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Implications of light emitting diodes on photo biology and production of ornamental crops: A review

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Abstract
Light is an important environmental factor which influences on plant growth and development. Plant utilizes the light energy for photosynthesis and as well as light signalling in different assimilation process. In intensive horticulture production system, natural light levels often limit the crop production during certain periods. Artificial lighting is used on numerous flowering species to increase photosynthesis, create an inductive photoperiod, or both. To improve plant production and product quality, light intensity, spectrum and photoperiodic adaptation is the need of the hour. Change in light intensity, duration and quality causes change at plant physiological and biochemical level thus it influences their morphology and functioning. Among the use of varied artificial light sources in horticultural sector, use of Light Emitting Diodes (LEDs) in floriculture ensures the increased light (energy) use efficiency in greenhouse production. It is understand that, LED technology allows the application of monochromatic wavelengths or their combinations to improve plant growth.

Keywords: Traditional lighting, light emitting diodes, spectral light quality (red LED, blue LED, white LED, far-red LED), photosynthesis, physiological implication

Introduction

The use of light emitting diodes in the development of high-value horticultural crops is a relatively new technique. Compared to traditional lighting systems, light emitting diodes have numerous advantages. Light has a significant impact on plant growth and shape (Avercheva *et al.*, 2014; Lee *et al.*, 2016; Rehman *et al.*, 2017) [1, 16, 31]. In controlled facility farming, an artificial light source is provided to achieve high yields and quality products (Manivannan *et al.*, 2015; Wang *et al.*, 2016; Yuanchun Ma *et al.* 2021) [21, 43, 47]. Fluorescent and incandescent lamps were utilised as light sources until recently, but they have a number of drawbacks, including low luminous efficiency, high power consumption, and an incomplete spectrum distribution (Peng *et al.*, 2017; Silva *et al.*, 2017) [30, 36]. Because of its low power consumption, high light efficiency, and low heat output, Lighting Emitting Diodes (LEDs) lights have since been used into agricultural production, and they are more environmentally friendly. LEDs have a lot of monochromatic light sources, and their wavelength is right in the middle of the spectral region that triggers plant morphogenesis.

The implications of traditional lighting

The greenhouse sector has a long and tumultuous history of disruptive transformation in terms of both time and perspective. This means that it was transformative to harness the notion of photoperiodism in flower production. It boosts bloom production all year and enables for more precise flowering management. It paves the way for other flowers and ornamentals to benefit from photoperiodism and improve their floriculture status. Plant growth was aided by lighting methods that were comparable to those used for other purposes, and it progressed along three distinct paths (Murdoch, 1985; Withrow and Withrow, 1947) [26, 45]. Carbon arcs may have been the first light used for growing plants (Siemens, 1880) [35], which he coined the term "Electro Horticulture." It produces light with a broad, bluish spectrum, but it necessitates the replacement the carbons on a regular basis and poses a risk due to ultraviolet emissions and exhaust pollutants (Parker and Borthwick, 1949; Siemens, 1880) [29, 35].

Fluorescent lamps (FL) are more widely utilized in plant development applications than incandescent lights because of their higher energy-efficient conversion and total photon emission within the photosynthetically active radiation (PAR) dependent on the lamps' correlated colour temperature (CCT). Traditional lighting sources, on the other hand, are neither spectrally ideal nor energetically efficient for the various photoperiodic responses of ornamental crops; in particular, when the lamps are hung close to the plants, the leaf tissue is destroyed by the light's stress (Datta Gupta and Jatothu, 2013; Nelson, 2014) [6, 28].

Continuous conventional illumination is thought to incur higher electricity costs. Interrupted illumination should only be employed when it has a major impact on growth from an economic standpoint. In such cases, it's critical to understand how the amount of interrupted light affects growth as compared to continuous lighting. In a non-continuous regime, determining a set point for managing the switching of continuous illumination to minimize electricity usage is equally critical (Ganesh *et al.* 2021) [7]. In the future, light-emitting diodes (LED) are projected to meet this criterion.

Light

It is impossible to overestimate the role of light in plant growth. Photosynthesis is the process of converting carbon dioxide and water into carbohydrates (sugars) and oxygen. Light is also necessary for the plant to get information about its surroundings. Growth and development may be adjusted to the environment (photomorphogenesis) and season as a result of this knowledge (photoperiodism).In nature, their reflexes are critical for survival. The plant shape will change depending on the information, or the plant will remain vegetative or generative depending on the length of the day.

The sun is the most important light source. The sun emits electromagnetic radiation with wavelengths ranging from 300 to 3000 nm. Photosynthesis requires wavelengths between 400 and 700 nm. About 45 percent of the sun's output is PAR light, which the plant uses for photosynthesis. The remaining energy is used to warm the atmosphere and surfaces.

Importance of light

Effects of lighting on:

1. Quality - wavelength
2. Quantity - intensity
3. Photoperiod - duration
4. Saturation

Influences of light quality

Light absorption will be favoured by the pigments. As the amount of red light increases, so does the length of the internodes and the movement of the leaves. The ratio of red to far red and phytochromes influence the floral phenotypes of some flowers. Green in the visible spectrum is often ineffective in encouraging flowering, whereas blue inhibits flowering. The wavelengths 580 nm to 680 nm in the red part of the spectrum have been found to be the most effective in stimulating blooming in both short-day and long-day plants. Wherever a brief flash of red light is delivered, a large number of short-lived intermediate molecules formed during the conversion of Pfr to Pr are completely different. Both Pfr and Pr have the potential to absorb light.

Materials used to change the quality of light

Aluminum flake mulch

1. A mulch sheet is laid on the soil around a plant's stalk as part of the invention. Aluminum flakes are bonded to a woven net to create the mulch. The sun's rays will be reflected upward to the undersides of the leaves by the aluminium flakes, while the porous mat will hold rainwater that has seeped into the ground.
2. Red mulch is applied to the plants to reflect red light. The canopy will increase yield in some cut flowers.
3. Photoselective shade-netting is a new approach in protected agriculture. Photoselective net products are created by incorporating various chromatic additives, light dispersive, and reflective elements into the netting materials. They're designed to filter out certain solar radiation spectrum components (UV, PAR, and beyond) and/or transform direct light into scattered light. The dispersion enables the changed light penetrate deeper into the inner plant canopy, while the spectrum alteration is designed to produce certain physiological reactions. Plant pests, helpful insects, and illnesses could all benefit from photoselective effects. Studies of decorative crops typically farmed in shade-net houses revealed unique sensitivities to the Red, Yellow, Blue Grey, and Pearl nets when compared to standard black nets with the same shading factor. Enhanced vegetative vigour can be seen in dwarfing, branching, leaf variegation, and flowering time. The concept of photoselective netting was next tested in net-house vegetable cultivation, as well as in conjunction with insect-proof nets and greenhouse plastic film covers. The Red and Pearl nets consistently increased the productivity of leafy crops, bell peppers, and ornamentals when compared to standard cover.

Phytochromes

Phytochromes are sensitive to light in the visible spectrum's red and far-red regions. Light can be sensed by photoreceptors in plants. It can detect light, which aids the plant in controlling developmental processes. Elongation (leaf, petiole, stem), bud dormancy, root growth, rhizome formation, bulb formation, bloom induction, anthocyanin synthesis, and photoperiodism are some of the physiological reactions mediated by phytochromes in flowers.

Influences of light intensity

The amount of light energy present is vital in determining the pace of photosynthesis, just as it is with carbon dioxide—simply put, the lighter or larger the illuminance (intensity) absorbed by the plant, the more photosynthesis may occur. Light is measured in lux or joules per square metre (j/m^2) in horticulture. Photosynthesis requires a light level of at least 500 lux. At 10,000-15,000 lux, maximum growth occurs. Plants can only use up to 30,000 lux of light at any given time. Aspidistra, Philodendron, and Sansveria are examples of interior landscaping plants that prefer low light (400-600 lux). Anthuriums, Cordyline, and Scindapsis prefer medium light (600-1000 lux). Ficus benjamina, Maranta, and Yucca are examples of high-light house plants (1000-2000 lux).

Table 1: Effect of light intensity and quality on cut flowers.

Crop	LED radiation/action on	Effect on plant growth	Reference
Rose	Flower senescence	Flower longevity was longer when grown under high pressure sodium lamps than the metal halide lamps. This indicates that changing the light source did not leads to change in leaf ABA but affects the petal ABA content. Higher petal ABA content at the harvesting stage in the cut flowers will have the shorter vase life.	Garello, 1994 [8]
	Mobilizing ability of rose shoot tips	Supplementary lighting with mixed fluorescent and incandescent light increased the growth and sink strength of uppermost young shoot of rose plants which is	Mor, 1980 [24]

		manifested by apical dominance. High light intensity promotes shoot sink activity by increasing the phloem unloading process.	
	Petal abscission	In Sonia rose, the petal abscission is not inhibited by the low light intensity placed in red light nor affected by the Pr/Pfr ratio.	Van Doorn, 1996 [41]
Chrysanthemum	Red 660 nm of 8 h	Reduced plant height in Euphorbia, but not in Chrysanthemum.	Bergstrand *et al.* (2016) [4]
	Stem elongation	At low temperature regime i.e., starts when 2 hrs before day break will reduce the internode length. Irradiated with red light will reduce the defect.	Jacobson, 1998 [11]
	4h Daily Extension Blue (PPF 7 µmol m^{-2} s^{-1})	Failed to inhibit flowering	Jeong *et al.* (2012) [12]
	Blue (450 nm)	Improved root formation and photosynthetic rate	Kurilcik *et al.* (2008) [15]
	Monochromatic R	RB: Increased photosynthetic rate and stomata size, decreased stomata number RFR: Increased stem length	Kim *et al.* (2004) [13] Bantis *et al.* (2018) [2]
	Far-red (735 nm)	The FR containing treatments increased shoot elongation compared to non-FR-containing treatments when applied at night-break	Liao *et al.* (2014) [20]
Carnation	Anthocyanin formation in detached petals	When detached petals were irradiated with various pure coloured fluorescent lamps, anthocyanin formation in the petals was more stimulated in the irradiation with fluorescent lamps than in the darkness, ant its content was highest under red or blue light, becoming gradually lower in the order of yellow, orange and green lights. The irradiation of far-red light either at short or long period gave rise to a markedly increased content of anthocyanin as compared with darkness. UV light suppressed the pigment formation.	Maekew, 2007
Alstromeria	Loss in quality	Low light intensity resulted in short term phytochromes mediated physiological responses.	Van Lieburg *et al.*, 1989 [42]

The use of LEDs in a controlled environment

The duration of the dark phase, often known as a critical night length, is a major determinant of light reactions (Thomas and Vince-Prue, 1997) [39]. Flowering plants are often divided into response groups based on how important night length affects flowering. Supplemental lighting in a controlled system has grown significant and widespread in all specialty areas where varied light sources influence the flowering of commercial flower crops in protected habitats such as polyhouses, shade net culture, indoor gardening, and soilless cultivation. Over the last two and a half decades, tremendous progress has been achieved in photoperiod regulation. The use of big resources and energy in terms of medium, structures, inputs, pesticides, fertilizers, environment control systems, irrigation systems, plant protection, harvesting, grading, and packing are all involved in controlled nature production systems. Supplemental lighting is used in the cultivation of crops such as chrysanthemums, orchids, roses, and other economically important cut flowers and greens. Growers and scientists are concentrating on energy conservation in greenhouse production. Growers want to find energy-saving light sources for horticulture lighting.

Different spectral range influence on plant morphology and yield

Light is the most basic and important component that controls a plant's life cycle processes, starting with seed germination and ending with seed production. According to previous research, light from the sun or any other light source is not entirely absorbed by the plant, and only PAR with an absorbance range of 400-700 nm is sensed by the plant for photosynthetic processes.

LEDs' effect on plant growth and development

LEDs have a lot of monochromatic light sources, and their wavelength is right in the middle of the spectral region that triggers plant morphogenesis (Manivannan *et al.*, 2017) [22]. Because LED light is cold, it can illuminate plants at a closer range without burning them, considerably increasing space utilisation efficiency.

Distinct colours of LED lights have different effects on plant growth and development, with the majority of studies focusing on red and blue light (Li *et al.*, 2017) [19]. Red light enhanced stomatal conductance in Cruciferous plants but decreased it greatly in Cucurbitaceous species (Ye *et al.*, 2014) [46]. Furthermore, some researches have revealed that the impacts of LED lights are influenced by the plant's life cycle at the time the LED lights were used (Hoffmann *et al.*, 2015; Simlat *et al.*, 2016) [10, 37]. Red light exposure, for example, reduced catalase (CAT) and ascorbic acid peroxidase (APX) activity in some annual plants while dramatically increasing it in perennial plants (Baque *et al.*, 2009; Li *et al.*, 2010) [3, 17].

Yuanchun Ma *et al.* (2021) [47] found that the effect of LED on plant growth and quality traits was species specific, and the effect was affected by the cultivation conditions. So researchers have to be more targeted to experiment, and collect traits associated with practical production, especially related to the quality of product data, such as carotenoids, anthocyanin and otherantioxidant compounds. LEDs have been connected to the activation or suppression of genes involved in a variety of processes, including bioactive chemical synthesis, blooming induction or inhibition, and so on (Murad *et al.* 2021) [25]. Green light has been found to have similar effects as blue light in some experiments, causing photoreceptor proteins to participate in photosynthesis. Green light, on the other hand, tends to reverse the effects of blue and red light via inductive biological antagonistic processes. Green light may effectively travel through tissues, therefore it may cause reactions that aren't immediately affected by the light stimulation. As a result, a vast number of light recipes must be tested in order to determine the best light regime for plant growth, development, nutrition, flavour flowering, and defense mechanisms.

Red LED light is one of the most fundamental components of the complete light spectrum, and it is ideal and sufficient for regular plant growth and photosynthesis. Phytochromes detect variations in red and far-red radiation, as well as their ratios, which may affect photomorphogenetic processes in plants. In comparison to far-red light, red light has more potential for plant development and production, and it is more desirable since it boosts plant yield, lowers nitrate levels, and increases vitamin C levels in plants. Red light had opposing effects, preventing basil from flowering while inducing upward or downward leaf curling in tomatoes (*Solanum lycopersicum*). At low to moderate light intensities, it was discovered that supplementing red LEDs with a tiny amount of blue LEDs resulted in better growth in lettuce and Chinese cabbage. Blue light, in addition to the red light essential for photosynthesis, is also required to boost development and diminish shadow avoidance reactions, such as excessively extended stems (Snowden *et al.* 2016) [38].

LED's advantages in horticulture

In commercial gardening and horticulture, gas-discharge lights, particularly 'high-pressure sodium,' have long been the lighting standard (Nelson, *et al*., 2015) [27]. They predate LED technology and had higher yields per square metre until the last five years. Gas-discharge lamps, on the other hand, provide a 'fixed spectrum'. Only a few combinations of cations and noble gases determine wavelength peak regions, and control over their spectrum intensity curve is limited (Tingzhu *et al.* 2018) [40].

The effects of LEDs on plant secondary metabolites and their antioxidant capabilities

The incidence of oxidative damage in plants is identical with the production of free radicals. Plant secondary metabolites are covalently bonded to long chain polymers in a strong intermolecular bond (Wink, 2015) [44]. Light is known to activate enzymes and influence their synthesis pathways, such as PAL (phenylalanine ammonialyase) activity in phenyl propanoid pathways, which are thought to help plants accumulate bioactive chemicals (Meng *et al.* 2004) [23].

Plants have photoreceptors that either gather light energy for photosynthesis or respond to changes in light quality and quantity (Kopsell *et al.* 2014) [14]. Phytochromes (PHYA and PHYE), cryptochromes (CRY1 through CRY3), phototropins (PHOT1 and PHOT2), and UV-B resistance locus 8 are photoreceptors that influence plant shape and development (UVR8). Plant phytochromes control phytochemical synthesis and plant physiological responses, whereas plant cryptochromes control stomatal opening, biomass production, and the formation of anthocyanins, carotenoids, and chlorophyll molecules (Li and Kubota, 2009; Samuolienė, 2012; Hasan *et al.* 2017; Brazaityte *et al.* 2015 and Samuoliene *et al.* 2017) [18, 32, 9, 5, 33]. Plants have developed detoxifying systems that include antioxidants and reactive oxygen species (ROS) scavengers like superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), and peroxidase to reduce oxidative stress in systemic tissues (Sharma *et al.* 2012) [34].

Conclusion

Light is regarded to be the most important environmental factor that influences plant growth, development, pigmentation, and morphogenesis. When light is scarce owing to geography, climate, or obsolete equipment, the need for a regulated environment for agriculture develops, which is satisfied by using LEDs as artificial lighting sources for plant growth and development. Because of their efficiency and low operating costs, LEDs have experienced a huge increase in popularity among plant growers. LED wavelengths of blue, red, green, and far-red have been shown to have a good effect on plant morphology, photosynthetic efficiency, and blooming, as well as the generation of secondary metabolites, shielding plants from oxidative stress. However, in order to achieve the best results, different researchers use different wavelength recipes across different species, and the outcomes vary between and within species. As a result, a combined LED light recipe must be developed, which will provide farmers with a more complete understanding of the various wavelengths and intensities of light to be used. Furthermore, LEDs have been connected to the activation or suppression of genes involved in a variety of processes, including bioactive chemical synthesis, blooming induction or inhibition, and so on. However, the processes behind these interactions between LED wavelengths and genes must be explored so that such genes can be altered or manipulated to increase crop productivity and quality under a variety of LED illuminations. Finally, LED technology provides the key to a future revolution in plant development and growth.

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