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REVOLUTIONIZING HORTICULTURE: POWER OF LED TECHNOLOGY IN HORTICULTURE CROP CULTIVATION

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ABSTRACT

The integration of light-emitting diode (LED) technology into horticulture has become a key innovation due to the growing global demand for sustainable agricultural practices and the need to maximize yields. Natural light is essential for plant growth and flowering. However, natural light does not provide plants with the spectrum they need. In horticulture, light-emitting diodes (LEDs) can be used to create artificial lighting in a controlled setting for pre-harvest to post-harvest storage inside, in greenhouses, and in outdoor. Light-emitting diodes (LEDs) feature narrow spectrum, non-thermal photon emission, longer lifespan, and energy-saving properties that are better than traditional light sources. This spectral precision is crucial for controlling plant shape, nutrient uptake and secondary metabolite production, and photosynthesis. More sophisticated insights into the complex interactions between light and plant physiology come from examining multiple spectra, including red, blue, far red and UV. LEDs can therefore revolutionize lighting technology in horticulture with regard to the production, protection and care of plants. This article explores the fascinating impact of LED lighting on horticultural crops, highlighting the science underlying these phenomena and its consequences for sustainable agriculture going forward.

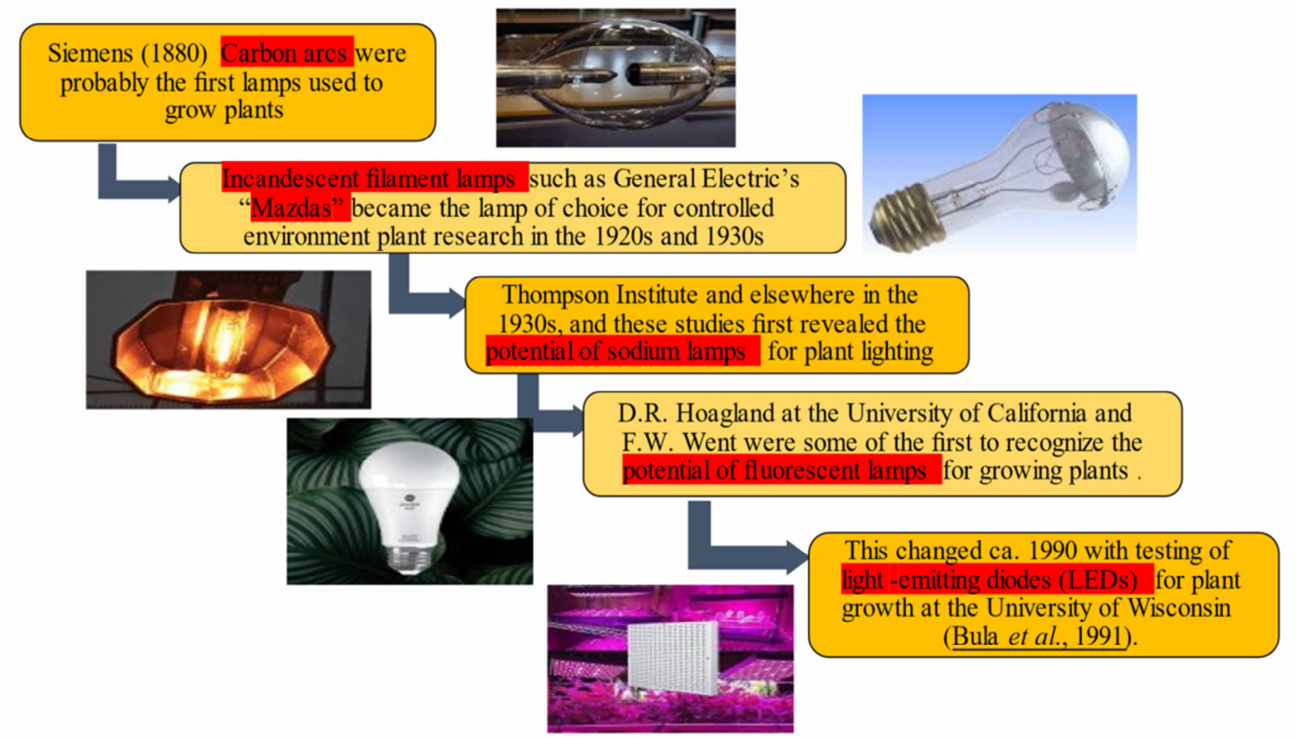
Keywords: LED light, Horticulture, Spectrum, nutrient quality, postharvest, pest and diseases

Introduction

The most crucial element for plant growth and development is light, which also frequently acts as the biggest constraint. Therefore, plants and farmers benefit from using grow lights in commercial greenhouses. There are several reasons to use grow lights such as regulating the photoperiod or increasing the light level for photosynthesis in plants. Natural light-driven photosynthesis regulates all aspects of a plant's life cycle, including growth, development, appearance, physiological responses, and yield. The introduction of LED lights brought about a revolutionary change in horticulture. They allow precise control of the light spectrum and transform the practice of growing plants under controlled conditions. Light-emitting diodes: When an electric current flows through a diode, it emits visible light. In order for the LED to work, the anode connection must be connected to a higher voltage than the cathode connection. Current flows from the anode to the cathode (positive to negative). LED lights offer a variety of benefits in agricultural production, including increased yields, energy efficiency and precise control of the growing environment. Plant growth, productivity, quality and even post-harvest storage stability can be improved by using light beams of different colors (Mandal, 2021). According to Koppell and Sams (2013) and Carvalho and Folta (2014), light is an essential part of the plant environment as it allows them to build defenses against reactive oxidative species (ROS) during light stress. Plants use radiant energy only in the photosynthetically active range of 400–700 nm (Boyle, 1996). Because LED technology allows precise control of light output in terms of wavelength and intensity, it offers a unique opportunity to create energy-optimized and technically optimal lighting systems for specific crops (Pattison *et al.,* 2018). Furthermore, according to some studies, the effect of LED lights may vary depending on the stage of the plant's life cycle at the time of light application (Hoffmann *et al.,* 2015; Simlat *et al.,* 2016). For example, exposure to red light reduces the activity of catalase (CAT) and ascorbic acid peroxidase (APX) in some annual plants; However, for some perennials this effect was much larger (Baque *et al*., 2010; Li *et al*., 2010). It is difficult to reach a consensus on the relationship between light color and some plant species. The length of the photoperiod can also influence the development of plants and ultimately their size (Yuanchum *et al.,* 2021).

Navigating the radiant path of light in horticulture

Henry Josef Round noticed that silicon carbide crystals emit light when current flows through them, leading to the invention of light-emitting diodes, or LEDs, in the early 20th century. However, it took several decades before the first commercial LEDs were manufactured. The first devices came onto the market in the late 1960s (Schubert *et al*., 2000). All of the theories on electric lighting discussed so far were discovered and developed in the mid-19th century. During the first half of, these concepts were further tested and refined. Since the invention of high-intensity arc lamps, there have been few significant advances in industrial lighting, with the possible exception of electrode less lamps (Warmby, 1993), most of which have not yet been proven for research and crop production (Both *et al.,* 1997; Krizek *et al*., 1998).The University of Wisconsin's testing of light-emitting diodes (LEDs) for plant growth about 1990 brought about this development (Bula *et al*., 1991). Unlike previous lamps used to date with plants, light-emitting diodes produce light by an electroluminescent mechanism (Craford *et al*., 2001).



Effect of different spectra of light on the horticulture crops

Agricultural productivity and resource optimization may be greatly impacted by the vigilant manipulation of these spectrum through the use of LED technology. By tailoring the light environment to the specific needs of their plants, growers may achieve higher crop quality, faster growth rates, and more energy efficiency. The red and blue spectrums are the main drivers of photosynthesis; red light increases biomass while blue light increases chlorophyll uptake. Far-red light is often used in concert with red light to impact processes like as seed germination and flowering. Moreover, research has shown that UV light promotes the creation of certain secondary metabolites that impact the flavor, aroma, and nutritional content of crops.

Table 1: Effect of different light spectra on the horticulture crop:

Plant	Effect on growth	Light colour	References
Red leaf lettuce (*Lactuca sativa* L.)	Elongation of Leaf	Far red 700–850 nm	Stutte *et al.,* 2009
Lettuce (*Lactuca sativa* L.) 'Frillice Crisp'	Addition of far red light increased leaf area index and fresh weight, Faster growth	Far red 700–850 nm	Pinho *et al.,* 2017
Red lettuce (*Lactuca sativa* L.) 'Sunmang'	Increased number of leaves and leaves were longer	Far red 700–850 nm	Lee *et al*., 2016
Tomato(*Solanum lycopersicum*)	Leaf curl up or down in all genotypes	Red 620–700 nm	Ouzounis *et al*., 2016
Transplants of cucumber 'Mandy' F1	Accelerated growth	Orange 585–620 nm	Brazaityte *et al*., 2009
Red leaf lettuce (*Lactuca sativa* L.) 'Banchu Ref Fire'	High intensity green LED (300 µmol·m-2·s-1) promoted lettuce growth (as compared to FL); 510 nm light had the greatest influence on plant growth	Green 490–550 nm	Johkan *et al.,* 2012
Transplants of cucumber 'Mirabelle' F1, Tomato 'Magnus' F1 and Sweet pepper 'Reda'	Increased leaf area in all vegetable transplants	Green 490–550 nm	Samuoliene *et al.,* 2012
Cucumber plants (Hoffmann's Giganta)	Required to prevent open, impaired photosynthesis. Photosynthesis capacity increase with increasing blue content during growth, measured up to 50% blue.	Blue 425–490 nm	Hogewoning *et al.,* 2010
Seedlings of cabbage 'Kinshun' (green leaves) and 'Red Rookie' (red leaves)	Promoted the elongation of petiole of the two type of cabbage	Blue 425–490 nm	Mizuno *et al*., 2011
Red leaf lettuce (Outeredgeous)	Leaf expansion	Blue 425–490 nm	Stutte *et al*., 2009
Tomato (Momotaro Natsumi)	Increased tomato yield	Red 620–700 nm	Lu *et al.,* 2012
Tomato ('Trust') and cucumber ('Bodega')	Additional blue light in the canopy increased plant biomass and reduced fruit yield	Blue 425–490 nm	Menard *et al.,* 2006
Pomegranate seedlings	Promotes seedling growth rate, shoot height, root length, fresh and dry weight, leaf area, and new root development	Moderately Blue 400-500nm & Red 600-700nm high Green 500-600nm	Bantis *et al*., 2018
Soilless cultivated Strawberry	Increased yield of strawberryunder protected conditions	Blue 436 nm	Nadalini *et al*., 2017
Seedling Passion fruit	Increase plant height, stem diameter, number of leaves, internode spacing, and fresh/dry shoot/root weights	Combination of Red, green and blue light	Liang *et al*., 2021
Strawberry	Promotes yield and the fruit quality.	Combined blue and red light	Choi *et al.,* 2015

Role of LED in growth of horticulture Plants

The development and productivity of both food crops and decorative plants depend on light, which is also essential for controlling metabolite synthesis and cellular activities plants (Carvalho and Folta, 2014; Kopsell and Sams, 2013; Massa *et al*., 2008). LED illumination is useful in many applications, such as growth chambers, where it improves both qualitative and quantitative physiological responses. Furthermore, to improve overall plant development, LEDs may be included into lighting systems in greenhouses and vertical farming settings, especially in nurseries for the production of seedlings. For a variety of plants and flowers, LEDs work well as artificial illumination sources and photoperiodic controllers. When applied to horticultural crops at different phases of growth, they stimulate photosynthesis and promote the synthesis of bioactive compounds, antioxidants, phenolics, and flavonoids, which improves nutritional content while maintaining the health advantages for human consumption (Hasan *et al*., 2017).

Role of LED light on Post harvest handling

Globally, between harvest and the retail market, over 14 percent of the world's food, worth $400 billion, is lost annually (FAO 2019). Meanwhile, food waste at the retail and consumer sectors is predicted to be 17% (UNEP, 2021). Food engineers and technologists confront tremendous hurdles when it comes to horticultural product, which is susceptible to damage and spoiling at every step (Gunders, 2015). Horticultural crops require careful management of variables such storage temperature, gas concentrations (carbon dioxide, oxygen, and ethylene), and relative humidity in order to maximize shelf life and preserve postharvest quality (Kader and Rolle, 2004). Improvements to storage facilities (Godfray *et al.,* 2010), changes to the food supply chain (Parfitt *et al*., 2010), and other measures are being investigated. Afterwards It has been discovered that harvested crops under controlled LED light, which emits little heat, have higher nutritional and antioxidant activity (Kim *et al*., 2011). Plants can react differently to different colors and wavelengths of light produced by LEDs (Kasim and Kasim, 2017), and post-harvest research is increasingly using LEDs.

Research has indicated that the use of warm-white LED light can postpone the decomposition of chlorophyll in lamb's lettuce (Braidot *et al.,* 2014). Ma *et al.* (2017) found that broccoli exposed to red light (660 nm) experienced similar effects, with senescence reduction occurring under both red and white illumination (in lettuce). Tomatoes and broccoli ripened later when exposed to blue light (Braidot *et al.,* 2014; Hasperue *et al*., 2016). Furthermore, compared to untreated samples, blue LED treatment of Chinese bayberries enhanced the amounts of total soluble solids (TSS), glucose, fructose, and sucrose (Shi *et al*., 2016). After ten days at 32°C, red Chinese sand pears treated with white and UV-B LED light showed enhanced red color, firmness, and TSS (Sun *et al*., 2014). Citrus fruits treated with blue (470 nm) and red (660 nm) LED light for six days at 20°C at a fluence rate of 50 W m^{-2} showed elevated antioxidant levels, including beta cryptoxanthin (Ma *et al*., 2012).

Role of LED in resist to control to pest and disease

An important factor in improving horticulture crops' resilience to disease and pests is the use of LED lights. LED technology enables the generation of antioxidants and phytoalexins by facilitating the activation of plant defense systems through the provision of customizable light spectra. These organic substances reinforce plants' innate resistance to infection by acting as potent deterrents against pests and diseases. According to Liu *et al*. (2011), the application of LED therapy significantly minimizes fungal deterioration by preventing the conidial germination and sporulation of Colletotrichum on mango fruit. *Penicillium digitatum* and *Penicillium italicum* fungal infections were successfully suppressed by blue LED therapy for 18 hours at fluence rates of 120 W m^{-2} and 700 W m^{-2}, which also prevented spore germination while citrus was being stored (Lafuente and Alferez, 2015). Furthermore, studies have shown that green LEDs are effective in managing a variety of diseases, including cucumber anthracnose (*Colletotrichum orbiculare*) and gray mold (*Botrytis Cinerea*), strawberry anthracnose (*Glomerella cinglata*) and leaf spot disease (*Corynespora cassiicola*) in perillas (*Perilla frutescens*) (Kudo *et al.,* 2011).

Role of LED to enhance the nutritional quality of horticulture crop

During the process of photosynthesis, light stimulates the formation of different secondary metabolites, nutritional content, and antioxidants such reactive oxygen species (ROS) (Darko *et al*., 2014). According to Gupta and Agarwal (2017) and Dsouza *et al*. (2015), the application of LEDs increases the aromatic characteristics and increases the accumulation of vitamin C, anthocyanin, and total phenolic compounds. In comparison to the untreated control sample, a notable rise in the content of stilbene chemicals in the skin was seen after a 5-day red LED therapy on grape berries (Ahn *et al.,* 2015). Comparing peach content to the untreated control, zeaxanthin, β-carotene, β-cryptoxanthin, and lutein levels rose after 20 days of blue LED therapy (Shi *et al.,* 2014).

Conclusion

Utilizing LED technology in horticultural crop cultivation signifies an evolutionary leap toward accuracy, efficiency, and sustainability. Growers can build customized settings that improve plant development and resilience, all while saving a considerable amount of money thanks to LED lights' superior energy efficiency, adjustable light spectrum, and long lifespan. LED lighting's extended lifespan and low heat output make it ideal for regulated and sustainable growing environments. It is possible to precisely tailor spectral composition to the unique requirements of different crops and growth stages. Not only do the noteworthy developments in LED technology provide energy-efficient solutions, but they also optimize the light spectrum to promote better growth and development of plants. This involves controlling essential functions including fruiting, blooming, and photosynthesis. It also enables careful regulation of environmental variables, resulting in higher crop yields, better quality, and effective use of resources. With the help of LED technology, horticulture has a bright future ahead of it when it comes to producing food sustainably and meeting the demands of a growing world population while having the least negative environmental effects.

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