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Pigment composition and physico-chemical parameters of Bittergourd (*Momordica charantia* L. cv. Jadeite) during postharvest period as influenced by illumination colors

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Abstract: Fruits and vegetables that exhibit a higher chlorophyll content, as reflected in their visual appearance, are the preferred choice of consumers. The study aimed to evaluate the effects of Light Emitting Diodes (LEDs) on the physical, chemical, and pigmentation quality of bitter gourd using white, blue, and red at 1.5 W/135 lumens (Foshan Electrical and Lighting Co., Ltd [FSL], China). Bitter gourd, with a short postharvest life of 4-5 days due to physical and chemical disorders, was harvested weighing 300–400 g and 25 x 5 cm from the farm and subjected to varying illuminations within a 4-hour period for five days, with measurements taken daily. Statistical differences between treatments were observed in physicochemical parameters such as fruit shrivelling, yellowing, visual appearance, weight loss, dry matter content, total chlorophyll, pH values, and TA. The quality and shelf-life of bitter gourd fruits were found to be improved by the white LED. The visual appearance was maintained, and fruit shrivelling and yellowing were delayed, with lower weight loss observed. Slight changes in chlorophylls and carotenoids, vitamin C, and a shelf-life of 5 days were recorded.

1. Introduction

Momordica charantia L. is known as bitter gourd, with its good nutritional and medicinal properties, is grown in approximately 340,000 ha (Dhillon *et al.*, 2016) annually in tropical Asia, including Eastern Asia, India, and China, which is its center of origin (Behera *et al.*, 2010;

Prajapati *et al*., 2021 a). The production volume in the Philippines has increased by 1.8% to 32.05 thousand metric tons (PSA, 2022). Its primary demand arises from its anti-diabetic properties (Rosario and Macusi, 2009). The presence of phenols, terpenes, and flavonoids in bitter gourd contributes to its bitter taste and antioxidant properties (Dutta *et al*., 2021), which are desired by consumers (Behera *et al.*, 2010; Taiti *et al*., 2017) and can help prolong its shelf-life (Salas *et al*., 2015). The metabolites found in bitter gourd are affected by cultivars and cultural practices such as Light, temperature, soil, and nutrition (Valyaie *et al*., 2021). The importance of Light in postharvest produce cannot be overstated, as plants perceive stimulus for growth and development through light. Recent studies have discovered that even after plants are harvested, their light-dependent processes continue. To ensure the longevity of postharvest fruits and vegetables and maintain their metabolite levels, various treatments - both chemical and non-chemical - can be applied. For example, bittergourd fruits can be stored for up to five days under ambient conditions without ripening, yellowing, or losing their bitterness (Salas *et al.*, 2015; Prajapati *et al*., 2021 a). As a means of preserving postharvest produce, researchers have begun exploring the use of Light Emitting Diodes (LEDs). In fact, supplemental lighting from LEDs has been shown to enhance the market value of harvested sweet peppers by inducing colour break (Jones, 2018).

Researchers have therefore explored the use of Light Emitting Diodes (LEDs) to prolong shelf-life and maintain metabolites in various crops (Ma *et al*., 2014; D'Souza *et al*., 2015; Bantis *et al*., 2018; Loi *et al.*, 2020; Poonia *et al*., 2022). The findings of these studies have been corroborated by the upregulation of vitamin C, antioxidants, anthocyanins, and the physical appearance of fresh produce towards market acceptability. For example, white LED lighting facilitates the accumulation of phenols in harvested vegetables (Poonia *et al*., 2022), which are known to have antioxidant and anti-inflammatory properties and may enhance the health benefits of these crops. It was observed that the LEDs had a drying effect, leading to a rapid increase in transpiration, as reported by Chua *et al*. (2021). Various studies have shown that different types of light can have varying effects on different types of vegetables. For example, white and blue LEDs can modulate the stomata opening and number of stomates (Zhan *et al*., 2013), resulting in weight loss of certain vegetables such as *Brassica oleracea* L. var. *italica* Plenck (Favre *et al*., 2018), *Brassica oleracea* var. chinensis Lei (Zhou *et al*., 2020), and freshly-cut leaves of *Amaranthus dubius* L. (Jin *et al*., 2021). On the other hand, dark-stored celery has a lower dry matter content compared to fresh-cut celery due to lower total soluble solids, ascorbic acid, and chlorophylls (Zhan *et al*., 2013; Florkowski *et al*., 2014). In another study, freshly sliced cherry tomatoes exposed to white, blue, and green LEDs showed a transitory increase in vitamin C one day after slicing, while those exposed to red light remained stable (Kong *et al*., 2020).

It is worth noting that the effect of LED lighting on postharvest crops varies depending on the type of crop, LED intensity, and duration of exposure. For example, in previous studies, broccoli exposed to 9.5 and 19.0 W m^{-2} white LED illumination for three hours per day showed delayed chlorophyll degradation and lower weight loss (Pintos *et al*., 2020). Okra fruits treated with white and blue LEDs (17.28 W m^{-2}) for 8 h showed an increased total phenolics content (Thilini Deepashika Perera *et al*., 2022), while berry grape treated with 41 and 42 W m^{-2} of LED showed an increased anthocyanin content at 24 h, and blue LED decreased fungal infections in citrus fruits at a fluence rate of 120 W m^{-2} and 700 W m^{-2} for 18 h under 25°C (Nassarawa *et al*., 2020). In addition, bitter gourd exposed to UV-C LED for 40 min at 10°C and 85-95% RH had a prolonged shelf-life of up to 16 d (Prajapati *et al*., 2021 b). While chemical-based treatments have been the focus of many researchers to improve the postharvest life of vegetables, there is a growing interest in using LED treatments to increase shelf-life and enhance metabolites. It is hypothesized that varying illuminations of white, blue, and red LED with 1.5 Wattage (W) can delay pigmental degradation, preserve organic compounds, and extend shelf-life in harvested bitter gourd. This study tried to assess how the quality of bitter gourd change during post-harvest by applying varying illuminations color LED (white, blue, and red) with 1.5 Wattage (W).

2. Materials and Methods

Fruit samples and sample preparation

The cultural practices and harvesting process of sixty bitter gourds from a commercial vegetable farm in Barangay Buenavista, Baybay City, Leyte (lat. 10° 39’ 34.0” N, long. 124° 50’ 27.6” E) are described in this study. Organic and inorganic fertilizers were applied, including chicken dung through the basal method and soil drenching for urea and complete fertilizers during the vegetative and reproductive stages. The fruits, weighing 300-400 g and measuring 25 x 5 cm, were harvested at the dark green stage and were carried out carefully to minimize mechanical injuries. Fruits with defects were excluded from the study. The farmer-harvester, an expert in harvesting, chose the fruits for marketing based on the local market standard from the City mentioned above. The fruits were then transported from the farm to the Department of Horticulture Crop Physiology Laboratory for postharvest assessment from October 28 to November 03, 2022. The shelf-life of the fruits was 5 days (d), and the treatment application was done after 24 hours (h) to acclimatize and equilibrate the fruits at ambient conditions. The amount and time of fertilizer application were not included in the present study, as it was based on the farmer’s feedback during the harvest since the study utilized fruits from the farm instead of from the wet market.

Treatment preparation

The cardboard boxes with aluminum foil were arranged on the surface and equipped with 1.5 W/135 lumens (Foshan Electrical and Lighting Co., Ltd [FSL], China) LED lights, measuring 56 [L] x 45 [W] x 24 [H] cm. The LED source was positioned at a distance of 19 cm from the fruits. In the current study, each treatment was subjected to white, blue, and red LEDs for a duration of 4 h, with five (5) fruit samples per treatment. After incubation, the lights inside each cardboard box were switched off. However, the irradiated fruit samples were transferred and placed in plastic trays (40 × 30 cm) under ambient conditions (26-28°C). Each tray represented a replicate exposed to lights that remained switched on continuously for 8 h daily, including non-incubated fruit samples for storage and postharvest evaluation. Enhanced and stable metabolites were demonstrated during storage, resulting in a prolonged shelf-life from exposure to UV-C LED for 40 minutes (min), blue and red LEDs for 24 h, white and blue light for 8 h, and white LED for 3 h daily, as shown in previous studies (Nassarawa *et al*., 2020; Pintos *et al*., 2020; Prajapati *et al*., 2021 b; Thilini Deepashika Perera *et al*., 2022).

Experimental design

In a completely randomized design (CRD), the study had five samples per treatment replicated three times. The treatments were designated as follows:

T1 - Control (Room light condition),
T2 - Incubated 4 h with white LED at 1.5 Watt/135 lumen (FSL, China),
T3 - Incubated 4 h with blue LED at 1.5 Watt/135 lumen (FSL, China),
T4 - Incubated 4 h with red LED at 1.5 Watt/135 lumen (FSL, China).

Data collection

Physico-chemical parameters. The fruits were assessed before and after gathering using a digital weighing scale (General Master, Japan), with the parameters being determined for each fruit from the five samples in replication manually every day for six days using different indices.

The cumulative weight loss from the five samples from each replication was determined by weighing the initial weight and daily as known storage period (Prajapati *et al*., 2021 b).

The fruit shrivelling index was assessed with slight modifications (Benitez *et al*., 2015; Lualhati and Del Carmen, 2018) using a 4-point scale ranging from 1 to 4 (where 1 indicated no shrivelling, 2 indicated slight shrivelling (1-25% fruit surface affected), 3 indicated moderate shrivelling (26-50% fruit surface affected), and 4 indicated severe shrivelling (more than 50% fruit surface affected).

The visual quality rating (VQR) of Bitter gourd was evaluated daily as reported by Valida *et al*. (2018). In brief, VQR was assessed using a 9-point scale, where 9 indicated excellent, field fresh or no defects, 7 indicated good, defects minor, 5 indicated fair, defects moderate, limit of marketability, 3 indicated poor, defects serious, limit of edibility, and 1 indicated non-edible under usual condition.

The degree of yellowing was rated manually daily as reported by Valida *et al.* (2018) using a 5-point scale, where 1 indicated full green, 2 indicated 1-10% surface yellowing, 3 indicated 11-30% surface yellowing, 4 indicated 31-50% surface yellowing, and 5 indicated extensive yellowing/discoloration.

The dry matter content (%) was determined by subjecting the samples (50 g) to oven drying at 70°C for 24 h until they reached a constant weight. The remaining weight of the samples after drying served as input to calculate the percent dry matter content as a percentage of the wet sample (Gonzales and Benitez, 2019).

The pigment composition (mg g^{-1}) was determined by soaking a gram of each representative bitter gourd fruit in 10 ml of 95% ethanol overnight. The absorbance of the filtrates at wavelengths of 666, 653, and 470 nm was measured using an ultraviolet-visible spectrophotometer at the VSU-CASL (Salas *et al*., 2020).

The shelf life was determined when sample fruits reached a VQR of 5, which is fair with moderate defects and limited marketability (Salas *et al*., 2015; Valida *et al*., 2018).

Chemical Parameters. For the examination of chemical parameters, one fruit from each replication was randomly selected as a representative. The protocol appears to have been based on the report of Gonzales and Benitez (2019) and Salas *et al*. (2020).

The fresh-cut samples were homogenized in 10 g per 50 ml distilled water for 10 min using a homemade blender (CAMEL®), and the filtrates were measured for potential hydrogen (pH), electrical conductivity (EC) and total dissolved solids (TDS) using a smart combined meter (Milwaukee, MW 802)

Total soluble solid (°Brix) was measured using a hand-held refractometer (Atago N1, Japan) by placing 1-3 drops of juice on the instrument prism and taking the reading.

Titrable acidity (%) was determined by adding 5 ml extract with two drops of 1% phenolphthalein indicator into a volumetric flask containing 4 g NaOH diluted with 1 L distilled water, followed by titration with 0.1% NaOH until a faint pink colour was obtained.

Finally, for Vitamin C analysis (mg 100 g fresh fruit^{-1}), fresh cut (12 g) was subjected to 5 min with 120 ml distilled water in a blender until supernatant filtered. An aliquot (1 ml) extract was mixed in a 125 ml Erlenmeyer flask containing 50 ml distilled water and three drops of starch solution as an indicator. Iodometric titration and volumetric techniques were employed for the analysis.

Statistical analysis

After the analysis of variance (ANOVA) was conducted, the treatment mean was compared and separated by the Honest Significant Difference (HSD) using the Statistical Tool for Agricultural Research (STAR) program, which had been developed by the International Rice Research Institute (IRRI).

3. Results and Discussion

Fruit shriveling

Table 1 shows a gradually increasing index of bitter gourd fruit shriveling. At 3 days (d), delayed shriveling for those fruits with white and blue light treatments. Consequently, shriveling was slight to moderate until 6 d of storage. Endalew (2020) states that shriveled fruit reduces consumer acceptability and marketability. During the transport, the cushioning materials such as newspaper, foam nets, leaves, and other local materials then packed in cardboard boxes or plastic trays could help prevent fruits from bruising and touching, which leads to morpho-physiological disorder and increased entropy (Ahmad and Siddiqui, 2015; Valida *et al*., 2018; Hussein *et al*., 2020).

Table 1 - Fruit shrivelling of bittergourd as influenced by illumination colors during storage

Treatments	Fruit shrivelling				
	2 d	3 d	4 d	5 d	6 d
Control (No LEDs)	1.00±0.00 NS	1.06±0.12 ab	1.78±0.57 NS	2.42±0.24 NS	2.72±0.05 NS
White LEDs	1.00±0.00 NS	1.00±0.00 b	1.27±0.12 NS	2.40±0.40 NS	2.60±0.35 NS
Blue LEDs	1.00±0.00 NS	1.00±0.00 b	1.33±0.42 NS	2.40±0.40 NS	2.78±0.71 NS
Red LEDs	1.00±0.00 NS	1.21±0.03 a	1.50±0.30 NS	2.33±0.42 NS	3.13±0.23 NS
CV (%)	0.00	5.56	26.28	15.51	14.74

Data represent mean ± deviation standard.
Mean values (n = 5) from three replicates in each column of sampling times followed by different letters are significantly different from each other at 5% Tukey's test. NS= not significant.
CV= Coefficient of variation.

Yellowing index

Bitter gourd is a climacteric fruit that ripens and turns yellow during storage due to ethylene production (Yahia *et al.*, 2019). As shown in Table 2, there is a 1-10% (YI=2) yellowing after the third. Fruits exposed to white LEDs (WL) and Blue LEDs (BL) maintained the greenness at 3 d of storage but compared to control. As the days passed until 6 d, the yellowing progressed to 11-30% (YI=3), and the quality began deteriorating. Several factors, including senescence, free radicals, energy, metal ions, and some secondary metabolites in fruits and vegetables, can cause postharvest yellowing (Luo *et al*., 2019). Diaz *et al.* (2006) observed that chlorophyll degradation and anthocyanin accumulation cause the yellowing of *Arabidopsis thaliana* leaves.

According to other studies, light treatment prevents some fruit postharvest problems, for example: (a) the use of Red LED light delays yellowing and reduces ethylene production in broccoli inflorescences (Ma *et al.*, 2014); (b) white and Blue LEDs of 20 molm^{-2} s^{-1} controls yellowing and maintains the green color of the outer and inner leaves of Brussels sprouts during storage (Hasperué *et al.*, 2016); (c) artificial lighting modulates stomata opening in green tissues keeps fruits from dehydration and delays degreening by delaying cell aging and disorganization (Pintos *et al*., 2020); (d) continuous exposure to white and blue LEDs under 5 and 22°C results to have higher chlorophylls a and b which remains stable and green during storage (Hasperué *et al*., 2016 a, b). It is in line with the findings of Loi *et al.* (2019), which the broccoli heads increased the chlorophylls resulted from metabolic activity exposed with BL, 467 nm, 4.1 W/m and WL, 31 lm/W.

Visual quality rating

In the selection of fruits and vegetables, visual characteristics are frequently used by consumers. Visual quality loss with moderate defects after 5 d of storage was delayed by white and blue light, as shown in Table 3. Poor quality with serious defects was observed in those fruits without LED and red LED

Table 2 - Yellowing index of bittergourd as influenced by illumination colors during storage

Treatments	Yellowing Index				
	2 d	3 d	4 d	5 d	6 d
Control (No LEDs)	1.00±0.00 NS	1.06±0.12 ab	1.91±0.38 NS	3.14±0.43 NS	3.33±0.76 NS
White LEDs	1.00±0.00 NS	1.00±0.00 b	1.40±0.40 NS	2.45±0.40 NS	3.01±0.52 NS
Blue LEDs	1.00±0.00 NS	1.13±0.12 ab	1.64±0.34 NS	2.75±0.43 NS	3.03±0.29 NS
Red LEDs	1.00±0.00 NS	1.28±0.10 a	1.98±0.23 NS	2.83±0.76 NS	3.50±0.50 NS
CV (%)	0.00	8.64	19.70	18.86	16.91

Data represent mean ± deviation standard.
Mean values (n = 5) from three replicates in each column of sampling times followed by different letters are significantly different from each other at 5% Tukey's test;NS= not significant.
CV= Coefficient of variation.

Table 3 - Visual quality rating of bittergourd as influenced by illumination colors during storage. Data represent mean ± deviation standard

Treatments	Visual quality rating				
	2 d	3 d	4 d	5 d	6 d
Control (No LEDs)	9.00±0.00 NS	7.84±0.73 NS	6.18±0.84 NS	3.85±0.13 b	3.06±0.82 NS
White LEDs	9.00±0.00 NS	8.73±0.23 NS	6.47±0.61 NS	6.24±0.80 a	4.13±0.81 NS
Blue LEDs	9.00±0.00 NS	8.73±0.46 NS	6.53±0.50 NS	5.50±0.87 ab	3.97±0.29 NS
Red LEDs	9.00±0.00 NS	8.00±0.20 NS	5.93±0.31 NS	3.71±0.92 b	3.28±1.49 NS
CV (%)	0.00	5.52	9.48	15.55	26.45

Data represent mean ± deviation standard.
Mean values (n = 5) from three replicates in each column of sampling times followed by different letters are significantly different from each other at 5% Tukey's test; NS= not significant.
CV= Coefficient of variation.

treatments, leaving them unfit for consumption (Fig. 1). The deterioration of visual quality over time following harvest has been observed in various studies. However, the visual appearance and shelf life of fresh produce can be improved by postharvest lighting using LEDs. The effect of white-blue LEDs on the outer and inner leaves of Brussels sprouts during a 10 d storage period at 22°C was investigated. Lower respiration rates and better visual quality were found

Fig. 1 - A visual quality rating (VQR) of bitter gourd fruit 'Jadeite' cultivar at 5th day of storage. (A) T1- Control (No LEDs), the fruits were poor with serious defects and limit edibility; (B) T2- White LEDs, the fruits were good with minor defects; (C) T3- Blue LEDs, the fruits were fair with moderate defects and limit marketability; (D) T4- Red LEDs, the fruits were poor with serious defects and limit edibility.

than in the controls (Poonia *et al.*, 2022). The levels of vitamin C (35 mg 100 g FW^{-1}) and soluble carbohydrates (8.3 mg g FW^{-1} sucrose on the fourth day) in fresh-cut lettuce were increased by postharvest lighting. On the initial day, light at 50 % falls to 15 mg 100 g FW^{-1} vitamin C and 0.2 mg g FW^{-1} sucrose, respectively (Witkowska, 2013).

The observed improved visual appearance and, eventually, longer shelf life can be attributed to this (Bantis *et al.*, 2018). As demonstrated by freshly cut leaves amaranth, photosynthesis is unsustainable with insufficient light intensity (Jin *et al.*, 2021). As a signal driving this process, the conversion of sugars via gluconeogenesis is driven by low irradiance, producing glucose through the TCA cycle (Wolter and Seifu, 2015). Fresh-cut celery had a higher total dissolved solids than dark-stored celery (Zhan *et al.*, 2013). It indicates that photosynthesis continued functioning, allowing postharvest crops to remain viable. Because stored organic acids such as malic and citric are undissociated from the vacuoles, preservation of titratable acidity is a good indicator of fruit quality, reflecting shelf-life (Utama *et al.*, 2022). Furthermore, the activity of polyphenol oxidase, responsible for cell integrity breakdown, can be inhibited by ascorbate, making it a universal antioxidant that can help preserve the freshness of fruits and vegetables (Toivonen and Brummell, 2008).

Weight loss (%)

In Table 4, weight loss (%) is shown in increasing order. The acceptable limit (1-11%) for bitter gourd is observed in the present findings; if it exceeds, it leads to severe fruit shriveling and undesirability (Lualhati and Del Carmen, 2018). As a result, significant weight loss after three days of storage is prevented in bitter

Table 4 - Weight loss (%) and dry matter content (%) of bittergourd as influenced by illumination colors during storage

Treatments	Weight loss (%)				Dry matter content (%)
	3 d	4 d	5 d	6 d	
Control (No LEDs)	1.95±0.23 ab	4.48±0.68 NS	7.42±1.23 NS	11.41±1.42 NS	20.87±0.64 b
White LEDs	1.58±0.12 b	4.04±0.19 NS	6.52±0.08 NS	9.99±0.17 NS	20.67±0.31 b
Blue LEDs	2.15±0.20 a	4.64±0.39 NS	7.46±0.78 NS	11.26±1.11 NS	21.40±1.31 b
Red LEDs	1.88±0.12 ab	4.83±0.49 NS	7.79±0.80 NS	12.17±0.77 NS	20.47±0.46 b
Initial data	-	-	-	-	26.00±0.00 a
CV (%)	9.08	10.44	11.39	8.77	3.19

Data represent mean ± deviation standard.
Mean values (n = 5) from three replicates in each column of sampling times followed by different letters are significantly different from each other at 5% Tukey's test; NS= not significant.
CV= Coefficient of variation.

gourd treated with white and red light. The findings are consistent with Li's (2016) study on strawberries, which found that fruits illuminated with blue light lost more weight than fruits in white and dark treatments due to increased calyx transpiration under blue light. Bitter gourd wilts and shrivels due to weight loss, which lowers its market value and consumer acceptability (Prajapati, 2021 a).

Furthermore, shelf life is extended by slowing the water absorption rate, as with pepper (Wills *et al*., 1998). Weight loss in fresh produce is caused by water loss due to transpiration and respiration (Zhu *et al.,* 2008). Throughout the storage period, the percentage of weight loss increases. Typically, weight loss during fruit storage results from the respiratory process, humidity transfer, and some oxidation processes (Ayranci and Tunc, 2003). Quality parameters were preserved, and storage was prolonged from 15 to 20 d by treating bitter gourd fruits with 100 mmol L^{-1} /mM Calcium lactate (CL) at 10°C and 85-95 % RH, 1-MCP, edible coating with carnauba wax (1.0 %), UV-C LED 40 min, modified atmospheric packaging using LDPE (100 microns) (Prajapati *et al*., 2021 b). The enhanced membrane integrity was due to calcium stabilizing the cell membrane and turgor pressure. In UV-C LED exposure, the epicuticular wax morphology changed by reducing microcrystalline structure, which gave a better protective layer and thus reduced weight loss (Prajapati *et al*., 2021 a).

Dry matter content (%)

The data presented in Table 4 clearly demonstrate an inverse relationship between the moisture content and dry matter content of eggplant, both during storage and after harvest. The high respiration rate of eggplant fruit results in high water loss and low dry matter content, which can lead to shrivelling and reduced consumer acceptability, unless proper postharvest treatments are applied. In this regard, fruits treated with 1% Alginate and lacking an edible coating showed a lower dry matter content on the initial day, decreasing from 8.4% to 7.5%. Despite the positive results reported by Huang *et al.* (2017) on the dry biomass of oyster mushrooms under blue LED light, our study found that the dry matter content was unaffected by this type of light.

Ripening is a complex process that involves the accumulation of various metabolites, such as carbohydrates, sugars, vitamins, and other compounds, which contribute to the dry matter content and the conversion into other products. The fresh-cut celery treated with LEDs revealed a higher dry matter content than dark-stored celery, due to the higher levels of total soluble solids, ascorbic acid, and chlorophylls, as reported by Zhan *et al.* (2013) and Florkowski *et al.* (2014). Finally, the results are consistent with those of Bantis *et al*. (2018), who found that high levels of blue LED light exposure can increase the dry matter content and enhance radical scavengers and soluble sugars in mushrooms, thanks to the higher metabolic activity in synthesizing other products as a result of respiration.

Pigmental composition (mg g^{-1})

Bittergourd fruits before treatment contained chlorophyll a (6.57 mg g^{-1}), b (3.61 mg g^{-1}), and total (10.19 mg g^{-1}), respectively. Table 5 shows that the fruits at 5 d storage had maintaining levels of pigments but were degrading. Fruits exposed to

Table 5 - Pigmental composition (mg g^{-1}) and shelf-life (d) of bittergourd as influenced by illumination colors during storage

Treatments	Chlorophyll and carotenoid contents (mg g^{-1})				Shelf-life (d)
	Chl a	Chl b	T Chl	T Car^NS	
Control (No LEDs)	3.06±0.36 b	1.58±0.35 b	4.65±0.71 b	1.80±0.34 NS	4.67±0.58 NS
White LEDs	5.66±2.01 ab	2.64±1.08 ab	8.30±3.07 ab	2.53±0.58 NS	5.00±0.10 NS
Blue LEDs	4.91±1.21 ab	2.34±0.55 ab	7.25±1.75 ab	1.95±0.51 NS	5.33±0.58 NS
Red LEDs	4.56±0.85 ab	2.20±0.27 ab	6.76±1.16 ab	1.99±0.24 NS	4.67±0.58 NS
Initial data	6.57±0.00 a	3.61±0.00 a	10.19±0.00 a	2.48±0.00 NS	-
CV (%)	22.73	23.28	22.71	18.15	14.38

Data represent mean ± deviation standard.
Mean values (n = 5) from three replicates in each column of sampling times followed by different letters are significantly different from each other at 5% Tukey's test; NS= not significant.
CV= Coefficient of variation.

white, blue, and red LEDs had better pigmental composition than those exposed to control. Between the two pigments, chlorophyll a contained higher levels than chlorophyll b, resulting in reduced amounts during storage. It agrees with Prajapati *et al.* (2021 a), who found that total chlorophyll decreased with storage treatments. This event is considered a tug-of-war between two pigments during the yellowing process. High chlorophyll is sought after by consumers. The chlorophyll content decreased when the broccoli started yellowing (Loi *et al*., 2019). In contrast, there were carotenoid and chlorophyll syntheses in Brussels sprouts under low light intensity using WB LED for 10 d. However, photooxidation will destroy the carotenoid at higher light intensity (Hasperué *et al*., 2016). The delayed decline of carotenoid contents was due to exposure to white LED at 1.4 W m^{-2} for 8 d (Nassarawa *et al*., 2020). The carotenoid primary function is to act as an accessory light-harvesting system, which aids in light absorption. It is considered to be photoprotective by inhibiting free radicals in chloroplasts (Jones, 2018; Salas *et al*., 2019). It acts as an antioxidant by donating hydrogen to neutralize singlet oxygen (Gorni *et al*., 2021).

The phytochrome family perceives red light between 600 and 750 nm. At the same time, the blue light (320-500 nm) spectrum includes cryptochromes and phototropins under the ZEITLUPE/ADAGIO family. Similarly, the stability of Cryptochrome Circadian Regulator 1 (CRY1) depends on the illumination, but the Cryptochrome Circadian Regulator 2 (CRY2) receptor breaks after light exposure (Jones, 2018). Although Red LEDs (RL) did not induce chlorophyll accumulation, when combined with Blue LEDs (BL), the chlorophyll content of a non-heading Chinese cabbage increased (Fan *et al*., 2013; Bantis *et al.* 2018). LED illumination improved crop pigmental composition while lowering reactive oxygen species activity (Kong *et al*., 2020; Loi *et al*., 2020). The green pigments found in fresh vegetables and fruits originated from chlorophyll in the chloroplast, which would then destroy PSII by decreasing the chlorophyll contents during yellowing (Luo *et al*., 2019). Both chl a and chl b have collaborated to widen the light spectrum associated with photoreceptors to harvest light emissions (Salas *et al.*, 2019). Before yellowing, NYC1 levels increased, but after 5 d of storage, they decreased (Luo *et al.*, 2019). The intensity of RL at 50 molm^{-2} s^{-1} increased the carotenoid content of Satsuma mandarin after 6 d of storage. At the same time, BL did not improve carotenoid accumulation (Ma *et al*., 2014; Bantis *et al*., 2018).

Shelf-life

It was found that the use of different illuminations did not have a significant impact on the shelf life of bitter gourd, as per the study that was discussed (Table 5). Regardless of whether LEDs were used or not, the fruits were only lasting for around 4-5 d during storage (Salas *et al.*, 2015). However, it was suggested that future research could explore the possibility of increasing LED duration and lowering temperatures in order to prolong the shelf life of bitter gourd. It was noted that fruits are generally highly perishable when stored at room temperature, which can result in significant postharvest losses (Pott *et al*., 2020). As such, extending the shelf life of such crops can be considered a significant breakthrough in research. Bitter gourd, in particular, degrades quite rapidly due to various factors, such as the presence of protruding ridges, excessive seed development, tissue softening, yellowing, and ripening, which can make it challenging to market (Prajapati *et al*., 2021 b). Previous studies have shown that LEDs can have a positive impact on the metabolites and postharvest life of various crops, including bitter gourd. For example, it was found that the shelf life of crops like *M. charantia* (Prajapati *et al*., 2021 a), *Brassica oleracea* L. var. Italica (Loi *et al.*, 2019), and broccoli (Hasperue *et al.*, 2016; Pintos *et al*., 2020) was prolonged significantly when exposed to certain types of LEDs.

It was found that the study did not yield significant results on the shelf-life of bitter gourd. However, as argued by D'Souza *et al*. (2015), the shelf-life and quality of horticultural products can be influenced by postharvest light through the potential increase of soluble carbohydrates, which serve as the substrate for respiration during postharvest storage, and through the enhancement or preservation of visual appeal through pigment accumulation, such as lycopene, carotenoids, and anthocyanins. Significant potential has been demonstrated by LED technology for promoting the growth and synthesis of beneficial compounds and extending the shelf-life of fruits and vegetables during postharvest storage, as reported by Loi *et al*. (2020). It was observed that fruits did not experience any prevention from shrivelling, yellowing, and weight loss when exposed to blue and red LED. Additionally, there was no influence on visual quality with red LED on the fifth day. However, an increased content of total chlorophyll, vitamin C, pH, and total phenolics in cabbage was observed when exposed to continuous lights using white, blue, green, and red LEDs. Green tomatoes' delayed ripening and softening resulted from exposure to blue and red LEDs for 21 d, while an increase in contents of sugars, chlorophyll, and carotenoids in broccoli at 5°C and 22°C was observed when exposed to white and blue LED with a fluence rate of 20 W m^{-2} (reviewed by Nassarawa *et al*., 2020).

Chemical parameters

Fruit cell walls containing polysaccharides solubilized and hydrolyzed into simple sugars, which gives rise to the soluble solids (Ayu *et al*., 2020; Mirshekari *et al*., 2020; Suriati *et al*., 2022) and are affected by room temperature (Mutua *et al.*, 2021). However, the decrease in soluble solids resulted from respiration during fruit storage (De Paula *et al*., 2020). The enhanced shelf-life of fruits indicates slow utilization of soluble solids (Nassarawa *et al.*, 2020). One of the critical metabolites is Vitamin C, an antioxidant against free radicals and a nutrient source in fruits and vegetables (Loi *et al*., 2019; Mirshekari *et al*., 2020). As a precursor, glucose synthesis is necessary for synthesizing vitamin C via the L-galactose pathway and D-galacturonic acid (Fernandez and De Guzman, 2022). Using organic acids in respiration increases pH over storage (Gonzales and Benitez, 2019). The increase in pH values was concomitant with a reduction in Vitamin C and TA, which concurs with Salas *et al*. (2020). Cucumber's shelf life has been extended due to the preservation of TA over time (Zapata *et al*. 2008, as cited by Gonzales and Benitez 2019). Based on the study results, the electrical conductivity (EC) increased with storage time. Conforming to the Salas *et al*. (2020) study, eggplant fruits with a high amount of electrolytes deteriorate quickly. This is due to the gradual breakdown of cell membrane integrity mediated by lower lipoxygenase (Cai *et al*., 2006), resulting in ion imbalance and electrolyte leakage as well as excessive shriveling and softening (Tesfay and Magwaza, 2017; Cheema *et al*., 2018).

Table 6 shows significant results in bitter gourd chemical characteristics such as pH and TA as influenced by the varying illumination. However, the result of this study yielded insignificance in terms of EC, TDS, TSS, and Vitamin C. It agrees with the findings of D'Souza *et al*. (2015) that the white LED (500-700 nm) imposed did not influence the ascorbate production. It can deduced that light treatments with 1.5 W in 4 h have insufficient doses to bring significant improvement in the said metabolite. Exposure to continuous white and blue LEDs resulted in a slight increase in ascorbic acid (Asc) content at the end of broccoli storage (Hasperué *et al*., 2016). Sweet peppers with Blue light at 450 nm in 8 h per day had minimum changes in ascorbic acid content (Thilini Deepashika Perera *et al*., 2022). Blue LED at a lower intensity, 20 µmol m^{-2} s^{-1} under 5°C, decreased the Asc content of broccoli while maintaining the levels at a higher intensity, 50 µmol m^{-2} s^{-1} (Loi *et al.*, 2019). Red, blue, and green lights at 20, 40, and 60 W m^{-2} increased the TSS of

Table 6 - Chemical parameters of bittergourd as influenced by illumination colors during storage. Data represent mean ± deviation standard

Treatments	Chemical parameters					
	pH value	EC mS	TDS ppm	TSS °brix	TA %	Vit. C mg 100 g^{-1}
Control (No LEDs)	7.83±0.06 a	3.12±0.25 NS	2153.33±142.24 NS	1.83±0.14 NS	0.49±0.11 b	0.14±0.02 NS
White LEDs	7.73±0.12 a	3.26±0.55 NS	2233.33±390.68 NS	1.92±0.14 NS	0.38±0.08 b	0.12±0.04 NS
Blue LEDs	7.16±0.12 b	3.05±0.18 NS	2086.67±128.97 NS	1.83±0.14 NS	0.47±0.14 b	0.18±0.03 NS
Red LEDs	7.16±0.06 b	2.94±0.53 NS	2013.33±355.29 NS	1.75±0.25 NS	0.47±0.07 b	0.19±0.05 NS
Initial data	4.60±0.00 c	2.40±0.00 NS	1640.00±0.00 NS	2.00±0.00 NS	0.86±0.00 a	0.18±0.00 NS
CV (%)	1.18	12.49	12.41	8.47	17.34	19.98

Data represent mean ± deviation standard.
Mean values (n = 5) from three replicates in each column of sampling times followed by different letters are significantly different from each other at 5% Tukey's test; NS= not significant.
CV= Coefficient of variation.

fruits (Nassarawa *et al.*, 2020). A single application of RL to harvested vegetables increased the sugar, soluble protein, and vitamin C content (Loi *et al.*, 2020; Poonia *et al.*, 2022). Bitter gourd has a low TSS (°brix) compared to other fruits with high sugar content, such as pitaya, which contains several monosaccharides that contribute to sweetness. In addition, the sugar content of the skin of grape berries was enhanced after red and blue light exposure at 50 μmol m^{-2} s^{-1} (D'Souza *et al.*, 2015). Cell wall breakdown and postharvest decay were delayed by blue light emission within 2 h at 25°C, which decreased monosaccharides such as glucuronic acid in pitaya fruits (Pott *et al.*, 2020).

4. Conclusions

The current study aimed to investigate the effects of white, blue and red Light Emitting Diodes (LEDs) on the pigment composition, physical and chemical parameters of bittergourd (*Momordica charantia* L.). Irradiated and non-irradiated fruit samples were at ambient temperature with an 8 h continuous light source from the room ceiling. Based on the present findings, the white and blue LEDs delayed fruit shrivelling and yellowing on the third day and maintained an excellent visual appearance on the fifth day compared to the control and red LEDs. White LEDs had lower weight loss, followed by red and no LEDs on the third day. Among the treatments, the dry matter content decreased from the initial day. The white, blue, and red LEDs did not prevent fruits from yellowing, but there was a slight change compared to the control with the lowest amount of total chlorophyll a and b, whereas the carotenoids remained stable. Regardless of treatments, the pH values (neutral) increased from the initial day (acidic). However, the blue and red LEDs had lower pH values compared to white and control. Irrespective of treatments, the EC, TDS, and vitamin C remained stable during storage. In contrast, TA lowered from the initial day. White and blue reached a shelf-life of 5 d, whereas red LED and control until four days, numerically.

Generally, LEDs with 1.5 W had the potential to improve the quality and shelf-life of bitter gourd fruits. Among the treatments, the white LED positively affected the physical and chemical parameters. Increasing the wattages or light intensities under continuous or intermittent lighting with lower temperatures makes it possible to achieve preserved fruit quality beyond five days of shelf-life. Based on the results, it would suggests potentiality of LEDs for the future studies, which can be a useful information towards preserving the physico-chemical attributes of bittergourd and other postharvest crops.

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