# Light-Emitting Diode in Plant Metabolism

Subjects: Plant Sciences

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Light-emitting diodes (LEDs) are emerging as a powerful technology in the plant field which allows the selection of specific wavelengths and intensities, and therefore the targeted accumulation of plant antioxidant compounds.

light-emitting diode (LED) plant antioxidants food quality food safety polyphenols vitamin C postharvest

## 1. Introduction

Plant antioxidants include a wide variety of compounds, which are responsible for essential plant functions, including signaling, defense, oxidative damage prevention, and free-radical scavenging [1]. In addition, some antioxidants are responsible for the color, aroma, and taste of fruits, vegetables, and processed products. Thus, they determine the quality and shelf life of a food, consumers' appreciation, and their economic value [2]. Fruits, vegetables, herbs, and spices are rich in antioxidant compounds, and their consumption in the diet is encouraged, owing to their antioxidant and anti-inflammatory properties, the positive effects on blood pressure, lipids, insulin resistance, and cardiovascular health [3].

Polyphenols, photosynthetic pigments, glutathione, vitamin C (L-ascorbic acid, Vit C) and other vitamins, and antioxidant enzyme systems, such as generic peroxidases, polyphenol oxidases, ascorbate peroxidase (APX), glutathione peroxidase, glutathione reductase (GR), monodehydroascorbate reductase (MDHAR), dehydroascorbate reductase (DHAR), thioredoxins, peroxiredoxin, superoxide dismutase, and catalase are among the most important components involved in the modulation of the redox status of the cells and in the response to pathogens and adverse environmental conditions. Several factors are involved in the regulation of the synthesis, turnover, and degradation of such compounds, including both biotic and abiotic stresses, such as light [4][5][6]. Development, growth, and physiology of the plant depend on the availability of light [7][8]. Light duration (photoperiod), intensity, quality (wavelength), and direction play key roles in plant studies [9].

Through photosynthetic fixation, plants are able to transform the solar energy into reducing equivalents, and $CO_2$ into sugars. However, light is an essential factor driving several biochemical pathways for plant growth and development. In particular, the synthesis and accumulation of antioxidants such as Vit C, phenolic acids, carotenoids, flavonoids, anthocyanins, and α-tocopherol in leafy tissues and fruits in many horticultural and herbal crops are driven by the photoperiod, intensity, and quality [10][11][12] . Light intensity and wavelength vary during the daytime and by season, latitude, and climate and are perceived differently by cells according to the position of the leaf within a canopy and of the cell within a leaf [13].

Light quality and intensity are perceived by plants through different types of photoreceptors, namely, phytochrome (PHY), cryptochrome (CRY), phototropin (PHOT), flavin binding Kelch domain F box protein (FKF1), zeitlupe (ZTL), LOV Kelch protein2 (LKP2), and UV-B resistance locus 8 (UVR8). According to the receptor type, they can be sensitive to both low and high irradiance levels, as well as to specific light wavelengths [14]. Due to such implications, artificial light supplementation has been widely applied in horticulture on economically relevant crops to compensate for short photoperiods, to support photosynthesis, to control plant flowering and pests, and to improve plant nutritional quality [15].

At present times, LED technology has gained a massive popularity for its ability to produce specific spectra. In fact, compared to other artificial light sources, monochromatic LEDs show unique spectra outputs in terms of wavelengths, along with an equivalent luminous efficacy, lower operational cost, lack of radiant heat, and longer lifespan. Due to these unique advantages, LEDs are now used in controlled environments, e.g., growth chambers, greenhouses, and vertical farming, as well as in the postharvest storage of many vegetables to support plant growth and to specifically stimulate the synthesis of bioactive compounds [16].

An overview of the most recent findings in the horticultural field was provided, with particular regards to vitamin C, polyphenols, photosynthetic pigments, and glucosinolates. Eventually,  the challenges and perspectives of LEDs application at all levels of the supply chain were critically discussed.

## 2. LED Technology

LED is a solid-state semiconductor diode, allowing unidirectional current flow from anode to cathode within a specific voltage range. The diode is composed of two differently doped materials that joint form a p-n heterojunction, where the p-side contains excess positive charge (holes), while the n-side contains excess negative charge (electrons). As an electron crosses the depletion layer, near the junction, it recombines with a hole and falls from the conduction band in a lower energy level, the valence band, and releases energy in the form of a photon (Figure 1, panel A). In Figure 1, panel B the most important parts of a LED are shown. The cathode is connected to the n-side of the junction, instead the p-side is connected to the anode with a connecting wire. The emitted light wavelength, so its color, depends on the band gap energy of the junction’s materials [17]. The band gap represents the minimum energy difference between the top of the valence band and the bottom of the conduction band; it depends on the dopants used in the p and n sides.

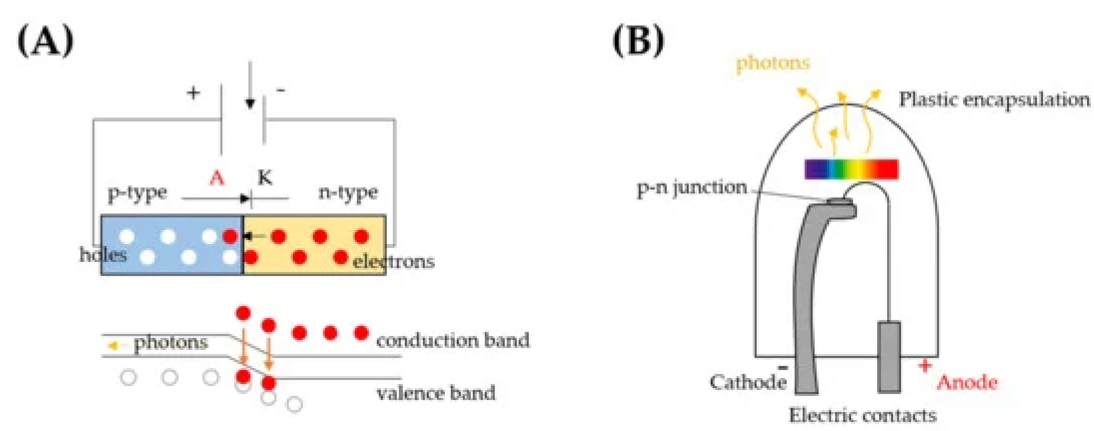


**Figure 1.** (**A**) Working principle and (**B**) structure of a light-emitting diode (LED).

## 3. LED Lighting: Advantages and Challenges in Plant Growth and Postharvest Management

LED technology has grown tremendously on a global scale over the last decade, quickly replacing traditional lighting systems (incandescent, fluorescent, High-Intensity Discharge lamps) in different fields, including the horticultural sector, as supported by a growing research community [16][18]. Higher energy efficiency, versatility, long lifetime, and cost saving features are some of the major advantages of LED lighting. Unlike HID and HPS, LEDs show reduced heat emission leading to prevent thermal degradation and optimizing space in indoor farming and storage management applications. Moreover, LED technology, compared to conventional lamps, enables a wide variety of spectral output, allows for controlling the directionality of light, and regulating light intensity. All of which makes it more suitable for the growth, preservation, and storage of fresh horticultural products [18][19][20]. In this review, we have focused on LEDs' effects on some plant metabolites, with particular attention to the content of some antioxidant compounds both during the plant growth and at the postharvest level. There is evidence that LED lighting can influence the shelf life and quality of fresh produce inhibiting weight loss, senescence, over-ripening, and enhancing the production of antioxidants compounds. [21][22][23][24][25][26].

Currently, RL and BL have been recognized as the most suitable treatment for plant growth and development of tailored food. However, there is a growing consensus that other LEDs, including YL or GL, may contribute, both monochromatic and combined, to promote higher biomass and yield or preserve plant quality [27][28][29].

Until recently, insufficient availability of data on lamp performance metrics and quality standards did not help growers to compare results and LED options, driving confusion and lack of references. In 2017, the American Society of Agricultural and Biological Engineers (ASABE) published the S640 standards on the quantities and units used to describe horticulture lighting (ASABE, 2017) [30], including 33 new metrics definitions for horticultural lighting, among which are PAR (photosynthetic active radiation), expressed as PPF (PAR emitted by a source, measured in units of micromoles) and PPFD (PAR that falls on a unit of surface area). Although these new metrics are compatible with metrics previously defined, they are, however, specific to the needs of horticulture and plant biology. Furthermore, the evidence that  outside the visible light (400-700 nm), plants respond to UV and FR radiation, the metrics are divided into three spectral ranges: photosynthetic (400-700nm), UV (100-400nm), and Far Red (700-800). Afterwards, in 2018, ASABE released the S642 standard, focusing on the performance of LEDs, arrays, and modules relative to the impact on plant growth and development (ASABE, 2018) [31].

Besides the appropriate LED metrics implementation to the horticultural sector, there are some other challenges that need to be tackled, depending on the aim of the request (growth, postharvest, development). Among these, there are the influence of light intensity, irradiance, temperature, power supply on the physiological and biochemical responses of the plant, and how those responses vary among species and within cultivars of the same species.

A growing number of studies suggest that the overall quality of vegetables prior to or even after harvest is highly dependent not only on the spectral composition but also on LED intensity and photoperiod [32][33][34]. Light distribution and irradiance uniformity are also important parameters to be evaluated because the photosynthetic properties depend on the leaf age and/or distance between the lighting device and plant canopy, then a different response might be revealed in lower canopy compared to the upper leaves [19][35]. Moreover, since the intensity of light radiation that reaches a surface is inversely proportional to the square of the surface's distance from the source, light levels vary and are inconsistent as plants grow, which suggests that light output could be modified according to the plant photosynthetic requirements.

Overall, understanding the physiological responses induced by LED lights is a crucial step to regulate plant morphogenesis, enhance nutritive value of crops, and preserve quality in postharvest fresh products. However, data from literature are often contradictory because over the years, many research projects focus their efforts on a few selected species or cultivars, and little is known about comparison among closed species, more cultivars, or type of the same cultivar [36][37][38][39].

## 4. Conclusions

In conclusion, LED technology has shown great potential to promote the growth and the synthesis of beneficial compounds and prolong the shelf life of fruits and vegetables during postharvest storage (Figure 2). So far, a comparison of studies in the literature is challenging because of the different experimental designs, plant species and cultivars, light types and intensities, and other environmental parameters which are not always fully disclosed or harmonized. Additionally, only recently have quality standards been introduced. A deeper knowledge of the spectral-dependent responses at the molecular level and the role of photoreceptors can be performed in controlled environments by means of an integrated approach, based on transcriptomics, proteomics, and metabolomics. Data on the plant–LED interaction effects are already available in the literature and, due to the interest of the scientific community, in the next years, a huge amount of data will be continuously added. These data can be analyzed to extrapolate and correlate different types of LED treatment with the fitness of the plant and its antioxidative profile. In this context, artificial intelligence and machine learning algorithms will allow us to predict the plant health and the shelf life of postharvest horticultural crops. Further improvements and studies are therefore essential to design specific LED protocols and enable us to exploit this technology at its fullest potential.

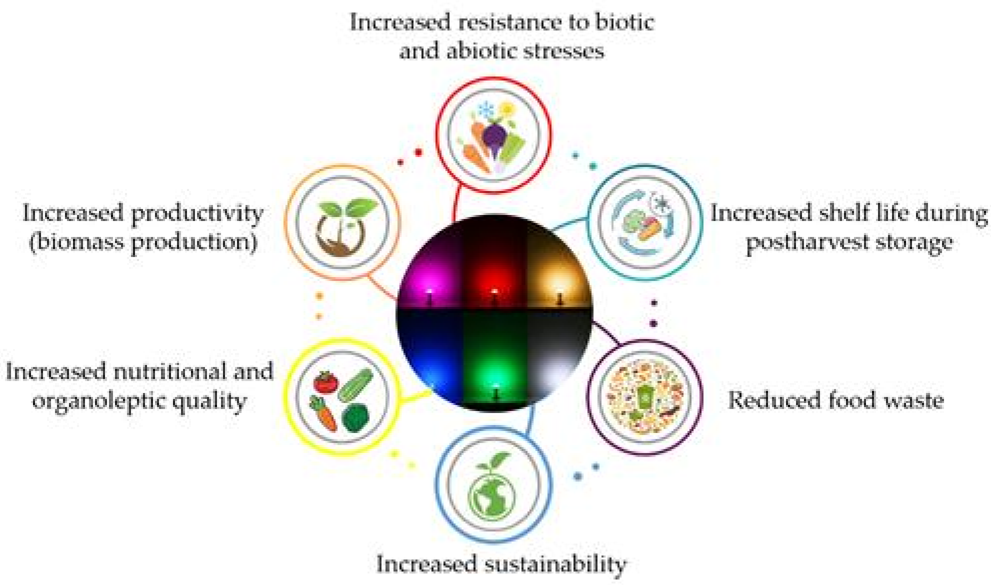


**Figure 2.** Future perspectives and positive outcomes of LEDs for growth and postharvest storage of food commodities.

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