling flowering of photoperiodic ornamental crops with light-emitting diode lamps: a coordinated grower trial. – HortTechnology 24(6): 702-711.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_017040

[65] Meng, Q., Runkle, E. S. (2014b): Evaluating different LEDs to control flowering. – GPN 2014(December): 14-19.
[66] Mengxi, L., Zhigang, X., Yang, Y., Yijie, F. (2011): Effects of different spectral lights on Oncidium PLBs induction, proliferation, and plant regeneration. – Plant Cell, Tissue and Organ Culture (PCTOC) 106: 1-10.
[67] Mills-Ibibofori, T., Dunn, B. L., Maness, N., Payton, M. (2019): Effect of LED lighting and gibberellic acid supplementation on potted ornamentals. – Horticulturae 5(3): 51.
[68] Mitchell, C. A., Dzakovich, M. P., Gomez, C., Lopez, R., Burr, J. F., Hernández, R., Both, A. J. (2015): Light-emitting diodes in horticulture. – Horticultural Reviews: 43: 1-88.
[69] Mohr, H. (1986): Coaction Between Pigment Systems. – In: Kendrick, R. E., Kronenberg, G. H. M. (eds.) Photomorphogenesis in Plants. Springer, pp. 547-564.
[70] Monostori, I., Heilmann, M., Kocsy, G., Rakszegi, M., Ahres, M., Altenbach, S. B., Darko, É. (2018): LED lighting–modification of growth, metabolism, yield and flour composition in wheat by spectral quality and intensity. – Frontiers in Plant Science 9: 605.
[71] Morrow, R. C. (2008): LED lighting in horticulture. – HortScience 43(7): 1947-1950.
[72] Morrow, R. C., Tibbitts, T. W. (1988): Evidence for involvement of phytochrome in tumor development on plants. – Plant Physiology 88(4): 1110-1114.
[73] Morrow, R. C., Wheeler, R. M. (1997): Physiological Disorders. – In: Langhans, R. W., Tibbitts, T. W. (eds.) A Growth Chamber Manual. 2nd Ed. North Central Regional Research Publication 340. Iowa State University Press, Ames, pp. 133-141.
[74] Mortensen, L. M. (1990): Effects of temperature and light quality on growth and flowering of *Begonia× hiemalis* Fotsch. and *Campanula isophylla* Moretti. – Scientia Horticulturae 44(3-4): 309-314.
[75] Mortensen, L. M., Strømme, E. (1987): Effects of light quality on some greenhouse crops. – Scientia Horticulturae 33(1-2): 27-36.
[76] Murdoch, J. B. (1985): Illuminating Engineering - From Edison's Lamp to the Laser. – Macmillan Pub. Comp., New York.
[77] Nelson, J. A., Bugbee, B. (2014): Economic analysis of greenhouse lighting: light emitting diodes vs. high intensity discharge fixtures. – PloS ONE 9(6): e99010.
[78] Ngilah, E. I., Tsan, F. Y., Yap, B. K. (2018): Photoperiod and light spectrum effects on growth, pigment and ascorbic acid content of *Lactuca sativa* cv. Fire Red under controlled growth environment. – International Food Research Journal 25(3): 1300-1308.
[79] Nishidate, K., Kanayama, Y., Nishiyama, M., Yamamoto, T., Hamaguchi, Y., Kanahama, K. (2012): Far-red light supplemented with weak red light promotes flowering of *Gypsophila paniculata*. – Journal of the Japanese Society for Horticultural Science 81(2): 198-203.
[80] Ochiai, M., Liao, Y., Shimazu, T., Takai, Y., Suzuki, K., Yano, S., Fukui, H. (2015): Varietal differences in flowering and plant growth under night-break treatment with LEDs in 12 chrysanthemum cultivars. – Environmental Control in Biology 53(1): 17-22.
[81] Olle, M., Viršile, A. (2013): The effects of light-emitting diode lighting on greenhouse plant growth and quality. – Agricultural and Food Science 22(2): 223-234.
[82] Olschowski, S., Geiger, E. M., Herrmann, J. V., Sander, G., Grüneberg, H. (2016): Effects of red, blue, and white LED irradiation on root and shoot development of Calibrachoa cuttings in comparison to high pressure sodium lamps. – VIII International Symposium on Light in Horticulture 1134: 245-250.
[83] Ouzounis, T., Fretté, X., Ottosen, C. O., Rosenqvist, E. (2015a): Spectral effects of LEDs on chlorophyll fluorescence and pigmentation in Phalaenopsis 'Vivien'and 'Purple Star'. – Physiologia Plantarum 154(2): 314-327.
[84] Ouzounis, T., Fretté, X., Rosenqvist, E., Ottosen, C. O. (2014b): Spectral effects of supplementary lighting on the secondary metabolites in roses, chrysanthemums, and campanulas. – Journal of Plant Physiology 171(16): 1491-1499.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_017040

[85] Ouzounis, T., Rosenqvist, E., Ottosen, C. O. (2015): Spectral effects of artificial light on plant physiology and secondary metabolism: a review. – HortScience 50(8): 1128-1135.
[86] Owen, W. G., Lopez, R. G. (2017): Geranium and purple fountain grass leaf pigmentation is influenced by end-of-production supplemental lighting with red and blue light-emitting diodes. – HortScience 52(2): 236-244.
[87] Oyaert, E., Volckaert, E., Debergh, P. C. (1999): Growth of chrysanthemum under coloured plastic films with different light qualities and quantities. – Scientia Horticulturae 79(3-4): 195-205.
[88] Park, Y., Runkle, E. S. (2016): Investigating the merit of including far-red radiation in the production of ornamental seedlings grown under sole-source lighting. – VIII International Symposium on Light in Horticulture 1134: 259-266.
[89] Park, Y., Runkle, E. S. (2017): Far-red radiation promotes growth of seedlings by increasing leaf expansion and whole-plant net assimilation. – Environmental and Experimental Botany 136: 41-49.
[90] Park, Y., Runkle, E. S. (2018a): Growing ornamental seedlings under white LEDs. – https://www.greenhousegrower.com/technology/growing-ornamental-seedlings-under-white-leds/#Tinsel/143903/4.
[91] Park, Y., Runkle, E. S. (2018b): Spectral effects of light-emitting diodes on plant growth, visual color quality, and photosynthetic photon efficacy: white versus blue plus red radiation. – PLoS ONE 13(8): e0202386.
[92] Park, Y. G., Muneer, S., Soundararajan, P., Manivnnan, A., Jeong, B. R. (2016): Light quality during night interruption affects morphogenesis and flowering in Petunia hybrida, a qualitative long-day plant. – Horticulture, Environment, and Biotechnology 57: 371-377.
[93] Parker, M. W., Borthwick, H. A. (1949): Growth and composition of Biloxi soybean grown in a controlled environment with radiation from different carbon-arc sources. – Plant Physiology 24(3): 345.
[94] Pfeiffer, N. E. (1926): Microchemical and morphological studies of effect of light on plants. – Botanical Gazette 81(2): 173-195.
[95] Poel, B. R., Runkle, E. S. (2017): Spectral effects of supplemental greenhouse radiation on growth and flowering of annual bedding plants and vegetable transplants. – HortScience 52(9): 1221-1228.
[96] Prilleux, E. (1869): De l'influence de la lumie`re artificielle sur la re´duction de l'acide carbonique par les plantes. – Compt. Rend. Acad. Sci. Paris. 69: 408-412.
[97] Ranade, S. S., Gil, M. G. (2016): Application of monochromatic blue light during germination and hypocotyl development improves outplanted Scots pine (*Pinus sylvestris* L.) trees performance. – Forest Ecology and Management 361: 368-374.
[98] Randall, W. C., Lopez, R. G. (2015): Comparison of bedding plant seedlings grown under sole-source light-emitting diodes (LEDs) and greenhouse supplemental lighting from LEDs and high-pressure sodium lamps. – HortScience 50(5): 705-713.
[99] Rehman, M., Ullah, S., Bao, Y., Wang, B., Peng, D., Liu, L. (2017): Light-emitting diodes: whether an efficient source of light for indoor plants? – Environmental Science and Pollution Research 24: 24743-24752.
[100] Roh, Y. S., Yoo, Y. K. (2023): Light quality of light emitting diodes affects growth, chlorophyll fluorescence and phytohormones of Tulip 'Lasergame'. – Hortic. Environ. Biotechnol. 64: 245-255. https://doi.org/10.1007/s13580-022-00481-z.
[101] Runkle, E. (2018): White LEDs for Plant Applications. – https://gpnmag.com/article/white-leds-for-plant-applications/.
[102] Runkle, E. S., Heins, R. D. (2001): Specific functions of red, far red, and blue light in flowering and stem extension of long-day plants. – Journal of the American Society for Horticultural Science 126(3): 275-282.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_017040

[103] Runkle, E. S., Heins, R. D. (2003): Photocontrol of flowering and extension growth in the long-day plant pansy. – Journal of the American Society for Horticultural Science 128(4): 479-485.
[104] Sancar, A. (2003): Structure and function of DNA photolyase and cryptochrome blue-light photoreceptors. – Chemical Reviews 103(6): 2203-2238.
[105] Sharakshane, A. (2017): White LED Lighting for Plants. – Kotel'nokov Institute of Radio-Engineering and Electronics of Russian Academy of Sciences, Russia.
[106] Sharrock, R. A., Clack, T. (2004): Heterodimerization of type II phytochromes in Arabidopsis. – Proceedings of the National Academy of Sciences 101(31): 11500-11505.
[107] Sharrock, R. A., Quail, P. H. (1989): Novel phytochrome sequences in Arabidopsis thaliana: structure, evolution, and differential expression of a plant regulatory photoreceptor family. – Genes & Development 3(11): 1745-1757.
[108] Shen, B., Li, Y., Zhao, S., Ding, W., Hui, N., Li, J. (2014): Effect of dark period lighting regulation on cucumber seedling morphology and comprehensive evaluation analysis and comprehensive evaluation. – Transactions of the Chinese Society of Agricultural Engineering 30(22): 201-208.
[109] Shin, J. H., Jung, H. H., Kim, K. S. (2010): Night interruption using light emitting diodes (LEDs) promotes flowering of *Cyclamen persicum* in winter cultivation. – Horticulture Environment and Biotechnology 51(5): 391-395.
[110] Siemens, C. W. (1880): III. On the influence of electric light upon vegetation, and on certain physical principles involved. – Proceedings of the Royal Society of London 30(200-205): 210-219.
[111] Simpson, R. S. (2003): Lighting Control - Technology and Applications. – Focal Press, Oxford.
[112] Singh, D., Basu, C., Meinhardt-Wollweber, M., Roth, B. (2015): LEDs for energy efficient greenhouse lighting. – Renewable and Sustainable Energy Reviews 49: 139-147.
[113] Smith, H. (1995): Physiological and ecological function within the phytochrome family. – Annual Review of Plant Biology 46(1): 289-315.
[114] Takimoto, A., Hamner, K. C. (1965): Effect of far-red light and its interaction with red light in the photoperiodic response of Pharbitis nil. – Plant Physiology 40(5): 859.
[115] Tanaka, M., Takamura, T., Watanabe, H., Endo, M., Yanagi, T., Okamoto, K. (1998): In vitro growth of Cymbidium plantlets cultured under superbright red and blue light-emitting diodes (LEDs). – The Journal of Horticultural Science and Biotechnology 73(1): 39-44.
[116] Terfa, M. T., Poudel, M. S., Roro, A. G., Gislerød, H. R., Olsen, J. E., Torre, S. (2012): Light emitting diodes with a high proportion of blue light affects external and internal quality parameters of pot roses differently than the traditional high pressure sodium lamp. – VII International Symposium on Light in Horticultural Systems 956: 635-642.
[117] Terfa, M. T., Solhaug, K. A., Gislerød, H. R., Olsen, J. E., Torre, S. (2013): A high proportion of blue light increases the photosynthesis capacity and leaf formation rate of Rosa× hybrida but does not affect time to flower opening. – Physiologia Plantarum 148(1): 146-159.
[118] Thomas, B., Vince-Prue, D. (1997): Photoperiodism in Plants. – Academic Press, San Diego, CA.
[119] Trivellini, A., Toscano, S., Romano, D., Ferrante, A. (2023): LED Lighting to Produce High-Quality Ornamental Plants. – Plants 12(8): 1667.
[120] Urbonavičiūtė, A., Pinho, P., Samuolienė, G., Duchovskis, P., Vitta, P., Stonkus, A., Halonen, L. (2007): Effect of short-wavelength light on lettuce growth and nutritional quality. – Scientific Works of the Lithuanian Institute of Horticulture and Lithuanian University of Agriculture, Sodininkystė ir daržininkystė 26: 157-165.
[121] Urrestarazu, M. G., Bures, S., Kotinranta, S. (2018): Artificial lighting in agriculture. – Technical Article. Horticulture Library.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_017040

[122] Van Iersel, M. W. (2017): Optimizing LED Lighting in Controlled Environment Agriculture. – Datta Gupta, S. (ed.) Light Emitting Diodes for Agriculture: Smart Lighting. Springer Nature, Singapore, pp. 59-80.
[123] Vänninen, I., Pinto, D. M., Nissinen, A. I., Johansen, N. S., Shipp, L. (2010): In the light of new greenhouse technologies: 1. Plant-mediated effects of artificial lighting on arthropods and tritrophic interactions. – Annals of Applied Biology 157(3): 393-414.
[124] Viršilė, A., Olle, M., Duchovskis, P. (2017): LED Lighting in Horticulture. – Datta Gupta, S. (ed.) Light Emitting Diodes for Agriculture: Smart Lighting. Springer Nature, Singapore, pp. 113-141.
[125] Wan, Y., Wu, Y., Zhang, M. (2020): Effects of photoperiod extension via red–blue light-emitting diodes and high-pressure sodium lamps on the growth and photosynthetic characteristics in Paeonia lactiflora. – Acta Physiol Plant 42: 174. https://doi.org/10.1007/s11738-020-03157-2.
[126] Wang, S., Liu, X., Liu, X., Xue, J., Ren, X., Zhai, Y., Zhang, X. (2022): The red/ blue light ratios from light-emitting diodes affect growth and flower quality of *Hippeastrum hybridum* ‘Red Lion’. – Front. Plant Sci. 13: 1048770. DOI: 10.3389/fpls.2022.1048770.
[127] Wheeler, R. M. (2008): A historical background of plant lighting: an introduction to the workshop. – HortScience 43(7): 1942-1943.
[128] Withrow, A. P., Withrow, R. B. (1947): Plant growth with artificial sources of radiant energy. – Plant Physiology 22(4): 494.
[129] Yamada, A., Tanigawa, T., Suyama, T., Matsuno, T., Kunitake, T. (2009): Effects of red: far-red light ratio of night-break treatments on growth and flowering of Eustoma grandiflorum (Raf.) Shinn. – VI International Symposium on Light in Horticulture 907: 313-317.
[130] Yeh, N., Chung, J. P. (2009): High-brightness LEDs—Energy efficient lighting sources and their potential in indoor plant cultivation. – Renewable and Sustainable Energy Reviews 13(8): 2175-2180.
[131] Yihe, Z., Lieth, H. (2019): LED Technology for Crop Production in Controlled Environments. – UC Nursery and Floriculture Alliance, University of California, Davis.
[132] Yorio, N. C., Goins, G. D., Kagie, H. R., Wheeler, R. M., Sager, J. C. (2001): Improving spinach, radish, and lettuce growth under red light-emitting diodes (LEDs) with blue light supplementation. – HortScience 36(2): 380-383.
[133] Zhen, S., Van Iersel, M. W. (2017): Far-red light is needed for efficient photochemistry and photosynthesis. – Journal of Plant Physiology 209: 115-122.
[134] Zheng, L., Van Labeke, M. C. (2017a): Long-term effects of red-and blue-light emitting diodes on leaf anatomy and photosynthetic efficiency of three ornamental pot plants. – Frontiers in Plant Science 8: 917.
[135] Zheng, L., Van Labeke, M. C. (2017b): Chrysanthemum morphology, photosynthetic efficiency and antioxidant capacity are differentially modified by light quality. – Journal of Plant Physiology 213: 66-74.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_017040