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Design of light emitting diode system for postharvest shelf-life enhancement of fresh produce

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ABSTRACT Light emitting diodes (LEDs) is one of the revolutionized modern technologies that has found extensive application in the agrifood industry, particularly for small scale farming. The advantageous properties associated with LEDs, including low heat radiation, high electrical and photonic efficiency, minimal production cost, and high power and narrow bandwidth optical emission, make them an attractive candidate for post-harvest preservation of agrifood products. This study investigates a post-harvest LED system. Optimization in terms of wavelength and physical parameters was performed. The post-harvest LED system was applied to fresh produce and the shelf-life enhancement performance indicators were quantified. The results obtained suggests that the applied system can be used as a promising postharvest preservation technology.

Keywords: Light emitting diodes, postharvest preservation, total phenols, soluble solid content

INTRODUCTION

For every three tons of food produced in the world, there is one ton of food that is wasted in the dynamic food-supply system and this amounts to 1.3 billion tons every year (Gustavsson et al. 2011). This wastage can be attributed to an absence of efficient post-harvest infrastructure (Moustafa 2016), poor harvesting and storage techniques (Kiaya 2014), and issues with marketing facilities (Prusky 2011). As stated by the Food and Agriculture Organization of the United Nations, fruits and vegetables are the most wasted commodity, amounting to 40-50% losses (Gustavsson et al. 2011). In fact, spoilage of fruits and vegetables occurs at every stage of the food chain supply, from farm to table, and this represents a fundamental challenge for food engineers (Gunders 2012). Given this challenge, there is an increasing interest in reducing (or eliminating) spoilage of fruits and vegetables (Ma et al. 2017). This interest is a focus of recent research, given modern trends in consumer behaviour towards increased intake of health-promoting foods like fruits and vegetables (Slavin and Lloyd 2012). In response, various approaches are being developed and utilized. Examples of these developing approaches included increased storage facilities and infrastructure (Muir et al. 2010), strategic modifications to the food chain supply (Parfitt, Barthel, and Macnaughton 2010), optimization of processing technologies (Gustavsson et al. 2011), and the application of light emitting diodes (LEDs) in the food industry (Hasperué et al. 2016).

This application of LEDs in the food industry is a particularly appealing approach to reduce spoilage of fruits and vegetables, as LEDs have many advantageous properties, including low radiant heat emissions, electrical luminosity, strong emission of monochromatic (well-controlled) light (D'Souza et al. 2015), high photon efficiency, and long operational lifespan (Chen et al. 2016). These advantageous properties make the application of LEDs for post-harvest preservation a viable option. Additionally, light plays a major role in affecting phytochemical concentrations, biosynthesizing secondary metabolites (Xu et al. 2014), and driving photosynthesis and ripening processes (D'Souza et al. 2015). Furthermore, the reduced heat generation and the control over light quality of LEDs can enhance nutritional and antioxidant activity (Kim et al. 2011) and LEDs of different colours/wavelengths can initiate a variety of responses in plants (Kasim and Kasim 2017).

The objective of this study was to determine the effect of different coloured LEDs on blueberry post-harvest preservation and evaluate how the shelf-life of fresh produce can be enhanced. The research makes contributions in the development of a postharvest LED system capable of reducing food wastage and ensuring quality of produce for consumers.

MATERIALS AND METHODS

Plant Materials. Blueberries were procured from a local grocery stores and kept under refrigerated condition till further use.

Led System. The postharvest LED system was designed based on the parameters of the duty cycle, optical intensity variation, and conversion efficiency. The LED sources, consisting of 18 individual LEDs of either red (630 nm), yellow (591 nm), green (535 nm), or blue (480 nm) colour, were normalized to the same intensity (27 $\mu W/cm^2$), within an error of 5% using a Thorlabs silicon photodiode (DET36A). Each LED source was located in a single chamber, providing thermal and optical isolation. A separate chamber with no LED source was used as control.

LED Treatment. Fresh blueberry samples were placed in the apparatus in different chambers with the specific LED sources. A voltage source was then engaged and allowed to run for two, four, and six hours (depending on the experiment). The two-hour experiment was repeated three times to ensure that any errors due to time were accounted for.

Shrinkage. The initial diameter of blueberries was measured using a Vernier calliper (Mastercraft 58-6800-4) and then kept in the chamber for treatment time of two, four, and six hours. Final readings were taken to analyse the change in diameter that gave the shrinkage data.

Weight Loss. Before performing the experiment, the initial mass of the blueberries was taken by placing each sample on a weighing balance (Mettler PJ3000). After exposing the samples for two, four, and six hours, the samples were weighed again and the change in weight was recorded.

Colour Measurements. Colour change in LED-treated and untreated samples were analysed using a chroma meter (Konica Minolta CR-400 colorimeter) where, L^*, a^* and b^* values were measured. Measurement was taken on the upper surface of the blueberries after calibration.

Total Soluble Sugars. Blueberries were homogenized to form a liquid to measure total soluble sugars (TSS). The TSS of the LED-treated and untreated samples were measured using a refractometer (Milwaukee MA871).

Total Phenolic content. Total phenolic content (TPC) was determined using a protocol developed by Singh *et al.* (2011). One milliliter of sample was added to 7.5 mL double distilled water, 0.5 mL Folin-Ciocalteau reagent, followed by 1 mL of 5% Sodium Bicarbonate solution. The mixture was incubated at room temperature (23°C) for 90 minutes. Absorbance was then measured at 765 nm using a spectrophotometer (Ultraspec 2100 pro). A standard curve was plotted using different concentrations of Gallic acid to estimate TPC.

Statistical Analysis. The estimation of weight loss, colour, TSS, total phenolic and shrinkage was done in triplicates for each treatment time of two, four, and six hours. The average values, standard deviations, and standard error were calculated using Microsoft Excel.

RESULTS AND DISCUSSION

Effect on Weight. Blueberries were subjected to different colours in the LED system and compared with the control sample. It was observed that there was no significant change in the weight of the blueberries, suggesting that LED treatment can be used for fresh fruits and vegetables with minimal to no effect on weight (resulting in preservation of wholesomeness).

Effect on Shrinkage. Blueberry samples were analysed for shrinkage and it was observed that there was no significant change in the diameter with respect to LED light colours and treatment time, as illustrated in Figure 1.

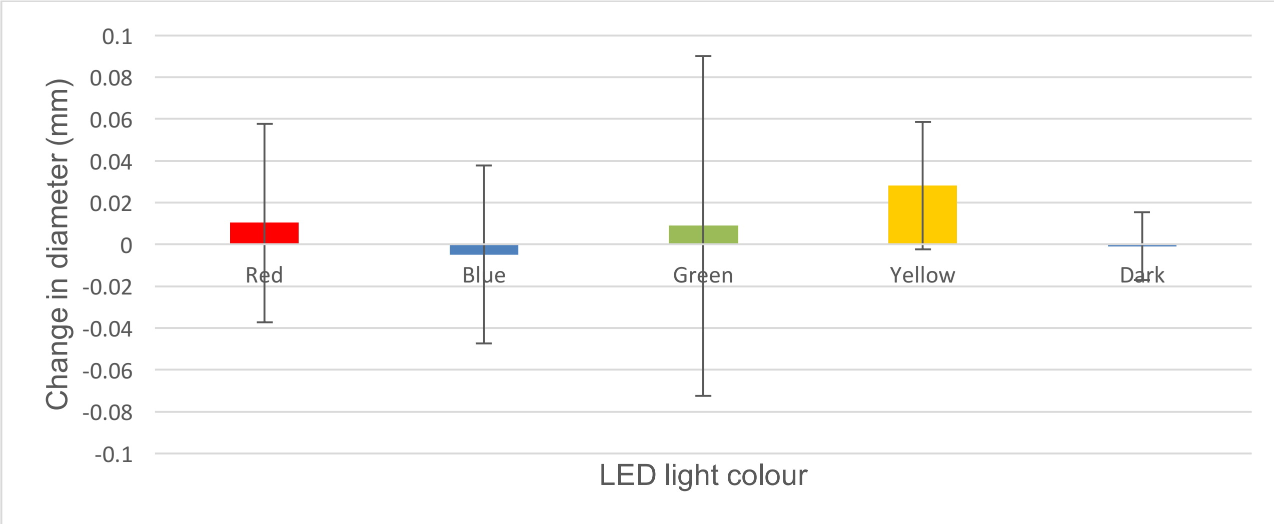

Figure 1 Effect of LED treatment on shrinkage rate for blueberries for various LED light colours.

Effect on Colour. Figure 2 presents the effect of different colors (red, blue, green and yellow) LED lights on the *L** values of blueberry. It was observed that the lowest and highest *L** values for blueberry samples were obtained for yellow light for two and four hours treatment, respectively. In 2017 Kasim and Kasim suggested that lower *L** values under a given light indicates that they delay the biochemical process that leads to increase in the lightness of fresh produce. When the *L** values for light treatments are compared with that of the initial, it can be observed that treatment time (i.e., duty cycle) and specific light both had significant effect. Further intensive studies are required to understand the relation between different light wavelengths and the biochemical processes taking place inside the fresh produce.

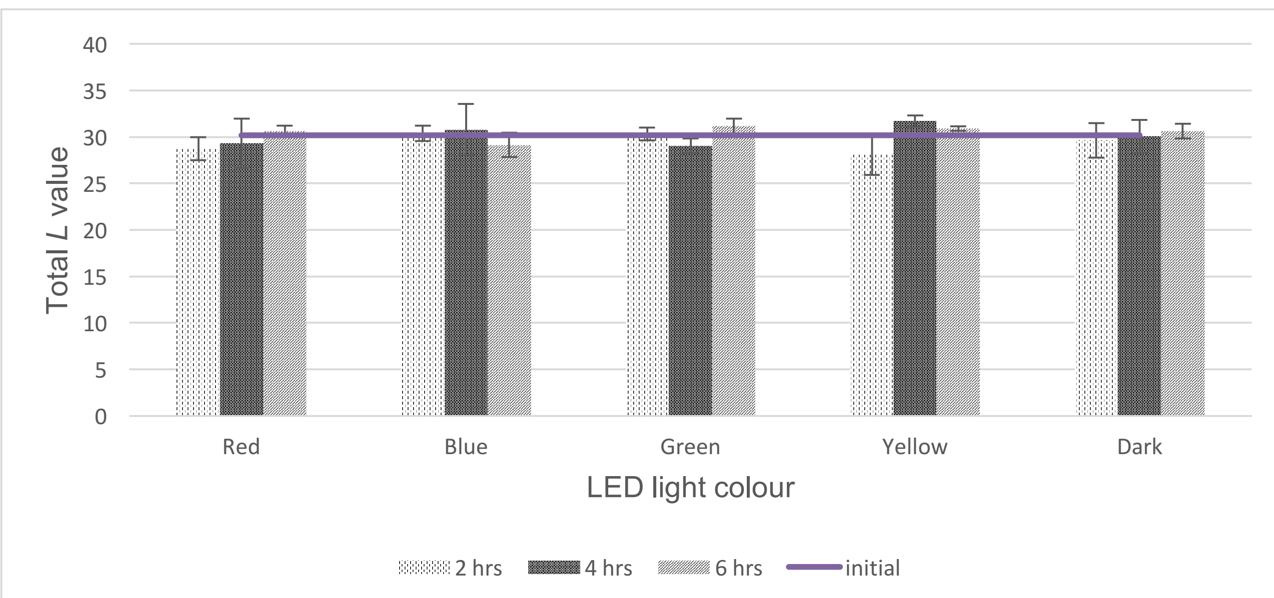

Figure 2 Effect of the LED treatment on *L* value for blueberries for various LED light colours.

Effect on Total Soluble Sugars (TSS). In 2015, Bian et al. (2015) suggested that light significantly affects the biosynthesis and accumulation of phytochemicals, soluble sugars, and proteins in vegetables produced in controlled environment. In this study, similar observations were made. A minor increase in TSS was observed for red, blue, green, and control samples between two and four hour treatment (Figure 3). The TSS for all treatments were not significantly different from the initial value suggesting that LED treatment does not enhance the ripening process making it appropriate for shelf-life extension of fresh produce.

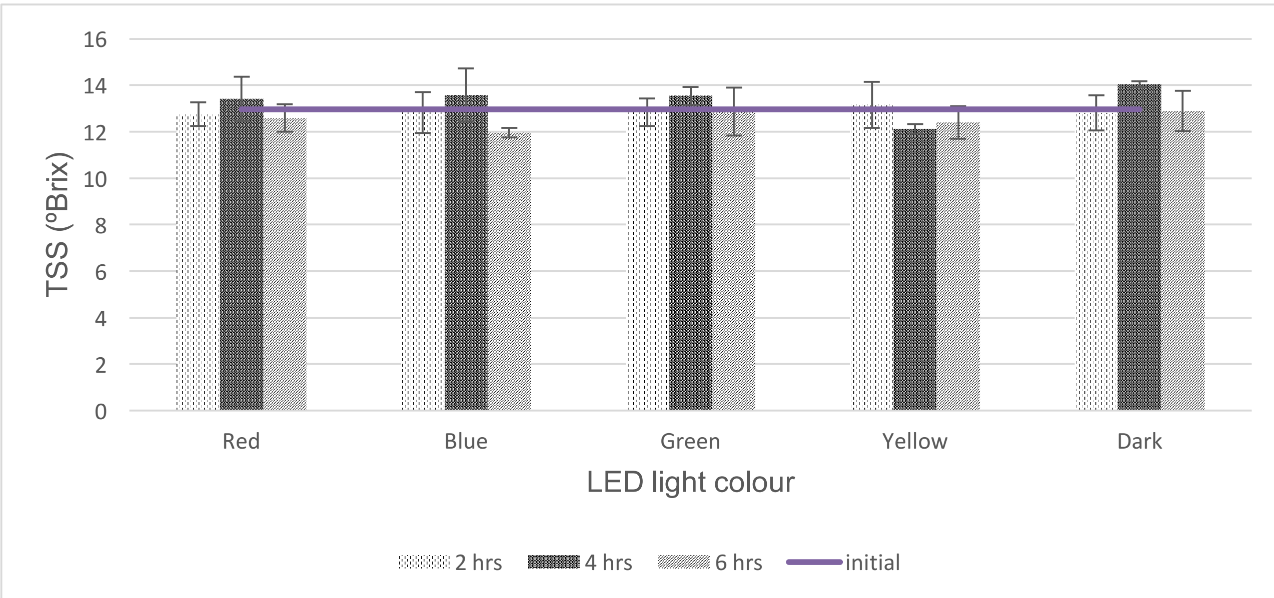

Figure 3 Effect of LED treatment on the total soluble sugars content for blueberries for various LED colours.

Effect on Total Phenolic Content (TPC). Figure 4 presents the observed variation in TPC in blueberries with respect to different LED lights exposure. For blue LED light a decrease in TPC was observed with an increase in treatment time. Whereas, exposure to red LED light led to an increase in TPC with an increase in treatment time. For yellow LED light no significant variation in the TPC content was observed as compare to the initial value. The varied observation for LED light effect on TPC requires further intensive investigation.

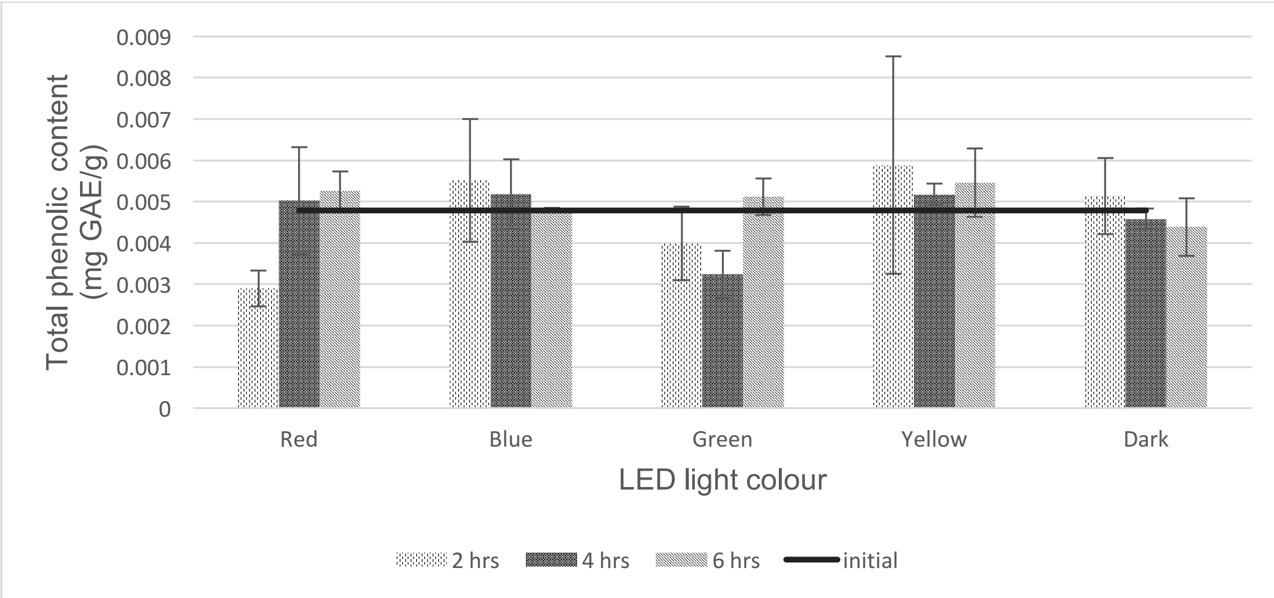

Figure 4 Effect of LED treatment on TPC for blueberries for various LED light colours.

CONCLUSION

The effect of different LED light colours (red, yellow, green, and blue) on blueberries was studied. Parameters including weight loss, shrinkage, colour, TSS, and TPC were analysed after the LED treatment of blueberries for two, four, and six hour durations. It was found that there was no significant change in the weight loss and shrinkage. However, there was an observable difference on colour, soluble sugars, and total phenols.

The impact of LEDs on fresh produce is quite significant that can prove to be a novel approach in food production and postharvest preservation to increase shelf-life and reduce food waste. Future research work includes the design and development of a postharvest LED system and further optimization of its parameters (wavelength, optical intensity, etc.). Implementation of this postharvest LED system should include characterising the effect of light on antioxidant activity, anthocyanin content, and microbial load of fresh produce (fruits and vegetables in particular). By process optimization and scaling up this technology to commercial scale, postharvest systems at a food retail and distribution level can be greatly improved.

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