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Harnessing Blue LED Technology for Advanced Food Preservation and Safety

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The food processing and preservation industry is undergoing significant transformations, driven by advancements in technology and changing consumer preferences. These trends reflect a shift towards more efficient, health conscious and eco-friendly practices, meeting the evolving demands of consumers and the global market. The novel food preservation technologies, such as ohmic heating, cold plasma, pulsed electric field and high-pressure processing, are used as alternatives to conventional technologies in the food industry. Among them, light emitting diodes is one of the preservation technologies is used in agriculture and food sectors. In recent years, interests in light emitting diodes with blue wavelength in alternative to the ultraviolet irradiation have increased.

Light emitting diodes

LEDs are semiconductor devices that produce light with narrow band emission wavelengths. The human eye can perceive LED light within the visible spectrum, which ranges from 400 to 760 nm. This spectrum is divided into six wavelength categories: violet (400-450 nm), blue (405-500 nm), green (500-570 nm), yellow (570-590 nm), orange (590-610 nm) and red (610-760 nm). In the food industry, blue, green and red LEDs are most frequently utilized.

Mechanism of blue LED bacterial inactivation

Blue LEDs emit light typically in the range of 405-500 nanometres. This wavelength range is absorbed by certain endogenous photosensitizing molecules within bacterial cells, such as porphyrins and flavins. When these molecules absorb blue light, they become excited and photochemical reactions takes place with the production of reactive oxygen species (ROS). ROS damages the cellular components and they oxidize lipids, proteins and nucleic acids within bacterial cells, disrupting cell membranes, inactivating enzymes and causing DNA damage. This leads to cell death Hamblin et al. (2016).

Applications in food industry

Surface Sterilization

Blue LEDs are being utilized more frequently for sterilizing surfaces in food processing environments. They have been shown to significantly reduce *Escherichia coli* and *Listeria monocytogenes* on stainless steel surfaces typically used in these facilities. This application supports a hygienic processing environment, thereby reducing the risk of cross contamination Ghate et al. (2019).

Packaging and Storage

Blue LED technology is now being integrated into packaging and storage systems to prolong the shelf life of food items. The application of blue LED lights in active packaging was observed and a notable reduction in microbial growth on fresh cut fruits and vegetables was noted. Furthermore, incorporating blue LEDs into cold storage environments effectively keeps microbial levels low, thus preserving the freshness and quality of stored foods Kim et al. (2020).

Water and Liquid Food Treatment

Blue LEDs prove effective in treating water and liquid foods, ensuring the removal of harmful microorganisms. Blue LED light can effectively inactivate pathogens in drinking water and juices, providing a chemical free method for microbial control. This approach is especially beneficial for the beverage industry, where it is essential to ensure the microbiological safety of liquid products. Shen et al. (2020).

Meat and Seafood Preservation

Blue LED lights help in preserving the quality and safety of meat and seafood products. They significantly can reduce microbial counts on chicken and fish fillets, extending their shelf life without affecting sensory properties. This processing helps to reduce spoilage and food waste while ensuring the safety of perishable products Haughton et al. (2021).

Dairy Product

Blue LEDs can also be used to enhance the safety of dairy products. They can reduce the microbial load in milk and cheese. Blue LED treatment effectively inactivated common dairy pathogens such as Staphylococcus aureus and Escherichia coli, offering a potential method for improving dairy product safety. Kim et al. (2021).

Studies done on blue LED light

Chen et al. (2023) studied the effectiveness of blue LED light at 405 nm wavelength in eliminating bacterial pathogens such as *Escherichia coli O157:H7*,

Listeria monocytogenes, *Pseudomonas aeruginosa*, *Salmonella Typhimurium* and *Staphylococcus aureus* from surfaces and packaging materials commonly used in food processing. Stainless steel (SS), high density polyethylene (HDPE), low density polyethylene (LDPE) and borosilicate glass were used as materials typically encountered in food processing, food service and clinical environments. This innovative approach offers a promising, chemical free method for enhancing food safety. By targeting materials integral to food production and packaging, this technology could significantly reduce the risk of bacterial contamination throughout the food supply chain. The study highlights a potential breakthrough in food safety practices, combining the simplicity of LED technology with the critical need for pathogen control in the food industry.

Wu et al. (2021) studied the potential of blue light emitting diodes to inactivate Shiga-toxin-producing Escherichia coli (STEC) in laboratory conditions. STEC is a significant foodborne pathogen that can cause severe illness in humans. The antimicrobial effects of blue LED were carried out on seven Shiga-toxin-producing *Escherichia coli* strains (STEC 7 serotypes) using two LED formats at 405 nm (Prototype A, bulb array emitting 22.77 ± 1.054 mW/cm^2; Prototype B, strip array emitting 4.25 ± 0.25 mW/cm^2). The 405 nm LED illumination acted as an effective sanitization approach against the STEC 7 strains *in vitro*. Notably, they showed significant antimicrobial effects in limited nutrient condition indicating its potential as an add-on sanitization for environmental cleaning in food processing plant.

Prasad et al. (2021) explored the dual benefits of high intensity blue LED light pulses at 455 nm wavelength. This research investigates not only the antimicrobial properties of blue light but also its potential for drying applications in food processing. Decontamination of low water activity (a_w) foods, like pet food is a challenging task. Treatment using light emitting diode (LED) is an emerging decontamination method, that can induce photodynamic inactivation in bacteria.

Conclusion

LED technology, particularly in the blue light spectrum, is emerging as a promising innovation in food preservation. Its numerous advantages have sparked interest in its potential to enhance food safety and quality. Blue light can inhibit the growth of various foodborne pathogens and spoilage microorganisms, potentially extending shelf life. As a non-thermal technology, it can help to preserve nutritional quality and sensory attributes of foods that may be sensitive to heat. They are more energy efficient compared to traditional lighting systems used in food processing facilities. This method offers a non-chemical approach to food preservation, aligning with consumer preferences for cleaner labels. Since, they had been implemented in laboratory scale their usage is limited so studies need to be carried out to expand their availability in large scale.

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