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REVIEW

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Application of light emitting diodes (LEDs) for food preservation, post-harvest losses and production of bioactive compounds: a review

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Abstract

Light-emitting diode (LED) technology is a new non-thermal food preservation method that works by converting light energy into heat. LED has potential to revolutionize crop production, protection and preservation. This technology is economical and environmentally friendly. LEDs have been shown to improve the nutritive quality and shelf life of foods, control the ripening of fruits, induce the synthesis of bioactive compounds and antioxidants and reduce the microbial contamination. This technology also has great scope in countries, where safety, hygiene, storage and distribution of foods are serious issues. While comparing this technology with other lighting technologies, LEDs can bring numerous advantages to food supply chain from farm to fork. In case of small growing amenities which exploit only LEDs, energy expenditure has been successfully reduced while producing nutritious food. LEDs can be used to give us better understanding and control over production and preservation of food with relation to spectral composition of light. LEDs also play significant role in food safety by inactivating the food borne pathogens. Therefore, LED lighting is a very effective and promising technology for extending shelf life of agricultural produce by increasing disease resistance and with increased nutritional values.

Keywords: Light emitting diodes, Food preservation, Anti-microbial, Bioactive compounds, Non -thermal

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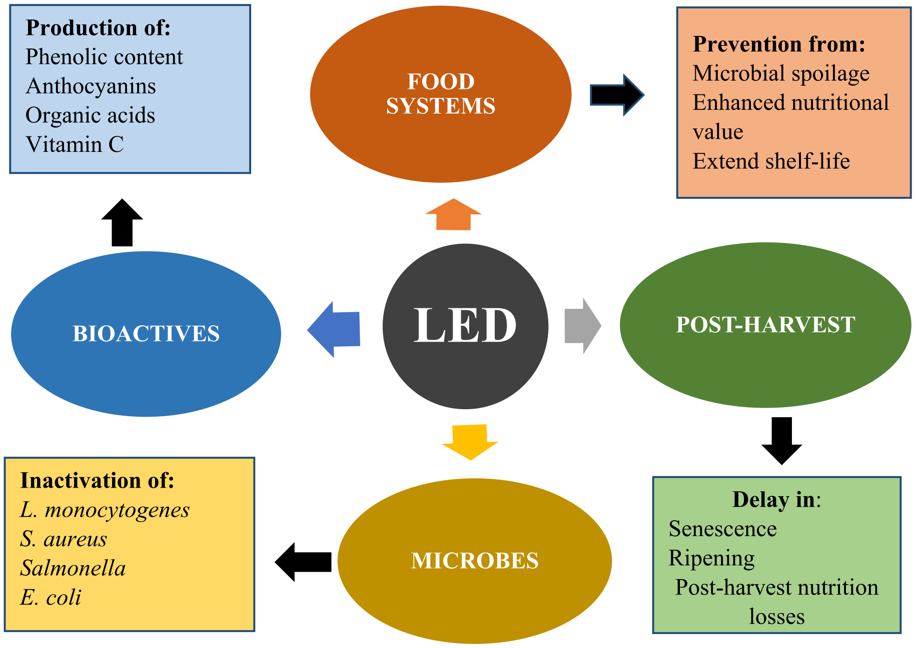
Graphical abstract



Introduction

Although ultraviolet (UV) radiation is well known for its sterilising properties, under some conditions, visible light has been proven to have bactericidal characteristics, allowing it to play an important role in food preservation. Visible light plays an evident role in food production, as well as in agriculture and horticulture, because it stimulates photosynthesis, which is essential for plant growth and development. However, its use in other elements of food preparation receives less attention. Low light levels are now known to help the crops to retain postharvest quality by reducing senescence and enhancing phytochemical and nutritional content in a variety of species (Costa et al. 2013; Braidot et al. 2014; Glowacz et al. 2014). In agriculture and food industry, artificial light treatments are being used to disinfect water and food, as well as to enhance plant health and development by employing light energy of various wavelengths (Koutchma and Orlowska, 2012; Lian et al. 2010; Song et al. 2016).

LEDs operate in a solid-state environment which produce light with limited emission wavelengths, high photoelectric efficiency and photon flux or irradiance, low heat production, compactness & mobility and easy integration into electronic systems. It is a non-thermal food processing method that uses light radiation with wavelengths ranging from 200 to 780 nm (Prasad et al. 2020). The spectrum features, radiant or luminous intensity, and temporal settings of the light produced may be easily controlled because of LEDs special capabilities (Branas et al. 2013). LEDs constructed from semiconductor materials that produce monochromatic illumination are used in agriculture and food industries due to their benefits over conventional sources. Certain wavelengths of light, as well as pulsed and continuous operating modes can remove hazardous germs in food and water and thus making LEDs very effective. LEDs operate on the electroluminescence concept, which means they produce light under the influence of electric or magnetic field. In order to reach lower energy states, excited electrons in an electric or magnetic field produce light and release energy as electromagnetic radiation. LEDs are made of semiconductor materials that are impurity-laced to create a boundary or interface (known as a p-n junction) among the two categories of semiconductor materials, one being sufficient in holes (the positive or p-type) and the other (the negative or n-type) being sufficient in electrons (Prasad et al. 2020). The colour and wavelength of light produced are determined by the impurities and semiconductors employed in the LEDs manufacturing process. A semiconductor of p-type could possibly be constructed by infusing an element such as magnesium (Mg) belonging to group II, over any group III element substrate to create more cavities. An n-type semiconductor is created by doping a group IV element into a group III element substrate to provide additional free electrons (Bohn et al. 2009).

Effect of LEDs in food system

The effectiveness of LED therapies for solid meals is determined by the kind and character of the end food products, its constituents, as well as the water activity (a^{w}) and surface features of the food. Significant elements that need to be considered are light wavelength, treatment time, dosage, illumination temperature, relative humidity and microbiological conditions. In *Salmonella* inoculated fresh-cut papaya, LEDs producing light with a wavelength 405 nm caused a depletion of 1–1.2 log CFU/cm^2. The papaya was given a complete dose of 1.7 kJ/cm^2 for 48 h at 4 °C (Kim et al., 2017b). Another study supporting the antibacterial efficacy of 405 nm LEDs on freshly-cut mango was conducted by Kim et al. (2017c), utilized a total dosage of 2.6–3.5 kJ/cm^2 over 36–48 h and cell counts in a three- strain cocktail of *E. coli* O157:H7, three serotypes of *L. monocytogenes*, and five serotypes of *Salmonella* spp. and reported that all three strains were decreased to less than 1.6 log CFU/cm^2. The effects of visible light LED therapy on the sanitation of fresh-cut fruits have also been explored. Ghate et al. (2017) investigated the antibacterial impact of a 460 nm LED on freshly-cut pineapples infected with a cocktail of *S. enterica* at various illumination temperatures and irradiances. A maximum reduction of 1.72 log CFU/g was achieved with 92 mW/cm^2 irradiance at 16 °C illumination temperature in *E. coli* O157:H7, *S. typhimurium*, *E. coli* K12, and *S. enteritidis*. Lacombe et al. (2016) used a 405 nm LED to treat shelled almonds and found highest decrements of 2.44, 0.96, 1.86, and 0.7 log CFU/g, respectively. Srimagal et al. (2016) investigated the inactivation of *E. coli* in milk using blue LEDs with wavelengths of 405, 433, and 460 nm, at 5, 10 and 15 °C, and treatment periods ranging from 0 to 90 min. Inactivation of microbes was found to be greater at higher temperatures and shorter wavelengths, with an *E. coli* O157:H7 reduction of 5.27 log CFU/mL after 60 min at 405 nm irradiation. The 460 nm LED resulted in a 2 to 5 log decrease, similar to the findings of Ghate et al. (2016), with a greater effect on bacterial inactivation at higher temperatures. Both studies showed significant colour changes in food items (orange juice and milk) after exposure to blue LEDs, suggesting that the blue LEDs had an impact on the quality of liquid meals. LED lights in the blue wavelength inhibit bacterial activity, mostly owing to photodynamic inactivation (PDI) of the microorganisms. Akgun and Unluturk (2017) used UVC-LEDs at 254 nm (0.3 mW/cm^2) and 280 nm (0.3 mW/cm^2), as well as UVC-LEDs combined with 365 nm (0.8 mW/cm^2) and 405 nm (0.4 mW/cm^2), to inactivate *E. coli* K12 in both hazy and clear apple juice. With reductions of 2.0–2.01 and 2.0–2.04 log CFU/mL, the turbid apple juice showed the highest antibacterial activity when treated with 280 nm alone and a combination of 280 nm/365 nm, respectively after 40 min of LED treatment. In case of clear apple juice, there was much more inactivation than in the cloudy apple juice. With a log decrease of 4.4 log CFU/mL, transparent apple juice treated alone with 280 nm (771.6 mJ/cm^2, 40 min.) showed the greatest log decrement.

Effect of LEDs on nutritional profile

Horticultural produce are significant source of human nutrition. LEDs have been extensively used and

Table 1 Effect of LED treatment in prevention of post-harvest losses

Food	Led Used	Applications	References
Broccoli (*Brassica oleracea* L. var. *italica*)	Red (660 nm)	Delaying of senescence in vegetables; Reduced yellowing and less ethylene production observed as compare to blue and white LED	Ma et al. (2014)
Broccoli (*B. oleracea Var. italica, cv. You-xiu)*	Red (At a fluence rate of 50 W m^{-2}	Inhibit yellowing and degradation of chlorophyll and reduced weight loss	Jiang et al. (2019)
Mature green tomatoes (*Solanum lycopersicum* L. cv. Dotaerang)	Blue (440–450 nm)	Delaying of ripening; Slows down the rate of color change from green to red and loss of firmness observed compared with red light.	Dhakal and Baek (2014b)
Strawberries (*Fragaria ananassa*)	Deep UV (272, 289 and 293 nm)	Preventing food spoilage by Mold growth (*Botrytis cinerea*)	Britz et al. (2013)
Lamb's lettuce (*V. olitoria* L. Pollich)	Warm White	A slower decrease of carotenoids content observed compared with dark control	Braidot et al. (2014)
Solanum lycopersicum	Blue	Prevent post-harvest spoilage; reduced spore germination of *A. niger*	Murdoch et al. 2013
Lettuce (*Lactuca sativa* L.)	White LED At a fluence rate of 150 W m^{-2} at 6 °C	Improved quality of lettuce for one week at 6 °C by decreasing browning, minimizing weight loss and respiration, compared with control	Charles et al. (2018)
Pak- choi *(Brassica rapa ssp. Chinensis)*	Red and Blue At a fluence rate of 0, 10, 35, and 70 W m^{-2}	Red LEDs inhibited the senescence and reduces loss of photochemical efficiency, while blue light has weaker effect	Shezi et al. (2020)
Chinese Bayberries (*Myrica rubra*)	470 nm (Blue) 40 μmol m^{-2} s^{-1}	Enhanced anthocyanin content as compare to control sample	Shi et al. (2014)

Table 2 Application of LED against various spoilage causing microorganisms in different food products

LED Wavelength	Food	Micro organisms	Observations	References
80 μmol m^{-2} s^{-1} (Light intensity)	Grapevine *Vitis vinifera*	*B. cinerea*	Induced resistance against bacterial population	Ahen et al. (2015)
585 nm	Fruits and vegetables	*B. cereus*	Reduction of 0.7, 1.1 and 1.3 log CFUg^{-1} on surface of plums, apricots and cauliflower respectively, as compared to control	Aponiene et al. (2015)
Blue: 410–540 nm Green: 470–620 nm) Red: 580–670 nm for 3 days at 5 °C	Citrus fruit 'Fallglo' tangerines	*Penicillium digitatum, Penicillium citri* and *Penicillium italicum,*	Significantly inhibited the fungal pathogenic microorganism	Alferez et al. 2012
At three wavelengths 200 nm, 300 nm and 365 nm	Food matrix	*Campylobacter jejuni*	A four log cycle reduction was observed	Soro et al. (2021)
461 nm (Blue LED); 18 h at 25 °C	Citrus fruits	*Penicillium digitatum* and *Penicillium italicum*	Controlled the fungal infections	Lafuente and Alférez (2015)
Blue:50-150 μmol m^{-2} s^{-1}	*Solanum lycopersicum*	*B. cinerea*	Induced resistance against moulds	Imada et al. (2014)
Three wavelengths 272, 293 and 289 nm; 9 days	Citrus fruits	*Botrytis cinerea*	Significantly inhibited the infections	Papoutsis et al. (2019)
395 nm; 1115 s	Food matrix	*Escherichia coli*	The bacterial population of *E. coli* K-12 in maximum recovery diluent was decreased by 1.37 log CFU mL^{-1}	Birmpa et al. (2014)
405 and 520 nm; at 25, 10 and 4 °C for 9 h	Soy agar	*Bacillus cereus* ATCC 14579, *Listeria monocytogenes* 1/2a BAA-679 *Staphylococcus aureus* ATCC 35932 *Pseudomonas aeruginosa* ATCC 10145 *Salmonella Typhimurium* ATCC 14028 *Escherichia coli* O157:H7 EDL 933	*B. cereus* was reduced by about 2.3 log *L. monocytogenes* was reduced by 1.9 log *S. aureus* was reduced by 4.0, 2.1 and 1.9 log at 25, 10 and 4 °C, respectively. *P. aeruginosa* was most resistant *S. typhimurium* and *E.coli* O157:H7 showed moderate susceptibility	Kumar et al. (2015)
LED: 460-470 nm at 4 °C for 4 days	Packaged sliced cheese	*Listeria monocytogenes* and *Pseudomonas fluorescens Salmonella*	Injured the RNA, peptidoglycan metabolism, protein and also caused disruption of cell membrane and cytoplasmic components	Hyun and Lee (2020)
405 ± 5 nm At 20 °C for 24 h	Fresh cut Mango	*Escherichia coli* O157:H7, *Listeria monocytogenes,* *Salmonella*	LED-illumination inactivated 1.0–1.6 log CFU/cm^{2} of populations at 4 and 10 °C for 36–48 h (total dose, 2.6–3.5 kJ/cm^{2})	Kim et al. (2017c)
405 and 460 nm	Cantaloupe rind	*Listeria monocytogenes* and *Salmonella spp*	Significant antibacterial effect	Josewin et al. (2018)
Blue LED: 95, 405, 415, and 425 nm	Apple juice	*Escherichia coli O157:H7*	6 to 7 log reductions	Kim and Kang (2021)
461 nm at 7.5 h 10-15 °C	Tryptophan soya broth	*Staphylococcus Aureus*	Decreased approximately 5.2 and 4.7 log CFU mL^{-1}, respectively	Ghate et al. (2015)
460 nm (Blue LED) (At irradiances of 92, 147.7 and 254.7 mW/cm^{2} and temperatures of 4, 12, and 20 °C)	Orange Juice	*Salmonella*	Inactivation of *Salmonella* ranged from 2 to 5 log CFU/mL	Ghate et al. (2016)
405 nm(MBL LED) Time: 0, 1, 2, 4, 6, 8, and 10 min.	Shelled Almonds	Pathogenic *E. coli* O157:H7, non-pathogenic *E. coli* K12, pathogenic *S. enteritidis* (PT30, Stanley, and Anatum), and non-pathogenic *S. typhimurium* strain Chi3985	Reduction of 2.44 and 1.44 log CFU/g *E. coli* O157:H7 *S. enteritidis*, 0.7 and 0.55 log CFU/g reduction *S. typhimurium,* 0.54 and 0.97 log CFU/g reduction *E. coli* K12, 1.85 and 1.63 log CFU/g	Lacombe et al. (2016)
LEDs in Green, blue, red and white Time: 72 h Working distance: 30 cm	Blueberries	*Bacillus amyloliquefaciens* and *Lactobacillus brevis* for fermentation and *Propionibacterium acnes* and *Staphylococcus*	White and green LEDs were efficient in improving fermentation and antibacterial activity	Jeong et al. (2018)
405 (UV-Vis), 433, and 460	UHT skim	*E. coli* ATCC 25922	A 406 nm LED treatment at 13.8 °C for	Srimagal

Table 2 Application of LED against various spoilage causing microorganisms in different food products *(Continued)*

LED Wavelength	Food	Micro organisms	Observations	References
nm (blue) LED; Time:0–90 min Illumination temperature:5–15 °C	milk(< 0.5% fat)		37.83 min. Can result in 5 log decrease with slight colour change	and Sahu, (2016)
254, 280, 365, and 405 nm (UV LEDs)	Clear and cloudy apple juice	*E. coli* K12 (ATCC 25,253)	280 nm and 365 nm LEDs caused a 2 log CFU/mL inactivation in hazy apple juice 280 nm LEDs produced a 4.4 log decrease in clear apple juice.	Akgün and Unluturk, (2017)
460 nm Time: 24, 13.91 and 8.66 h Irradiance: 92.0, 147.7, or 254.7 m W/cm^2	Fresh cut Pineapples	A fusion of five serovars of *Salmonella enterica Gaminara, Montevideo, Newport, Saintpaul, Typhimurium*	Inactivation of microbes varied from 0.61 to 1.72 log CFU/g	Ghate et al. (2017)
266, 270, 279, and 275 nm Radiation intensity: 4 W/cm^2	Sliced camembert cheese	*S. typhimurium,* *E. coli* O157:H7 *L. monocytogenes*	A reduction of 4 to 5 log was found in *E. coli, S. typhimurium; L. monocytogenes*	Kim et al. (2016)

considered as a useful source of lighting and are preferred for horticultural produce because they regulate the light source for plant growth. LEDs have the ability to enhance agricultural yield and also improving nutritional value (Mitchell et al. 2012). Taulavuori et al. (2017) reported that the use of blue LEDs is associated with its effect on several metabolic pathways and accumulation of phenolic compounds, polyphenols, carotenoid, ascorbic acid and anthocyanin. Similar trend was reported by (Hasperue et al. 2016). The authors studied the effect of white-blue LEDs on outer and inner leaves of Brussels sprouts for 10 days storage at 22 °C and reported lower respiration rate, better visual quality, with more than 10 times chlorophylls, higher contents of antioxidants and total flavonoids than controls. DiNardo et al. (2018) investigated the total phenolic content (TPC) and antioxidant capacity of Yellow European plums using high performance liquid chromatography. The authors reported that TPC and ferric reducing antioxidant potential were highest for freeze dried samples extracted at 60 °C.

LED treatment also increases the antioxidant activity of tomato, Chinese cabbage, pea and Chinese Kale during storage (Hee-Sun Kook, 2013). Kang et al. (2020) studied the effect of LEDs on overall nutritional profile of cabbage and reported the enhancement of total phenolic content, total chlorophyll content, ascorbic acid and decrease in reactive oxygen species.

Effect of LEDs on post-harvest preservation

One of the most significant functions of food processing procedures is to reduce quality loss. Experts in agriculture continue to confront issues such as fruit rotting after harvest and the protection of standing crops from disease assault. LEDs are gaining popularity as a useful medium for sustainable agricultural operations. Various studies have been conducted to support the effectiveness of LED treatment in food system as listed in (Table 1). Tomatoes can be pre-treated with blue light to lengthen their ripening period before being stored in the dark. (Dhakal and Baek 2014a; 2014b). The authors pretreated the mature green tomatoes with blue light (440–450 nm) emitted from blue light emitting diodes (LEDs) for one week and found that the pre-treatment of green tomatoes with blue light had delayed the softening. These tomatoes ripened fully after three weeks of storage in darkness due to the increased levels of lycopene. Blue light treatments at 40 μmol m^{-2} s^{-1} for 5 to 7 days decreased soft rot area, mycelial development, and sporulation of several fungi (*Penicillium digitatum, Penicillium italicum,* and *Phomopsis citri*) on the surface of fruits when compared to white light LED and darkness (Alferez et al. 2012; Liao et al. 2013). Disease resistance to a wide range of phytopathogens can be induced in standing crops using particular wavelengths of light, particularly red, blue, and green LEDs (Kim et al. 2013; Ahn et al. 2013). When compared to the effects of white fluorescent light, red light reduces lesion growth, activates the expression of defence-associated genes, and also promotes the synthesis of stilbenic components (Ahn et al. 2015). Plant defensive responses are aided by stilbenes, also known as phytoalexins (Jeandet et al. 2002). Furthermore, after using different wavelengths of LED illumination of plant products, enhanced production of stilbenes was detected along with increased expression of 16 defence-related genes (Ahn et al. 2013; Ahn et al., 2015). LEDs can potentially cause the expression of defence-related genes and as a result, the production of ginsenosides in Ginseng plants (Ali et al. 2006).

Action of LED against microbes

Recently, it was found that various diseases can be inactivated by using light from LEDs (Prasad et al. 2020). *Listeria monocytogenes* can survive a variety of stresses,

Table 3 LED employed for enhancement of secondary metabolites and biological activity in fruits and vegetables

LED Light used	Light Intensity	Crops	Secondary metabolites/ biological activity	References
Blue: 470 nm	Fluence rate 40 Wm^{-2}	Immature strawberries	Total phenolic content increased by 13.0%	Kim et al. (2011)
Blue: 525 nm	At a fluence rate of 20 Wm^{-2}	Immature broccoli	Total phenolic content increased by 1.80%	Zhan et al. (2012a, 2012b)
Red: 635 nm, Blue: 460 nm Yellow: 585 nm		Pea sprouts	Total phenolic content and total flavonoid contents of pea sprouts under blue, red and white fluorescent light were 1.46, 1.25, 1.45 times and 24.55, 21.01, 24.29 times, respectively	Liu et al. (2016)
Red	50 $\mu mol\ m^{-2}\ s^{-1}$	*Malus domestica* Borkh	Anthocyanin production	Lekkham et al. (2016)
Blue: 460 nm	133 ± 5 $\mu mol\ m^{-2}\ s^{-1}$	Green oak leaf (*Lactuca sativa var. crispa*)	Chlorophyll content was highest(1.31 mg/g) with red LED plus florescent light	Chen et al. (2014)
UV-A: 365 nm, UV-B: 311 nm	300 $\mu W{\cdot}cm^{-2}$	Ziyan leaves (*Camellia sinensis* L.)	The anthocyanin content was the highest under UV-A treatment (66.0% (107.98 mg/100 g FW) and delphinidin, cyanidin, and pelargonidin contents increased by 64.57, 80.12, and 49.34%, respectively, compared with control	Li et al. (2020)
Red: 638 and 665 nm	300 $\mu mol\ m^{-2}$ s-1 for 16 h	Mustard	Total β- carotene content increased from 0.028–0.073 mg/g.	Brazaityte et al. (2016)
Blue and white	20 $\mu mol\ s^{-1}\ m^{-2}$	Chinese kale sprouts	Total phenolic content of sprouts increased by 34.55 and 69.09%, respectively under blue and white LEDs	Qian et al. (2016)
Blue and red	80 μ mol $m^{-2}\ s^{-1}$	Chinese cabbage and lettuce	Total phenolic content production	Li et al. (2012), Lin et al. (2013)
Red and blue		Strawberry *Fragaria× ananassa*	Highest contents of total anthocyanin was 136 $\mu g{\cdot}g^{-1}$ and Pelargonidin 3-glucoside 122.18 $\mu g{\cdot}g^{-1}$ when treated with blue LED. Increased fucoxanthin content (25.5 mg/g)	Zhang et al. (2018)
Blue:450 nm–470 nm)	–	*Panax ginseng*	Total ginsenosides increased from 2.0 to 74.0%	Park et al. (2012)
370 and 385 nm (UV-A LEDs)	30 W/m^{-2} for 5 days	Kale	Total phenolic content at UV-A 370 nm increased by 14.0%	Lee et al. (2019)
Purple: 380 nm, Blue: 440 nm, Red: 660 nm	50–80 $\mu mol\ m^{-2}\ s^{-1}$	*Vitis vinifera*	*Trans*-resveratrol and *cis*-piceid accumulation were increased with concentrations of 18.2 and 55.7 $\mu g\ g^{-1}$ FW, respectively in blue and red LED treated leaves	Ahn et al. (2015)
Blue + Red	168 $\mu mol\ m^{-2}\ s^{-1}$	Carrot (*Daucus carota L.*)	Phenolic acids and rutin increased by 45.0 and 65.0%,respectively compared to darkness	Castillejo et al. (2021)
	50–80 $\mu mol\ m^{-2}\ s^{-1}$	*B. rapa, B. oleracea var. capitata*	Vitamin C and polyphenolic content production	Lee et al. (2014)
Blue:440–450 nm Red:(650–660 nm	85–150 $\mu mol\ m^{-2}\ s^{-1}$	*Solanum lycopersicum L.,* (Mature green tomatoes)	γ - aminobutyric acid (GABA) increased to 797 $\mu g{\cdot}g^{-1}$ dw treated with blue LED	Dhakal et al. (2014a)
Green	~ 200 $\mu mol\ m^{-2}\ s^{-1}$	*Lactuca sativa, Lens culinaris, Triticum aestivum L.,*	Phenolic content, vitamin C, tocopherol and anthocyanin production	Bantis et al. (2016)
Yellow	~ 100 $\mu mol\ m^{-2}\ s^{-1}$	*Raphanus sativus, Malus* sp., *S. lycopersicum,* *C. annuum*	Vitamin C, α and β-tocopherol and lutein production	Samuoliene et al. (2011); Kokali et al. (2016)
Red and Blue	Red, 45; Blue, 86; RB, 52 $\mu mol/m^2$ s	Chinese Cabbage (CR Ha Gwang) and Kale	The total polyphenols in 'CR Ha Gwang' were increased by red + blue LED by (3.889), Red (3.817), Blue LED (3.776 µg/mL), and in 'Kale TBC' by RB (3.738), Red (3.772), Blue (3.772)	Lee et al. (2016)
(Blue: 430 nm + Red: 660) (Blue+Red+Far-Red: 730 nm)	173 and 197 $\mu mol\ m^{-2}\ s^{-1}$ for B + R and B + R + FR, respectively	Carrot (*Daucus carota* L.)	Both LEDs treatments (B + R and (B + R + FR) increased the phenolic content (phenolic acids and rutin) by 45 and 65%, respectively compared to darkness.	Martinez et al. (2021)
UVC Radiation	1.0, 3.0, and 12.2 kJ m^{-2} for 1, 3, or 12 h	Light red tomatoes	The lycopene content was found to increased by 14.0%	Hu et al. (2019)

Table 3 LED employed for enhancement of secondary metabolites and biological activity in fruits and vegetables *(Continued)*

LED Light used	Light Intensity	Crops	Secondary metabolites/ biological activity	References
Blue and Red	167 lx for 12 h	Radish Sprouts (*Raphanus sativus*)	Sprouts grown under blue LED light had about 11.0% higher content of phenolic compounds than sprouts grown under red LED light	AbdElgader et al. (2015)

which contributes to its widespread dispersion and distinct pathogenic characteristics. Using 405-nm LED illumination at 4 °C for 150 min, the survival of *L. monocytogenes* was studied after exposure to oxidative stress (0.04% H_2O_2), UV irradiation (253.7-nm), low temperature (4 °C), osmotic pressure (10, 15, or 20% NaCl), SGF (pH 2.5), or bile salts (2%). The pathways responsible for differences in stress tolerance were uncovered by studying the transcriptional responses and membrane integrity of *L. monocytogenes*. It was found that 405-nm LED treatment lowered *L. monocytogenes* resistance to all stresses, suggesting that it might be utilised effectively for prevention of *L. monocytogenes* contamination across the food-processing chain-line, from production to consumption (Kang et al. 2019). Furthermore, the antibacterial impact of blue 460-nm LEDs on *Salmonella* in orange juice was investigated. *Salmonella enterica serovars Gaminara, Montevideo, Newport, Typhimurium*, and *Saintpaul* were injected into pasteurised orange juice and illuminated with 460-nm LEDs at irradiances of 92, 147.7, and 254.7 mW/cm^2 at 4, 12, and 20 °C. With D-values of 1580 and 2013 J/cm^2, the most bactericidal pairings were 92 mW/cm^2 irradiance and temperatures of 12 and 20 °C, respectively. The findings revealed the efficacy of 460-nm LEDs in preserving fruit juices in retail markets and reducing the danger of salmonellosis (Ghate et al. 2016). Depending on the target requirements, LED systems can be programmed to deliver continuous or pulsed treatments. Kim et al. (2017a) used a pulsed LED producing light at 405 nm to test its effect on *S. enteritidis* inoculation on cooked food. Using 4 °C, with a cumulative dose of 3.8 kJ/cm^2 resulted in a 0.8–0.9 log CFU/cm^2 reduction. Table 2 summarizes some of the examined LEDs wavelength ranges against various microorganisms.

Effect of LEDs on synthesis of bioactive compounds

The utilization of LEDs under controlled conditions in agricultural produce could be a most suitable choice for increasing the nutritional profile of various crops (Kozai, 2016). Lee et al. (2008) reported that a combined effect of red and blue light can increase the accumulation of bioactive compounds such as total polyphenols, anthocyanins and flavonoids. Red LEDs has a great impact on anthocyanin as compared to blue LEDs. Phenylalanine ammonia-lyase (PAL) enzyme plays an important role in induction of secondary metabolites by LEDs in plants. Red and blue LEDs stimulate the PAL and thus increase the synthesis of bioactive compounds in plants. Wang et al. (2009) studied that blue and red light helps in the build-up of flavonoids and glycosides. Blue light is also important in activating the metabolic pathway in production of phenolic compounds. They also reported that photosynthetic activity and stomatal opening by inducing photophorylation is promoted by red light.

LEDs are swiftly gaining popularity as a viable tool for growing greenhouse crops and preserving food (Mitchell et al. 2012). Light quality has a considerable influence on the accumulation of numerous bioactives in plants (Bian et al. 2015). Individual single-spectral red or blue LEDs greatly boosted the concentration of primary and secondary plant metabolites (e.g., soluble sugars, starch, vitamin C, soluble protein, and polyphenols) (Kim et al. 2013). Various spectrum of LEDs, including red, blue, green, and even white light, can enhance the accumulation of vitamin C, anthocyanins, total phenols and nutritional content of harvested vegetables (Lee et al. 2014, Kanazawa et al. 2012) as shown in (Table 3). The red LEDs aid in moisture retention in tissues of fruits and vegetables. This can also help to prevent water from evaporating too quickly, boosting its visual quality and market acceptability (Lee et al. 2014, Muneer et al. 2014, Massa et al. 2008). Furthermore, red or blue LEDs delay fruit senescence by reducing ethylene and ascorbic acid production (Ma et al. 2014). The use of single-spectral blue or red LEDs has been shown to boost the quality and productivity of vegetables and fruits (e.g., cucumber, pepper, and strawberry fruits) (Choi et al. 2015, Hao et al. 2012, Li et al. 2016).

Future prospects and conclusions

Very few studies had been reported about the applications of LEDs in spices & condiments, dairy products and medicinal herbs. Future studies and research might be conducted on phytochemical content, antioxidants, and other important nutrients. Different wavelengths of LEDs can be explored to enhance the various bioactive compounds, health promoting components and increased storage life (Hasan et al. 2017).

LEDs are novel technology that may be employed in a wide range of food processing applications, including the disinfection of solid and liquid food items. LEDs have several advantages over traditional light sources, such as the ability to emit a narrow range of light, high purity and effectiveness, compact size, longer shelf-life, and lower power consumption. A combination of different wavelengths of LEDs in variable concentrations during postharvest processing may improve the nutritional content, regulates the ripening rates, reduce the pathogenic microbial load in fresh produce. LEDs also regulates various processes such as photosynthesis and bioactive compounds yields in fruits and vegetables. LEDs technological and operational benefits might be enhanced by merging desirable wavelengths.

Abbreviations

UV: Ultraviolet; LEDs: Light Emitting Diodes; ATCC: American Type Culture Collection; CFU: Colony Forming Units; TSS: Total Soluble Solids

Supplementary Information

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Additional file 1.

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Authors' contributions

AP contributed to all sections and writing of the article. AP also contributed the idea and extracted data and review the literature. SP and Vasundhara contributed to all sections and writing of the article. The author(s) read and approved the final manuscript.

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Availability of data and materials

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Declarations

Ethics approval and consent to participate

Not required.

Consent for publication

All authors agree to publish.

Competing interests

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