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A Review Study on LEDs' Effects over the Production of Bioactive Compounds & Crop Quality

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ABSTRACT: Light-emitting diodes (LEDs) are distinguished from conventional light sources by their narrow-spectrum, non-thermal photon emission, longer lifespan, and energy-saving features. LEDs have the potential to completely transform horticultural lighting for crop production, protection, and preservation. The production of bioactive chemicals and antioxidants may be induced by exposure to various LED wavelengths, which can enhance the nutritional quality of horticultural crops. In the same way, LEDs boost nutritional content, decrease microbial contamination, and change the ripening of postharvest fruits and vegetables. Because of their high nutritional content and antioxidant characteristics, LED-treated agronomic goods may be helpful to human health. LEDs are also simple to employ in closed-canopy or within-canopy lighting systems due to their non-thermal characteristics. By maintaining optimum incident photon fluxes, such arrangements save power usage. Intriguingly, red, blue, and green LEDs may produce systemic acquired resistance to fungal diseases in a variety of plant species. In greenhouse settings, when seasonal clouds block sunlight, LEDs may offer a controlled, alternate supply of chosen single or mixed wavelength photons.

KEYWORDS: Antioxidant, Bioactive, Disease Resistance, Fruit Decay, Compounds, Light Emitting Diode, Nutrition.

1. INTRODUCTION

Photosynthesis and plant development need light. The effects of light on plant growth and development are complicated, and plants do not benefit from the full spectrum of light. The visible electromagnetic spectrum, which we shall call to as "light" henceforth, is usually harvested by living creatures. Light regulates blooming time and morphogenesis in addition to photosynthesis. Plant morphological and developmental changes are controlled by two main photoreceptors: phytochromes (absorbs red/far-red light) and cryptochromes (absorbs blue/ultraviolet A (UV-A) light) [1].

Several studies have shown that a regulated quantity of light enhances crop postharvest quality and shelf life by stimulating the synthesis of nutrients and bioactive substances. Plants' bioactive chemicals are known as primary or secondary metabolites, and they give the plants their fragrance, color, and flavor. Secondary metabolites also help plants fight infections that invade their environment. Several research have been conducted to enhance the synthesis of bioactive chemicals in plants by exposing them to various types of external stress. UV irradiation may be used to promote the synthesis of secondary metabolites in addition to crop sterilization [2]–[5].

Aside from UV, visible light acts as a bactericide, which enhances food safety and preservation. The most common sources of light used in crop production and preservation are high-pressure sodium (HPS), xenon, fluorescent, and incandescent lamps. Due to insufficient protective mechanisms against UV or infrared (IR) radiations, the use of traditional lighting systems with a wide range of wavelengths may result in excessive heat and negative effects on plant growth and development [6]–[9].

LEDs are quickly gaining traction as a potential solution for greenhouse crop production and food preservation. LEDs provide light with narrow bandwidths, a high photon flux or irradiance, and low thermal impacts; they can also be easily incorporated into electrical systems. LEDs are extremely helpful for agricultural applications because of their many positive features. LEDs also have other advantages such as ambient contact temperatures and non-breakable glass envelopes, making them state-of-the-art and easily-handled light sources for plant development capable of improving crop nutritional value. Because of their low heat irradiation and greater effectiveness, LEDs are also utilized in postharvest preservation. Furthermore, because of their function in disease resistance, LEDs are ideal for enhancing agricultural operations.

LED lighting systems are becoming a cost-effective technology, and are ready for implementation in the areas of agriculture and horticulture, thanks to its many advantageous characteristics (such as robustness, compactness, and extended half-life). LEDs may be adopted and adapted to the requirements of the food sector as a cost-effective and efficient way to produce and distribute satisfying and safe meals. The potential of LEDs in the synthesis of bioactive chemicals, which enhances crop quality and crop protection, is the subject of this study. We go through the most important new discoveries in these areas, as well as their limitations and countermeasures [10].

1.1.LEDs Induce Bioactive Compound Synthesis in Crops:

The accumulation of different metabolites in plants is influenced by the quality of light. When compared to white light, single-spectral red or blue LEDs resulted in increased accumulation of plant metabolites, both primary and secondary (e.g., soluble sugars, starch, vitamin-C, soluble protein, and polyphenol). The combination of blue and red (red: blue) LEDs, in addition to single-spectral red light, enhances the accumulation of primary metabolites, as well as anthocyanin, total polyphenols, and flavonoids. Red LEDs, on the other hand, have a greater impact on anthocyanin accumulation than blue LEDs. This is due to the enhanced expression of the anthocyanin biosynthesis gene when exposed to red LEDs. The buildup of organic acids, phenolic compounds, vitamin-C, -tocopherol, soluble sugar, and nitrate in many crops is also increased when ambient light is supplemented by red, blue, green, red:far-red, or red:blue LEDs.

The phenylalanine ammonia-lyase enzyme (PAL), which is engaged in the first stage of the phenyl propanoid pathway, seems to have a function in the stimulation of secondary metabolite synthesis in plants. As a result, higher synthesis of plant secondary metabolites may be due to up-regulation of PAL in the presence of red:blue LEDs. Ginsenosides are highly medicinal secondary metabolites generated by the isoprenoid pathway in ginseng plants.

As ginseng roots were exposed to blue LEDs (450 nm and 470 nm), there was an increase in the concentration of total ginsenosides (from 2% to 74%) when compared to ginseng roots cultivated in the dark. As a result, it's possible that LEDs can act as elicitors, triggering the expression of key enzymes in the isoprenoid pathway (such as squalene synthase) or inducing the production of reactive oxygen species, which can then trigger increased activity of defense-related genes, resulting in increased ginsenoside synthesis. Furthermore, LED illumination in red ginseng may cause the synthesis of large amounts of pharmacological components.

Previously, it was thought that the suppression of photosynthetic product translocation induced by LEDs may lead to increased accumulation of primary metabolites in crops. Increased secondary metabolite accumulation in response to light, particularly UV light, may represent a stress reaction or a sun-screening effect, protecting plants from ionizing radiations. Signal

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transduction pathways, which comprise enzymes, metabolites, and secondary messengers, are also affected by light. Light may be utilized to produce medicinally significant secondary metabolites in plants, according to the data presented above. However, depending on the plant species or cultivars, the impact of various single- or mixed-spectral light ratios may vary.

Under regulated agricultural methods, blue LEDs and/or mixed red: blue LEDs may be the optimum option for improving crop nutritional characteristics. Inconsistent reactions of various metabolic pathways to different light wavelengths offer a barrier, therefore additional mechanistic research is needed to better understand how we may harness the usage of LEDs for the improvement of plant developmental characteristics.

1.2.LEDs Enhance Antioxidant Properties:

Plant photo-oxidative characteristics are influenced by light quality, which modulates the antioxidant defense system, resulting in an increase in anti-oxidative enzyme activity. When compared to white light sources, enhanced antioxidant capabilities of various plants such as pea, Chinese cabbage, kale, tomato, and others have been found as a reaction to the usage of single-spectral or mixed red (625–630 mm): blue lights (465–470 mm). Furthermore, white LEDs that are green (510 nm), yellow (595 nm), or even mixed red enhance antioxidant qualities and anthocyanin accumulation. The induction of -carotene, glucosinolates, free radicals (e.g., DPPH; 1, 1-diphenyl-2-picrylhydrazyl), scavenging activity, ROS-scavenging enzymes (e.g., superoxide dismutase), phenolic compounds, and vitamin C may result in such increases in antioxidant properties. Antioxidant-rich fruits and vegetables may be beneficial to your health. As a result, it would be fascinating to investigate the health advantages of eating LED-treated crops.

1.3.LEDs Improve Nutritional Traits of the Postharvest Produce:

LEDs have been utilized to increase plant biomass and nutritional content in growth chambers and greenhouses. LEDs are also utilized in agricultural postharvest processing because of their energy efficiency, compact size, extended life, and relatively cold surfaces. Postharvest processing attempts to preserve the crop's intended aesthetic qualities, as well as farm texture, enhanced nutrients, and taste quality.

When compared to white light or dark growth conditions, narrow-bandwidth LEDs with different wavelengths can affect the accumulation of volatile compounds (e.g., benzenoid and phenylpropanoid) related to aroma or taste in flower and fruit products of different crops, such as petunia, tomato, strawberry, and blueberry. The usage of red and far-red light has also been linked to higher amounts of 2-phenylethanol (a key volatile component) in petunia blooms. This implies that LEDs may enhance the aromatic characteristics of plant products in a manner that meets our olfactory requirements (human consumption).

Different spectrum LEDs, such as red, blue, green, or even white light, may enhance the nutritional quality of harvested vegetables, such as cabbage, by boosting the accumulation of vitamin C, anthocyanin, and total phenolics, in addition to improving the olfactory appeal. In Chinese bayberry fruits, single-spectral blue LEDs control anthocyanin production by upregulating the expression of anthocyanin biosynthesis genes. Furthermore, blue LEDs may aid moisture loss by increasing stomatal conductance and transpiration during postharvest storage of agricultural products. Red LEDs, on the other hand, assist in the preservation of moisture in the tissues of fruits and vegetables. This may also help to minimize rapid water loss, enhancing their visual quality and customer acceptance.

Furthermore, by decreasing the synthesis of ethylene and ascorbates, red or blue LEDs postpone the senescence of fruits. Fruits are often transported over great distances, thus extending their shelf life is critical. Blue light, interestingly, slows the transition from green to red in tomatoes. Furthermore, as compared to tomatoes maintained in the dark, tomatoes treated with blue LEDs grow firm and accumulate greater amounts of free amino acids, particularly -aminobutyric acid-GABA. When compared to fruits grown in the dark, blue or yellow LEDs have been shown to accelerate fruit ripening and induce the synthesis of -carotene, lutein, -tocopherol, and -tocopherol. The enhanced rates of respiration and ethylene production induced by the LEDs promote rapid ripening.

Fruit ripening is a complicated developmental process that is influenced by a variety of variables, including cell wall breakdown and softening, cuticle thinning, and hormone interactions. Furthermore, climacteric and non-climacteric fruits have distinct ripening processes and molecular pathways. The molecular mechanisms in climacteric and non-climacteric fruits may be affected differently by the same LEDs. As a result, in the future, a thorough molecular study is required to fully comprehend the impacts of LEDs on a variety of postharvest agricultural products.

1.4.LEDs Offer Protection against Food Spoilage and Crop Loss

Agriculture experts continue to face challenges such as post-harvest rotting of fruits and the preservation of standing crops from disease assault; nevertheless, LEDs are gaining popularity as a useful tool for sustainable agricultural operations. When compared to dark circumstances, single-spectral blue LEDs minimize the postharvest deterioration caused by Penicillium species in citrus fruits. Furthermore, light-mediated activation of lipid signaling and consequent buildup of phospholipase A2, ethylene, and octanal has been shown to reduce fruit infection. Furthermore, blue light may prevent fungus from sporulating and germinating. As a consequence, blue light-mediated post-harvest crop protection may have a dual impact, inhibiting fungal development while also stimulating host defensive responses.

Disease resistance to a broad variety of phytopathogens may be induced in standing crops using certain wavelengths of light, particularly red, blue, and green LEDs. When compared to the effects of white fluorescent light, red light slows lesion formation, stimulates the expression of defense-related genes, and also enhances the production of stilbenic chemicals. Stilbenes, also known as phytoalexins, are essential components of plant defensive mechanisms. Furthermore, following various wavelengths of LED illumination of plant products, enhanced production of stilbenes was found, along with increased expression of 16 defense-related genes. LEDs may also cause the production of defense-related genes in Ginseng plants, which leads to the manufacture of ginsenosides.

Plant disease resistance is aided by salicylic acid (SA). SA signaling activation and resistance to P. syringae are known to be impaired in red:far-red light photoreceptor mutants. In pathogen-inoculated cucumber plants, red LEDs increase SA content and the expression of SA-regulated PR-1 and WRKY genes. Taken together, it's reasonable to believe that red light-induced resistance is linked to SA-mediated defensive responses. Furthermore, in Arabidopsis, a low red:far-red light ratio decreases SA and JA-mediated disease resistance by lowering the expression of SA- and JA-responsive genes. This finding also suggests that LEDs may have an impact on disease resistance mediated by SA and/or JA.

The interaction between SA and JA, as well as their functions against biotrophic and necrotrophic diseases, is very complicated in the plant defensive response. SA and JA, respectively, mediate the defensive response against biotrophic and necrotrophic infections.

Various wavelengths of LEDs may stimulate different chemical processes, causing defensive hormones to accumulate (i.e., SA and JA). To understand the molecular response in LED-treated plants during biotrophic and necrotrophic pathogen infection, a comparison study is needed.

1.5.The Impact of LEDs on Crop Yield:

LEDs produce less heat, allowing them to be used as an inter-lighting system in greenhouses. Furthermore, since LEDs use less electricity, they may save a considerable amount of energy. When compared to white fluorescent or solar light, the usage of single-spectral blue or red LEDs has resulted in substantial improvements in the quality and production of vegetables and fruits (e.g., cucumber, pepper, and strawberry fruits).

Furthermore, LED inter-lighting systems (57 W m2) hasten the development of the fruit. In addition to single-spectral light, blended red:blue light may boost crop production. In any event, red LEDs may be used as the primary light source for promising vegetable growth and increased dry mass and yield under regulated climatic conditions. Because blue and red light regulate photosynthetic rates by opening and shutting stomata, their impact on plant biomass and production is unsurprising.

2. DISCUSSION

Crop production's ultimate aim is to produce higher yields while improving nutritional quality. Due to environmental limitations and a decrease in the availability of farmed areas, indoor cultivation systems are urgently needed to achieve yield characteristics that are comparable to or greater than outdoor cultivation systems. Fluorescent and incandescent lamps, as well as high-pressure sodium lamps with changing spectrum outputs, have traditionally been employed for these applications. Short half-lives, heat generation, and high power consumption are all disadvantages of such light sources. LEDs offer a number of benefits over conventional light sources, including the ability to produce a narrow range of light, high purity and effectiveness, small size, longer half-life, and reduced power consumption. LEDs may be utilized in a number of horticultural contexts, including growth chambers, greenhouse inter-lighting systems, and vertical farming, because to their mobility.

In the field or during postharvest processing, a combination of various wavelengths of LEDs in varied quantities may enhance the nutritional content of crops or fruits. Furthermore, a combination of LEDs may postpone plant and vegetable senescence and change the ripening process in some fruits, even under postharvest circumstances. Food safety is improved by inactivating foodborne germs in postharvest vegetables, which LEDs produce with little heat. Because bacterial growth is more efficiently inactivated at low temperatures, LEDs (particularly blue LEDs) may be utilized as effective bactericides in cold storage. To meet the increasing worldwide need for food microbiological safety, LEDs may provide an alternative to chemical sanitizers.

3. CONCLUSION

LED-induced plant disease resistance may point to new ways to reduce the usage of pesticides in crop protection. Chemical priming is an alternative to using genetically engineered crops to make plants more robust to environmental stressors. LEDs, given their eco-friendly nature, may be utilized as a useful tool for inducing priming as an alternative to chemical priming. More study is needed, however, to identify the spectral characteristics that are necessary for effective crop protection. By combining desirable wavelengths, the technological and operational advantages of LEDs may be maximized. One of the main drawbacks of this technique is its poor penetrance, which makes it unsuitable for in vitro usage.

Furthermore, for a variety of crops, optimum spectral conditions are unknown. More greenhouse research with other leafy crops may lead to fresh ideas on how to use this technology in large-scale vegetable or fruit production. Depending on the plants, it would be fascinating to see whether LEDs might be utilized to regulate the shift from vegetative to reproductive phases. Workers and researchers' eyesight may be harmed by narrow-band blue, red, green, or yellow light. As a result, white light supplementation may be a future strategy to reducing such problems. Forecasting studies should evaluate crop-specific costs and benefits for the most cost-effective deployment of LEDs. However, a number of variables, including improved LED luminous effectiveness, field usage efficiency, manufacturing cost, and energy consumption, will influence its future use.

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