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Review Article

Role of Light Emitting Diode in Food Industry

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Abstract

Recently Light Emitting Diode (LED) technology has been emerging as an exclusively non-thermal and non-chemical treatment for surface disinfection and preservation of solid and liquid food materials, where the technology utilises the unique properties of light to interact with varieties of food. Consequently, light technology using LED of different wavelength offers long life expectancies, robustness, and compactness and can be able to solve the huddles regarding food safety during the production, postharvest, and storage when a food industry has concerned. The methods are seeming to be rapid, efficient and reliable alternatives to improve the quality of food and more effective to increase shelf life of food materials along with good preservation ability which is in contrast with traditional food preservation technologies, and moreover the light technology will affect the stability of inactive microorganisms, spoilage enzymes, nutritional and quality parameters of food. Besides majority of these techniques are to be more environment friendly rather than traditional technologies. This review article emphasise on the application and effectiveness of light technology using LED of different wavelength in food industries.

Abbreviations

LED- Light Emitting Diode
UV LED- Ultra Violet-Light Emitting Diode
Vis LED- Visible Light Emitting Diode
UV A- Ultra Violet A
UV B- Ultra Violet B
UV C- Ultra Violet C
PV- Photovoltaic

Introduction

Traditional food processing usually comprises heat kill to foodborne pathogens such as bacteria, viruses, and parasites to make the food safe to eat. Nevertheless, there are many foods that can be able to pose health risk even after thermal treatment by means of bacterial or viral foodborne pathogens, where researchers have been studying on various light techniques such as Deep Ultra Violet-Light Emitting Diode (DUV LED), Visible Light Emitting Diode (Vis LED), etc. which can inactivate pathogens and ensure food safe for consumption. Now days, consumers demand for minimally processed food with extended shelf-life has been increasing gradually; therefore, alternative methods are needed to overcome the challenges that have been facing by various foods processing industry. Accordingly, alternative processing methods using Light Emitting Diodes (LEDs) proved their potential to inactivate pathogens along with retaining desired food quality at various stages of the technology [1].

LEDs largely having unique properties that is extremely suitable for food processing industries, in addition they have reduced thermal damage and degradation in crops and foods along with suitable for cold-storage applications mainly due to the properties including low radiant heat emissions, high emissions of monochromatic light, electrical, luminous and photon efficiency, long life expectancy, flexibility and mechanical robustness. From literature, it has revealed that the use of LED techniques for agricultural field can bring increased yield, high nutritive content products, and the recent studies have shown that LED enhances the nutritive quality of foods in the postharvest stage together with reduction in fungal infection as well as pathogenic bacterial inactivation in processed foods [2]. In conclusion, LED techniques helps to keep food safe by means of non-thermal processing of food materials along with devoid of using chemical additives and this study offers information on the role of LED in food processing industries.

Overview of LED Technology

The exclusively non-thermal and non-chemical light technology has been emerged for surface disinfection and preservation of solid and liquid food materials utilises the unique properties of light to interact with varieties of food and food related micro-flora, where the technology comprises mercury or amalgam at low and medium pressure UV lamps (LPM and MPM), pulsed ultraviolet light (PUV), pulsed light (PL) and LEDs [3].

A LED is a semiconductor diode incapable of producing monochromatic light, consisting of a narrow bandwidth of wavelengths called as electroluminescence property, and it occurs when an electron–hole interaction taken place and it results in the emission of light of a distinct wavelength, and which appears as distinct colours to the eye. The colour of the emitted light depends on the band gap energy of the material of semiconductor [4,5]. Currently, LEDs have become increasingly feasible and advantageous including high photoelectric efficiency and photon flux or irradiance, low thermal output, compactness, portability, and can be easily integrated into electronic systems. In the areas food safety and preservation LEDs regarded as a novel technology which can satisfy consumers demands on food safety [5-8].

Application of LED Techniques in Food Industry

Increased demand of minimally processed high quality food leads to the emergence of new preservation technologies including pulsed white light, UV-C light and DUV irradiation. The methods are seeming to be rapid, efficient and reliable alternatives to improve the quality of food and more effective to increase shelf life of food materials along with good preservation ability which is in contrast with traditional food preservation technologies. Owing to the intrinsic characteristics of light technology, it is not easy to monitor in real time processing conditions and moreover the light technology will affect the stability of inactive microorganisms, spoilage enzymes, nutritional and quality parameters of food. In addition, majority of these techniques are to be more environment friendly rather than traditional technologies [1,9]. Moreover, the use of LED technology also finds application in packaging and surface sterilization of ready to eat food materials, besides the LED in blue region will inactivate pathogens without any additives [2].

In food industry, UV treatment is recently employed technology which is effective to ensure the food free from contamination, since the wavelength ranges of UV C (280nm) and UV B (280-315nm) are responsible for damaging the DNA replication as well as transcription and capable of inactivating a varieties of pathogenic microorganisms as well [10]. Hamamoto *et al.,* (2007) substantiate the same by constructing a UVA LED system for inactivating pathogenic species in food stuffs [11]. Subsequently, Lian *et al.*, revealed the efficiency of UVA LED for the irradiation of *Escherichia Coli* in solution containing colorants and orange juice for ensuring the microbial safety of beverages *E. coli*. [12].

Use of LED Technology in Uncooked Food Items

Recent studies on cultivation of crop plants by using LED has revealed that LED packages can produce large amount of visible light energy which is crucial for plant growth and development. LED lighting systems which are having long life expectancies, robustness, and compactness can be able to solve the huddles regarding food safety during the production, postharvest, and storage when a food industry has concerned. In addition, it is expected that LED technology will become more attractive to the food industry in the near future, where a substantial number of studies demonstrated the usefulness of LEDs in other aspects of food production and agriculture such as in fisheries and poultry rearing, ingredients, and other applications [2,13].

Moreover, Light Emitting Diodes (LEDs) provides some advantages such as reduction in the growth of micro-organisms along with production of high yield of plants especially citrus varieties in the post harvested storage stage. In addition, leafy vegetable would be susceptible to lose their green colour quickly after harvest, and several studies revealed that the storage as well as shelf life conditions of the leaf lettuce can be increased by providing white LED irradiation in supermarkets because, chlorophyll content of leaf lettuce was increased by white LED light treatment [14].

Fruit and Vegetables

Fruits and vegetable are highly susceptible to microbial spoilage, where, UV light processing techniques can meet these requirements. The use of UV light treatment proved to be effective at reducing microbial loads, even though the use of non-ionizing, germicidal UV-C light affects several physiological processes in plant tissues and damages microbial DNA, it could be an effective method for the decontamination of fruits and vegetables as a whole or as fresh cut products [3,15].

Ghate *et al.,* 2013 studied on survival of *Salmonella spp.* which colonizes and grows on fresh-cut pineapples at different irradiances (92, 147.7 and 254.7mW/cm^2) and temperatures (7, 16 and 25°C), where the antibacterial effect has been determined by examining the differences between control population and illuminated samples at the irradiation of 460nm blue light emitting diode and the colour of the slices were also measured [16]. Bactericidal action and growth inhibition were observed at 7 or 16°C and 25°C respectively, and the results shows that irradiance had no significant effect on antibacterial activity but temperature influenced the antibacterial effect on fresh cut pineapple, where the study demonstrated the potential of 460nm LEDs acted against *Salmonella* species. on fresh-cut pineapple slices. Kim *et al.,* (2017) investigated the antibacterial effect of LED technique having the wavelength range of 405 ± 5nm on *E. coli* O157:H7 and *Salmonella spp.* found on the surface of fresh-cut mango and also assessed the influence on fruit quality at different storage temperatures [17]. Regardless of bacterial species LED-illumination reduced 1.2 log of *Salmonella* and inhibited the growth of *E. coli.* O157:H7. Instead, those on non-illuminated mango remained unchanged or slightly increased during storage at 20°C for 24 hours, and there were no significant differences in colour, antioxidant capacity, ascorbic acid, β-carotene, and flavonoid between non-illuminated and illuminated cut mangoes. The results shown that 405 ± 5nm LEDs in combination with chilling temperatures could be applied to preserve fresh-cut fruits without deterioration of physicochemical quality of fruits at food establishments, minimizing the risk of foodborne diseases.

Ready to Eat Food

Furthermore, the effects of Ultra Violet LEDs (UV LED) on inactivation of *E. coli.* K12, *E. coli* 0157:H7 and polyphenoloxidase (PPO) in clear as well as cloudy apple juice were investigated, where 40 min UV exposure has been given to the apple juice samples by using a UV device made up of four UV-LEDs with peak emissions at 254 and 280nm. Cloudy apple juice achieved the highest inactivation of *E. coli* K12 when it treated with both 280nm and 280/365nm UV-LEDs, whereas the highest inactivation obtained for *E. coli* K12 in clear apple juice was achieved using 4 lamps emitting light at 280nm along with 40min exposure. In addition, a better inactivation effect on PPO shows when UV-A and UV-C rays in combination than UV-C rays used separately [18]. Besides, a novel UV-C irradiation device in laboratory scale was tested for its potential to inactivate bacteria in naturally cloudy apple juice, where liquid flows through a helically wound tubing wrapped around a quartz glass tube containing a 9W UV lamp with an irradiation intensity of 60 W/m^2 at 254nm. The equipment was capable of reducing numbers of inoculated *E. coli.* and *Lactobacillus* brevis from an initial concentration of cloudy apple juice. Although the technique incapable of eliminating and inactivating *E. coli.* effectively in self-extracted apple juice, but the industrially processed apple juice contaminating yeast and lactic acid bacteria were not completely eliminated [19].

Water Disinfection by LEDs

Song *et al.,* 2016 studied on UV disinfection which has several applications in industrial sector and is regarded as the effective technology for inactivation of pathogens in water [20]. The study reveals the different wavelength of UV-LEDs in which inactivation of microorganisms has occurred, furthermore UV-LED has emerged in the past decade with a number of advantages such as compactness and portability, wavelength diversity and adjustable pulsed illumination while compared to traditional UV mercury lamps which is less feasible due to release of toxic chemicals, along with fragility, expense of counterparts, and regular cleaning and the studies discloses potential of UV-LEDs for effective water disinfection. Aoyagi *et al.,* (2011) has found that the disinfection of bacterial viruses such as MS2, QβQβ, and φX174φX174 in water is also possible by using deep ultraviolet light-emitting diodes (DUV-LEDs) operated at 280nm and 255nm [21].

High quality disinfection by using LED technologies especially for point-of-use (POU) would be feasible within 10 years along with the possibilities of integration with photovoltaic, and the studies accomplishes that an alternative such as a semiconductor-based unit where UV-LEDs0.01.253 powered by photovoltaics (PV) have been emerging and requires effective development of these two technologies. Further studies are needed for the exploration of UV-C-LEDs, non-UV-C LED technology (e.g. UV-A, visible light, Advanced Oxidation), PV power supplies, PV/LED integration and POU suitability [11]. Lado and Yousef (2002) explains the mechanism of inhibiting microbial growth by UV-C in which radiation generates hydroxyl radicals from water, which remove hydrogen atoms form DNA components, sugar and bases [15]. In addition, UV light at 254 nm induces the formation of pyrimidine dimmers which alter the DNA helix and block microbial cell replication [22,23]. UV-C technology is widely used as an alternative to chemical sterilization and microorganism reduction in food products, and also induces biological stress in plants and defence mechanisms of plant tissues with the subsequent production of phytoalexin compounds [24].

Antimicrobial Activity of LED

Studies suggest that antimicrobial effect of the LED was highly dependent on the wavelength and the illumination temperature, where the antibacterial effect of LEDs of visible wavelengths (461, 521 and 642nm) were studied on selected foodborne pathogens such as *E.coli* 0157:H7, *Salmonella typhimurium, Listeria monocytogens* and *Staphylococus aureus* at different illumination temperature and the results shows that, 461 and 521nm LEDs produced a great bactericidal effect at temperature 10 and 15°C, where the gram nature of the strains had no influence on the process. In addition, no antibacterial effect was observed at 642nm LED treatment, and the observed sub-lethal injury shows that, in all bacterial strains regardless of the illumination temperature during illumination with the 461 and the 521 nm LED and the percentage of injured cells increased with increased treatment time. Hence the combination of 461 and 521nm LEDs has great potential in novel food preservation technology [17].

Ghate *et al.,* 2015 studied on the role of organic acids in the antibacterial effect of LEDs, where it has clear that blue LEDs in combination with organic acids can able to use for food preservation, because the organic acid can enhance the antibacterial effect, and the study reveals that organic acid has an influence on the photodynamic inactivation of four foodborne pathogens such as *E. coli* O157:H7, *S. typhimurium, L. monocytogenes* and *S. aureus* [25]. Irrespective of the bacterial strain, organic acids significantly influenced the bacterial inactivation due to the LEDs at the same pH, where lactic acid was found to be the most effective than citric and malic acids, in aiding the photodynamic inactivation of the pathogens. In addition, antibacterial effect of LEDs can be greatly enhanced by food acidulants and hence suggesting the potential of LEDs in preserving acidic foods.

Likewise, Srimagal *et al.,* (2016) investigated the effect of blue monochromatic LEDs on inactivation of *E. coli.* in milk, where wavelength, is appliedbetween 405nm - 460nm with a temperature gradient of 5˚C-15˚C, and the duration of treatment vary up to 0 min - 90 min. the results shows a maximum microbial reduction at higher temperature and lower wavelengths, where log reduction of *E. coli* and overall color change of the treated milk were considered as the dependent variable and Wave length (405nm - 460nm), temperature (5˚C-15˚C), and treatment time (0 min - 90 min) were considered as the independent variables [26]. Additionally, several methods which are similar to LED techniques to ensures the food safety includes the application of ozone at specific doses of 33 mg/min for 9 min in gaseous phase, successfully inactivates 2×106CFU/g of *L. monocytogenes*, a Gram positive ubiquitous psychrotrophic bacterium responsible for foodborne infections worldwide, on chicken samples before they reach outlets for consumers [27]. Furthermore, a 7 log reduction of population of *L. monocytogene* has observed by ozone exposure between 33 seconds and 49 seconds [28].

LEDs also have the influences on environmental conditions such as pH of the food contaminated by pathogens and the studies has revealed that pH influences on antibacterial activity of food materials, where 461nm LED illumination on the food materials containing *E. coli.* O157:H7, *S. typhimurium* and *L. monocytogenes* in trypticase soya broth and having the pH values ranges from 4.5,6.0,7.3,8.0 and 9.5 for 7.5 h at 15°C shows that a reduced bacterial population [25].

Shin *et al.,* 2016 has studied on the basic spectral properties of deep-UV-C light-emitting diodes (DUV-LEDs) and the efficiency of UV-C irradiation for inactivating foodborne pathogens, including *Escherichia coli* O157:H7, *Salmonella enterica serovar typhimurium* and *L. monocytogenes* [29]. Furthermore, the efficiency of DUV-LEDs has compared with low pressure UV lamps (LP-UV) that have been successfully using since last few years for disinfection as well as inactivating foodborne pathogens. The results show that DUV-LED light intensity decreased slightly in increasing temperature, whereas LP-UV lamps showed increasing intensity until they reached a peak at around 30˚C. Nonetheless due to the increasing irradiation dosage and temperature, pathogenic organisms such as *E. coli* O157:H7 and *S. Typhimurium* experienced 5- to 6-log-unit reductions, whereas *L. monocytogenes* was reduced by over 5 log units at a dose of 1.67mJ/cm^2. Consequently, the drawbacks of using LP-UV lamps such as possibility of mercury leakage may compensate by using DUV-LEDs to inactivate foodborne pathogens [29].

Fresh cut foods and ready-to-eat meat can be preserved by chemical free food preservation method using Blue LED, where the bacterial cells contain light sensitive compounds absorbs the blue light and thus the exposure can cause cells to die. Subsequently, the studies show that the detrimental effect can be observed among the major foodborne pathogens such as L. monocytogenes, E. coli. and S. typhimurium under blue LED illumination along with varied the pH conditions [17,30].

Conclusion

Non-thermal processes represent rapid, efficient and reliable alternatives to improve the quality of food, even though many innovative food-processing techniques have shown potential for improving the nutritive quality of all processed food ensuring food safety while meeting the demand, because of the rate at which LED technology has been improving and is expected to improve, there is a great potential for its application in the food industry. LEDs possess unique properties that are highly suitable for several operations in the food industry, such properties include low radiant heat emissions, high emissions of monochromatic light, electrical, luminous and photon efficiency long life expectancy, flexibility and mechanical robustness. Therefore, they reduce thermal damage and degradation in crops and offer bactericidal activity in foods and are suitable in cold storage applications.

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Conflicts of interests

The authors declare that they have no conflict of interest related to this article

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