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Impact of Photo-treatment on Tomato Physiological Qualities during Storage and On-shelf Display

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ABSTRACT

Tomato's short shelf life and economic significance resulted in its classification as a model for studying the physiological behavior of fruits and vegetables. This study employs light treatment to investigate the effect of various light spectrums on tomatoes' physiological qualities. Four light treatments, white LED, 5R:1B LED, 5B:1R LED , and the control (without light treatment) were placed under a storage condition with a temperature of 5ºC and relative humidity of 88% for 5 days and an on-shelf display condition of 22ºC and relative humidity of 78%. Response variables were colour changes, firmness, total soluble solids, and pH. It was observed that 5R:1B LED significantly increase red colour development in tomatoes during storage and on-shelf display condition, promoting lycopene accumulation, while 5B:1R LED delays red colour accumulation during storage but rather prolong pale-yellow colour development during shelf display condition, promoting ζ- carotene and xanthophyll accumulation. Tomatoes treated with 5B:1R and white LED enhance tomato firmness more than the control samples during storage and on-shelf display. 5B:1R LED reduces the pH of tomatoes significantly, making them more acidic and resistance to microbes, while 5R:1B enhances the sugar accumulation of tomatoes. This makes photo-treatment a sustainable technique for tomato physiological quality preservation and senescence postponement.

Keywords: Light-Emitting Diodes, Postharvest Stage, Quality Attributes, Tomatoes.

1. INTRODUCTION

Tomato (*Solanum lycopersicum L.),* is the most consumed and cultivated vegetable in the world with an annual production rate of 180 million tons in 2019 [1]. This is largely due to its rich health-beneficial compounds, which help promote human health and boost the immune system against some cardiovascular diseases [2]. It is considered a model for studying the behavior of fruits and vegetables because it is characterized by a well-defined genome and a rich collection of genetic resources, well-defined developmental stages, its short life span, and an enriched nutritional composition of which response to environmental and genetic manipulation offers an insight to other fruits and vegetables, which serve as a template for studying the development of other fruits and vegetables, [3, 4]. Due to the high amount of moisture (about 94%), its shelf life after harvest is very short [5]. Since physiological and biochemical changes still occur in fruit and vegetables after harvest, supplying these commodities with environmental factors that contribute to their development and growth before harvest can help reduce the rate of deterioration, hence extending their shelf life [6].

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Losses incurred after harvesting of tomatoes are reported to be in the range of 25 to 50% [5], whereas the USDA economic research quantifies the losses incurred by tomato retailers to be in the range of 15-25%, which constitutes a great economic loss [7]. Hence, there is a need for more studies to reduce the percentage of loss to the barest minimum while ensuring the quality and the health-promoting compounds are properly harnessed.

Photosynthetic active radiation (PAR) is a range of light wavelengths that can drive photosynthesis in plants, majorly wavelengths of light that are primarily absorbed by chlorophyll which is the pigment that captures light energy in plants [8]. Its wavelength spans from approximately 400 to 700 nm, which is the same as that of the visible light spectrum; within this range, chlorophyll in plant tissue efficiently absorbs and utilizes certain wavelengths for photosynthesis [9]. This energy derived from PAR is mostly utilized in the synthesis of carbohydrates and other organic compounds necessary for plant growth and development. PAR has been efficiently utilized during the growth and development of plants, but its application at the postharvest stage is actively explored. Nassarawa et al. (2021)[10] opined that photo-treatment within the PAR range can help preserve fruit's physiological characteristics and postpone the senescence of fruits and vegetables at the postharvest phase.

Pigment changes in tomatoes are a result of the increase in the accumulation of carotenoids. Llorente et al. (2016) [11] add that tomato perceives light mainly through the cryptochrome and the phytochrome photoreceptors. While the phytochrome receptor controls the changes in pigment in tomatoes, the cryptochromes receptor assists in forming and sustaining the chlorophyll pigment (Figure 1).

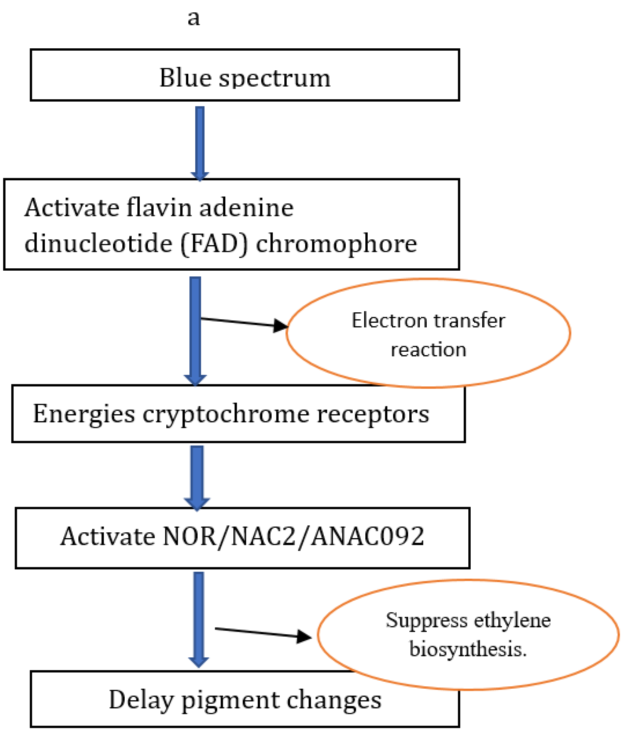

Figure 1: Flow diagrams of the influence of PAR on tomato pigment. When blue light is illuminated on tomatoes, it will activate flavin adenine dinucleotide chromophore, a special protein hich causes electron reaction resulting I n the energizing the cryptocheome receptor to activate the transcriptional factor (NOR/NAC2/ANAC092) to suppress ethylene biosynthesis, resulting in the delay of ripening (Fig. 1a), whereas when red light is illuminated (Fig 1b), the SIHY5 transcriptional factor will be activated which will empower the phytochrome receptor to produce more carotenoid, hence accelerating pigment changes.

2. METHODOLOGY

2.1 Material collection

Tomatoes were obtained at the green maturity stage from tomato growers and subjected to three light treatment conditions: white, 5R:1B, and 5B:1R LED, with darkness serving as the control, which has no light treatment. The LED light (SMD 2835, China) was arranged in in layers with two lights fixed to each tier and having a wavelength of 450 to 700nm. The samples were screened, and those free from any physical and mechanical damage were sorted to ensure uniformity in colour and size before subjecting them to the treatments.

2.2 Storage condition

A cold room with a temperature of 5 oC and relative humidity of 88% was adopted from [12] and used as the control environment chamber where the light treatments were administered to the samples under storage conditions for 5 days. The intensities of the light were measured, and there was no significant difference across the areas where the tomato samples were kept, ensuring even distribution. The samples were positioned 20cm away from the light source. To mimic the real condition on-shelf display environment, temperature and relative humidity from several retail shops were measured, the average value for temperature is 22 oC, and the average humidity is 78%. After 5 days of treatment, the samples were transferred to this environmental condition with lighting from fluorescence bulbs, and they were carefully observed until they reached stage 5 of maturity (light red stage) according to USDA standards.

2.3 Colour determination

Tomatoes were categorized at harvest based on the USDA standards colour requirements (six stages). L*, a*, and b* values which represent the brightness, transition from green to red, and yellow colour respectively were measured with a precision colorimeter (3nh NR-145 China) with an 8-mm aperture) and each record was an average of three measurements on every tomato fruit (one at the distal area and two in the equatorial zone). The Colorimeter was calibrated against a standard white tile (L*= 96.82; a*= -0.02; b*= 2.04), according to the method of Thole et al. (2020) [13].

2.4 Determination of total soluble solids

Measurement of the soluble solids of tomatoes was done before and after treatment and at stage 5 of maturity using the pocket brix-acidity meter (tomato) master kit (Atago PAL-BX/A3590. Tokyo, Japan). 10ml juice of the tomato samples was extracted and placed on the lens of the brix meter, and the meter was adjusted to display the brix value on the screen of the meter.

2.5 Determination of firmness

Firmness is the resistance or hardness of the fruit when pressure is applied to it. It is an essential quality characteristic that detects consumer preferences, shelf life, and postharvest handling. Measurement of firmness was carried out with an analog penetrometer (Tianpeng GY-1 12228, China) with a capacity of 15kg/cm^2 and a head diameter of 3.5mm. The head diameter was driven into the fruits by applying light pressure, which displayed the firmness of the fruit in the meter of the penetrometer scale.

2.6 Determination of potential of hydrogen (pH)

Each tomato sample was blended and poured into a beaker for measurement of pH. The pH meter (Atago, DPH-2, Japan) was calibrated, and measurements were done according to the description of De-Oliveira et al. (2020) [14].

2.7 Experimental design

A design of experiment with replicates was employed in designing the experiment, which comprises four treatments; darkness, which serves as the control, white, 5B:1R, and (5R:1B LED. Each treatment consists of 3 experimental units, with each unit consisting of four tomato samples. Each treatment has 12 samples of tomatoes. Samples were exposed to 16 hours of lighting for 5 days. Data are collected on four different response variables: total soluble solids, firmness, pH, and colour. These variables are measured to assess the effects of the different PAR light treatments on the tomatoes. Data are collected at three stages: before treatment, after 5 days of treatment in the cold room at 5ºC, and at maturity index 5 (light red stage) at a temperature of 22°C. Samples were randomly assigned to treatments without any specific restrictions, and each experiment was replicated three times. R programming software (4.2.2) was used in analyzing the data and the Shapiro- Wilks test was used in ascertaining whether the data requires parametric or non-parametric analysis and a one-way ANOVA was used in the analysis. Duncan multiple range tests were used in carrying out the post hoc analysis to determine which of the light treatments has a significant effect on the physiological qualities of tomatoes.

3. RESULTS AND DISCUSSION

3.1 Effect of photo-treatment on tomato colour changes.

Table 1 shows the effect of different treatments on the L* values of tomato samples. The L* value represents the brightness in the colour of the samples. The higher the value, the brighter the colour of the samples. Table 1 shows that the brightness reduces as the tomatoes ripen. The trend shows that tomatoes exposed to white LED had the lowest brightness after treatment and at stage 5 of the maturity index, while tomato samples treated with blue and red LED had the highest. Saad et al. (2016) [15] attributed the reduction in the brightness of the colour to an increase in carotenoid accumulation and a rise in chlorophyll degradation. With this assertion, white LED significantly enhances carotenoid accumulation as the L* values were found to be lower than the control samples. The ANOVA shows that the observed means are statistically significant for red and blue LEDs after treatment and during shelf display.

Table 1: L* value of tomato treated with PAR light.

Data collection period	Control	White LED	Red/blue (5:1) LED	Blue/red (5:1) LED
Before treatment	55.6^{a}	55.5^{a}	55.7^{a}	55.6^{a}
After treatment	49.9^{a}	47.73^{a}	52.83^{b}	54.06^{b}
Shelf display	46.2^{a}	41.89^{a}	50.32^{b}	49.33^{b}

The a* values indicate the transition from green to red pigment, which represents the rate of chlorophyll degradation in tomato samples [16]. From Table 2, it could be seen that after treatment, the 5R:1B LED had the highest a* value, followed by the blue/red 5B:1R LED before the control and the white LED, but as the tomatoes ripened to stage 5 at on-shelf display treated environmental condition, a* values were higher in the white and red/blue 5R:1B LED, exceeding that of 5B:1R LED and the control samples. This reveals that treating tomatoes with white LED during storage can inhibit red colour development while 5R:1B LED accelerates red colour development, whereas at on-shelf display conditions (22°C), white and 5R:1B LED increase red colour development while 5B:1R LED delays red colour development in tomatoes. This implies that 5R:1B and 5B:1R LED was unable to inhibit ethylene production when compared to the control samples during storage as the rate of red colour development in both treatments were higher than the control, whereas during shelf display condition 5B:1R LED was more effective in inhibiting ethylene biosynthesis proving the theoretical framework provided in Figure 1b, while white and 5R:1B LED had more red pigment accumulation.

Table 2: a* value of tomato treated with PAR light.

Data collection period	Control	White LED	Red/blue (5:1) LED	Blue/red (5:1) LED
Before treatment	-2.53^{a}	-2.52^{a}	-2.51^{a}	-2.5^{a}
After treatment	1.49^{a}	1.68^{a}	3.39^{a}	2.68^{a}
Shelf display	15.69^{a}	21.92^{a}	19.46^{a}	11.52^{b}

The development of yellow pigment in tomatoes is a function of the b* values in the CILAB space colour lab. Saad et al. (2016) [15] added that increases in b* values are seen within the first three stages of tomato maturity, and at later stages, the b* values decrease. This is attributed to ζ-carotenes (pale-yellow colour) and xanthophyll (yellow colour) reaching their highest concentration before lycopene, which causes red colour development to begin to dominate [17]. Table 3 shows a reduction in yellow pigment accumulation during treatments with different spectra of light during storage as no significant difference was observed but at on-shelf display condition, a high increase was observed with 5B:1R LED followed by 5R:1B LED while white LED recorded a value lower than the control samples. This shows that 5B:1R LED promotes the accumulation of β and ζ-carotenes and xanthophylls, some types of carotenoids that are responsible for pale-yellow colour development, hence increasing the carotenoid accumulation in tomatoes. A significant difference was observed in the means of the different photo treatments after treatment and during shelf display.

Table 3: b* of tomato treated with PAR light.

Data collection period	Control	White LED	Red/red (5:1) LED	Blue/red (5:1) LED
Before treatment	28.035^{a}	28.039^{a}	28.00^{a}	28.04^{a}
After treatment	20.33^{a}	22.54^{a}	28.08^{b}	26.34^{b}
on-shelf display	29.97^{a}	28.67^{a}	35.54^{b}	51.94^{c}

3.2 Effect of photo-treatment on the firmness of tomatoes

Firmness is one of the most essential parameters in tomato quality because it controls tomatoes' maturity and ripeness level, acceptability, and market value [18]. After treatments, the rate of loss of firmness with red/blue light was equivalent to the control samples, whereas white and blue/red LED samples maintained a higher firmness (Table 4). Batu, (2004) [19] pointed out that at a firmness score of 12.2 kg/cm^{-1}, tomatoes can still be sold at retail shops since they can be sliced easily; this shows that 5B:1R LED-treated samples during shelf display satisfy this requirement as a firmness score of 12.79kg/cm^{-1} was obtained. Standard error reveals that 5B:1R and white LEDs have higher precision and lower variability, while the control and 5R:1B LEDs reflect high variability and less precision. A significant difference was observed with group means after treatment and at shelf display condition, which indicates that photo-treatment has an impact on the firmness of tomatoes at this stage. Analysis of variance confirms the significant effect on the firmness of tomatoes.

Table 4: Impact of photo-treatment on the firmness of tomatoes.

Data collection period	Control	White LED	Red/blue (5:1) LED	Blue/red (5:1) LED
Before storage	13.43^{a}	13.56^{a}	14.07^{a}	14.00^{a}
After storage	10.50^{a}	13.00^{b}	10.60^{a}	13.30^{b}
shelf display	8.80^{a}	11.80^{b}	8.50^{a}	12.79^{b}

3.3 Effect of photo-treatment on the pH of tomatoes

pH is an important measurement in tomatoes. It determines the acidity and alkalinity of tomatoes, important information that is helpful in quality assessment, knowing the ability of tomatoes to resist microbial infestation, and estimation of shelf life [20]. Table 5 shows the pH of tomatoes during the experiment. It reveals that tomatoes' pH decreases as ripening progresses. Anthon et al. (2011) [21] submit that a rise in pH as ripening progresses is a bad indicator of shelf life as it reflects a decline in acidity, which weakens the strength of tomatoes to resist microbial infestation. Tomatoes samples treated with 5B:1R LED had the highest percentage reduction in pH values (47.5 and 44.5%), indicating its ability to extend the shelf life of tomatoes, resist microbial attack, and produce excellent quality characteristics in tomatoes more than other treatment conditions.

Table 5: Effect of photo-treatment on pH of tomatoes.

Data collection period	Dark	White LED	Red/blue (5:1) LED	Blue/red (5:1) LED
Before treatment	5.1^{a}	5.00^{a}	5.30^{a}	5.35^{a}
After treatment	3.67^{a}	3.90^{a}	4.27^{a}	4.17^{a}
shelf display	3.05^{a}	3.17^{a}	2.95^{a}	2.81^{a}

3.4 Effect of photo treatments on total soluble solid of tomatoes

Total soluble solid (TSS) measures the sugar content in tomatoes and is one of the sensory quality characteristics since it determines the sweetness of tomatoes [22]. Table 6 shows the brix value under different treatment conditions. The TSS increases as ripening progresses across the three different storage periods; samples with 5B:1R and white LED treatments accumulated a lesser amount of TSS than the control experiment, indicating the influence of light in inhibiting ethylene activities and delaying ripening and senescence. Whereas samples exposed to 5R:1B LED recorded the highest value of TSS. However, no significant differences were observed across the various treatment conditions.

Table 6: Brix value of tomatoes under photo-treatment.

Data collection period	Control	White LED	Red/blue (5:1) LED	Blue/red (5:1) LED
Before treatment	0.94^{a}	0.97^{a}	0.78^{a}	0.86^{a}
After treatment	2.50^{a}	2.37a	2.57^{a}	2.26^{a}
shelf display	3.97^{a}	3.84^{a}	4.06^{a}	3.83^{a}

4. CONCLUSION

Photo-treatment of tomatoes with different spectrums of light has established its importance in the postharvest management of fruits. This study reveals that 5R:1B LED hastens the ripening of tomatoes during storage and on-shelf display, which is represented by the red colour on the pericarp of the tomatoes, whereas 5B:1R LED delays the development of red colour in tomatoes rather, it facilitates the increase of ζ and β-carotenes which are types of carotenoids responsible for yellow and pale-yellow colours in tomatoes. Tomatoes samples treated with 5B:1R LED enhance firmness. 5B:1R LED significantly reduces the pH values, making tomatoes more acidic, while 5R:1B LED increases the total soluble solids. This study proves the efficiency of photo-treatment in tomatoes after harvest as it influences their physiological qualities, resulting in shelf-life extension and improved bioactive compounds.

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