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# The Impact of Various LED Light Spectra on Tomato Preservation

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**Abstract:** Major losses of fresh tomatoes happen during post-harvest storage due to prompt senescence and diseases. The aim of the research was to evaluate the effects of different spectra of LED lights on the post-harvest preservation of ascorbic acid, lycopene, and total soluble solids, the weight and size of tomato fruits, as well as to determine the optimal exposure time and distance of irradiation and extension of shelf-life. Therefore, experiments were carried out in a climate chamber with shelves equipped with three different light spectra: red light-emitting diodes, red–blue–white light-emitting diodes, and ultraviolet-light-emitting diodes. Light treatment had a certain positive effect on the firmness, size, and mass of samples. Thus, tomato fruits (Panekra) exposed to the spectra of LED lights demonstrated a better quality of firmness and mass compared to the control samples (non-preserved) of tomatoes. The treatments with RL significantly improved the concentration of lycopene than FL and UV-LED lights, although the highest concentration of lycopene was observed in the control samples for the first 7 days of the storage. After 21 days, the ascorbic acid content in the red spectrum was found to be much higher than in the other two spectra and control samples, coming in at about 1.8 mg/100 mL compared to 1.0 mg/100 mL for the control samples. Total soluble solids also increased significantly after preservation, rising from 3.9 °Brix in the control samples to roughly 7.3 °Brix in samples preserved using the full spectrum after 21 days. Overall, the results of the study demonstrated that tomato preservation using the investigated techniques induced lycopene concentration, ascorbic acid, and total soluble solids concentrations. The results derived from this study provide highly useful information in the field of post-harvest preservation.

**Keywords:** tomato fruits; LED light; preservation; lycopene; ascorbic acid; total soluble solids; shelf-life



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## 1. Introduction

The annual production of fresh tomatoes is roughly equal to 75% for the fresh market and 25% for processing on a global scale [1]. On the other hand, one of the main food sources of carotenoids is the tomato, which provides around 80% of the recommended daily intake of lycopene [2]. Due to their nutritional importance, fresh fruits have been recognized as a significant source of vitamins and antioxidants and as a crucial component of the human diet and welfare [3]. Numerous healthy vitamins and minerals can be found in fruits and vegetables. As a result, a healthy, balanced diet must include both fruits and vegetables as necessary ingredients [4]. They are a great source of dietary fiber, which

supports gut health and helps to prevent constipation and other digestive issues [5]. A high-fiber diet can also lower the risk of developing colon cancer [6–8]. Tomatoes are one of the most significant and popular greenhouse crops in the world. Lycopene, an antioxidant with several health advantages, including a decreased risk of cancer and heart disease, is mostly found in tomatoes [9]. Nutrients including vitamin C, potassium, folate, and vitamin K are also abundant in them [10].

Unfortunately, despite their significance in daily life, tomatoes are a highly perishable fruit with a short shelf life at ambient temperatures, and they continue to alter even after harvest [11,12]. In general, there are many technologies used for the preservation of perishable foods. However, efficiency and cost-effectiveness remain as significant issues of concern in the field. Fruit spoilage is one of the main contributors to food wastage, with an estimated 30% of produce rendered unfit for consumption due to deterioration [13]. One of the main reasons for the loss of tomato fruits is poor post-harvest handling of the produce. The lack of proper storage facilities and poor transportation and distribution channels are major factors that cause losses [14]. Microorganisms harm most fruits and vegetables, which makes them spoil quickly [15]. Water and nutrients are necessary for microorganisms such as bacteria, yeast, and molds to thrive, produce energy, and reproduce. As pectins are broken down by bacterial spoilage, tissues first become softer. Eventually, the entire fruit may turn into a slimy sludge. Following the metabolism of starch and sugar, unpleasant flavors and odors, as well as lactic acid and ethanol, develop [16].

Currently, the most commonly used method for fruit preservation is refrigeration [17]. However, vitamins B and C are destroyed by refrigeration [18]. Compared to fresh fruits, frozen fruits also have fewer antioxidants, which guard against cellular deterioration. Therefore, it is imperative to research and develop new technologies to enhance tomato preservation throughout the world. One of the potential technologies for the preservation of tomatoes is the use of ultraviolet light-emitting diodes (UV-LEDs). Compared to traditional UV lights, LED lighting is said to be an economical and energy-efficient technology [19]. As a residue-free physical sterilization and preservation method, light-emitting diode (LED) treatment has recently been applied for the post-harvest storage of fruits and vegetables. For instance, Kim et al. [20], conducted a study on the antibacterial effectiveness of 405 nm LEDs on freshly cut mango, Zhang et al. [21], used light-emitting diodes for improving the preservation of fresh foods, and as Kim et al. [22], used UV LED on carrots.

Supplemental red–blue LEDs have been shown to increase the photosynthetic light use efficiency and the levels of phytohormones such as jasmonate which improve crop quality [23]. This shows the potential for the beneficial post-harvest effects of visible light illumination. While some studies have already demonstrated the potential for LED illumination to retain or even enhance the physicochemical properties of post-harvest fruits such as mangoes and bananas [24], the effects of LED irradiation on the physicochemical properties of tomatoes have been minimally studied, mostly limited to only basic physical properties such as color and texture [25].

Based on the potential advantages of post-harvest LED lighting irradiation of fruits and vegetables and insufficient knowledge of its effects, the current study designed an experimental red spectrum, full spectrum LED, and UV-LED lighting facility and researched their optimal modes and effects on the post-harvest preservation of ASA, lycopene, and TSS content, as well as on the physicochemical properties and the extension of the shelf life of treated tomato fruits.

Apart from the shelf-life extension, UV LED lighting makes the fruits safer for consumption and prevents diseases caused by microorganisms [26]. As one of the most prevalent causes of disease in humans, intestinal parasite infections result in significant morbidity and mortality. Commonly eaten raw fruits and vegetables are among the ways that people become sick from important medical parasites [27].

Moreover, sanitizing fruit and vegetables with UV light has the potential to prevent the growth of microorganisms without degrading the quality of the produce [28]. Compared to regularly used chemicals such as chlorine, hydrogen peroxide, or ozone, which can leave

residues and eventually lower quality, UV radiation has the potential to be more successful at reducing microbial growth. The process is achieved by triggering the formation of specific thymine or cytosine dimers in deoxyribonucleic acid (DNA) and uracil dimers in ribonucleic acid (RNA), which causes the inactivation of microbes by causing mutations and/or cell death and failure to reproduce [29]. Due to the lack of sufficient and effective preservation technologies, the field continues to face tremendous challenges. Therefore, there is currently an increasing demand to develop sustainable methods to control these post-harvest losses.

Therefore, in this study, the potential applicability of various LED light spectra on tomato post-harvest preservation is investigated. The experiments were conducted for this aim in a climatic chamber that included shelves with three different light spectra: red light-emitting diodes (LED) (RL), red–blue–white light-emitting diodes (full spectrum), and UV-light emitting diodes (LED) UV-LED.

## 2. Materials and Methods

### *2.1. Sample Characteristics and Stored Conditions*

Tomato fruits (Panekra) (5.4 to 7.65 cm diameter) with a light red maturity level were taken from the greenhouse of the LED System Media LLP located in Astana, Kazakhstan. The average yearly temperature is between −5 °F (−20.6 °C) and 79 °F (26.1 °C), rarely falling below −24 °F (−31.1 °C) or rising above 91 °F (32.8 °C). With an average rainfall of 47 mm, July is the month with the most precipitation. Astana receives 292 mm of average precipitation per year. Additionally, Astana is 347 m (1138 feet) above sea level. The samples were stored (at room temperature around 20 °C) in the Water Management laboratory of L.N. Gumilyov Eurasian National University. Each tomato from the control samples and each group of the investigated preservation techniques was chosen on day 0 and marked for scaling and dimension measurements. Then the tomatoes were equally distributed into three storage shelves of the experimental facility, each with a different light spectrum and intensity mode. The samples were kept at a distance of 40 cm from the LED lights. The temperature in the climate chamber was maintained at 13–15 °C, with humidity at 85% correspondingly. The control samples were stored in cardboard in the dark at room temperature. Each week during the study period, the samples' investigation process was carried out.

### *2.2. LED Irradiation Modes*

The experiment consisted of three different preservation techniques (red light-emitting diodes (LED) (RL), red–blue–white light-emitting diodes (full spectrum), and UV-light emitting diodes (LED) UV-LED) and was replicated seven times. The temperature, humidity, and irradiation modes of the experimental facility were monitored 24 h a day by means of the remote digital control system installed in the experimental facility. Tomato fruits were subjected to irradiation for 21 days with 15 tomato samples in each group being sampled every seventh day for the determination of ascorbic acid, lycopene contents, total soluble solids, firmness and size, fruit mass, and moisture content. The same process was carried out with control tomatoes stored in the dark for the same period. Tomato fruits were irradiated with RL-LED lights and FL-LED lights for 2 h a day, and samples treated with UV-LED light were irradiated for 2 min 3 times a day. Excessive exposure to UV light causes stress in plant tissues and stimulates the biosynthesis of defensive secondary metabolites with antioxidant and screening activity. Examples of these compounds include lycopene in tomatoes. The irradiation modes were set by the remote digital control system and monitored on the mobile phone. Every seventh day, external quality parameters (mass and firmness) of the same four tomato fruits of a replicate were also evaluated to track weight loss and the dimension diminishing process. The summary of the preservation architecture is presented in Figure 1.

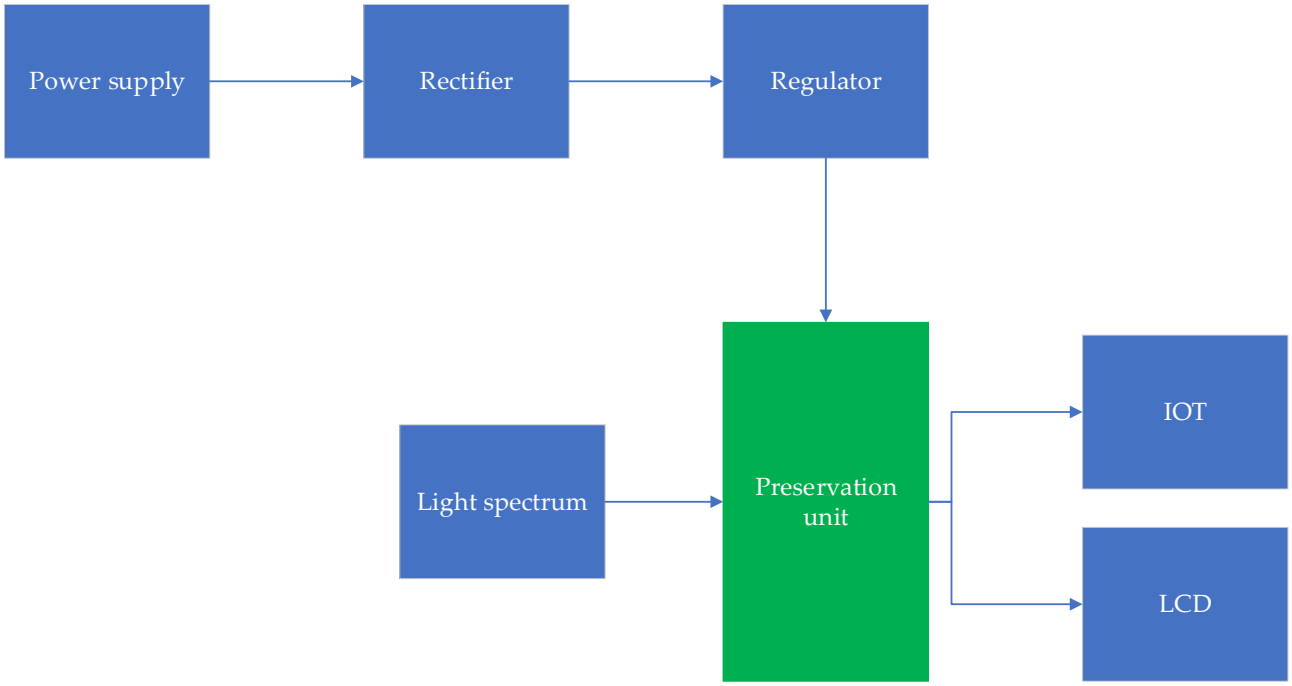



**Figure 1.** The general architecture of the preservation system.

A summary of the cases examined in the study at each exposure time is given in Table 1, which is primarily classified into three groups (7-day exposure time, 14-day exposure time, and 21-day exposure time).

**Table 1.** Cases investigated in the study (dependent and independent variables).

| Exposure Time | Impact on Tomato |
|---|---|
| Day 7 | Observed changes in terms of ascorbic acid, lycopene, total soluble solids, fruit mass, firmness and size, and moisture content. |
| Day 14 | Observed changes in terms of ascorbic acid, lycopene, total soluble solids, fruit mass, firmness and size, and moisture content. |
| Day 21 | Observed changes in terms of ascorbic acid, lycopene, total soluble solids, fruit mass, firmness and size, and moisture content. |

### *2.3. Experimental Setup*

The experimental facility was designed in the form of a refrigerator with three chambers. Each chamber was equipped with LED lights of a certain spectrum, as the first shelf was equipped with red spectrum LED lights, the second shelf-with full spectrum LED lights, and the third shelf of the climate chamber was irradiated with UV-LED lights. Each LED light was installed at a distance of 40 cm from the samples. The LED light modules and packaging did not contain materials and substances hazardous to life, human health, and the environment. LED lights consisted of LED modules, a power supply, heat sink housing, and suspension devices. The body of the LED lights was made of high-quality anodized aluminum. The protective glass of the LED lights was made of optical polycarbonate stabilized to LED radiation. The LEDs of NICHIA CORPORATION (Japan) were used in the lamps. The nominal lamp life was 40,000 operating hours (L 90 F 10 $\geq$ 40,000 h, complies with national standard GOST R 56230-2014 (RF), IEC/PAS 62717:2011 (EU)). Optical parameters of full spectrum LED lights are given in Table 1 below. LED modules consisted of LEDs of a certain spectrum and a printed circuit board. The research team

made sure that other parameters such as temperature and airflow conditions, which can affect storage conditions, remained constant throughout the investigation. The technical specifications of the full spectrum are summarized in Table 2.

**Table 2.** Technical specifications of the full spectrum.

| Parameter | Value |
|---|---|
| Light distribution grade | Direct light |
| The light intensity distribution curve | Cosine |
| Radiating power | 10–100 |
| Irradiance ($mW/cm^2$) | 97.4–730.52 |
| Photon flux efficiency | 1.7–2.1 |
| Spectral structure | Full spectrum |

### *2.4. Analytical Methods*

Every seventh day, external quality parameters (mass, size, and firmness) of the same four tomato fruits of a replicate were evaluated. For the evaluation of the preservation of ascorbic acid, lycopene, and total soluble solids (TSS), every seventh day a tomato fruit from each group was randomly selected and subjected to analysis. Several research works [30–33], have suggested the use of the simple and rapid analytical method of determining lycopene carotenoid–rich samples by using a simple and rapid spectrophotometric method for the extraction of lycopene from the food samples with hexane. The spectrophotometric method was employed to quantify the lycopene content in the food samples.

#### 2.4.1. Lycopene Content Analysis

The lycopene content of tomato fruits was measured spectrophotometrically using a UV-VIS Spectrophotometer (METTLER TOLEDO, Columbus, Ohio, United States) at 503 nm after extraction with hexane [34]. A total of 1 g of homogenized tomato was mixed with 20 mL of acetone: ethanol: hexane (1:1:2). The mixture was stirred for 15 min. Then, 3 mL of water was added, and the sample was shaken on ice. The sample was left at room temperature for 5 min. The upper layer was transferred to a cuvette and its absorbance was read at 503 nm [35]. The lycopene content was calculated using Equation (1):

$$\text{Lycopene content} \left(\frac{\mu g}{g}\right) = \frac{A503 \times V \times 106}{\varepsilon \times 100 \times m} \quad (1)$$

Whereby,
$\varepsilon$ = molar extinction coefficient
m—a mass of the sample in g
V = total volume of extract
A = absorbance of the diluted extract sample

The molar extinction coefficient ($\varepsilon$) is a unit of measurement for the degree to which a chemical species or substance absorbs light of a specific wavelength. Chemical species have this inherent quality, which is determined by their chemical makeup and structure. A total of 5 mL of acetone, 5 mL of ethanol, and 10 mL of hexane were added to each sample. Stirring on ice was performed for 15 min. A total of 3 mL of deionized water was added after shaking. Mixtures of the samples and added solvents were shaken for 5 min on ice and then left at room temperature for 5 min to allow the separation of both phases. The lycopene layer was then analyzed by scanning in a UV- VIS Spectrophotometer (METTLER TOLEDO, Columbus, Ohio, United States), and the concentration of lycopene was calculated by using the Beer–Lambert equation. The absorbance of the lycopene layer (upper layer) was measured in a 1-cm-path length quartz cuvette at 503 nm blanked with hexane after suitable calibration of the instrument with hexane.

2.4.2. Ascorbic Acid Content

Ascorbic acid content was analyzed with UV–VIS spectroscopy (METTLER TOLEDO, Columbus, OH, USA). Ten grams of the sample was blended, and the blended sample was homogenized with about 50 mL of acetic acid solution. Then it was quantitatively poured into a 100 mL volumetric flask and was shaken gently until a homogenous dispersion was obtained. Then it was diluted up to the mark by an acetic acid solution. After that, the solution was filtered, and the clear filtrate was collected for the determination of vitamin C in that sample. A few drops of bromine water were added to the filtrated sample solution until the solution became colored. Then a few drops of thiourea solution were added to the solution to remove the excess bromine and obtain a clear solution. Then 2,4-Dinitrophenyl hydrazine solution was added thoroughly with all standards and also with the oxidized ascorbic acid. The total vitamin C-employing coupling reaction of 2,4-Dinitrophenyl hydrazine dye with vitamin C and spectrophotometric determination were performed at a wavelength of 280 nm.

2.4.3. Change in Fruit Mass

To determine the physiological weight loss, tomato fruits were weighed using a weighing machine (METTLER TOLEDO, Columbus, OH, USA) before the treatment which served as the initial fruit weight. The fruit mass and loss in weight were recorded every seventh day. The weight on the 21st day served as the final weight of the samples. The physiological loss in mass was calculated by the following formula and expressed as a percentage.

$$\text{PLW } (\%) = \frac{\text{Initial fruit weight} - \text{fruit weight after preservation}}{\text{Initial fruit weight}} \quad (2)$$

2.4.4. Firmness and Size

The firmness of tomato fruits was manually evaluated by gently pressing the fruit with the fingertips. The firmness was measured every seventh day on a certain sample of tomato fruits to track the changes in firmness. Changes in the size of tomato fruits were measured every seventh day with a 150 mm vernier caliper. Tomato fruits were marked to measure at the same part to obtain more accurate data on the size changes.

2.4.5. Total Soluble Solids (TSS)

Total soluble solids (TSS) were measured from the blended and filtered sample with a held refractometer (URL-1) (Bioevopeak Co., Shandong, China) by dropping a small amount of the filtered sample on the lens and noting down the results expressed as $^{\circ}$Brix.

2.4.6. Moisture Content

After weighing some aluminum foil, the digital sensitive balance was reset to zero. The initial moisture content of the samples was determined by drying them at 105 °C for 24 h, moving them to a desiccator, allowing them to cool, and then weighing the dehydrated samples and expressing them as kg water/kg dry solids. The samples were then transferred to the desiccator and allowed to cool. Then, the samples were weighed after dehydration. The dehydrated tomato powders' percent moisture contents were estimated as follows [36];

$$\text{Moisture content } (\%) = \frac{w_1 - w_2}{w_1} \times 100 \quad (3)$$

where $w_1$ is the sample's weight prior to dehydration, and $w_2$ is the sample's weight following dehydration.

*2.5. Statistical Analysis*

The examined parameters of interest were used to compute the correlation indices. These indices had a significant role in determining how strongly the selected parameters

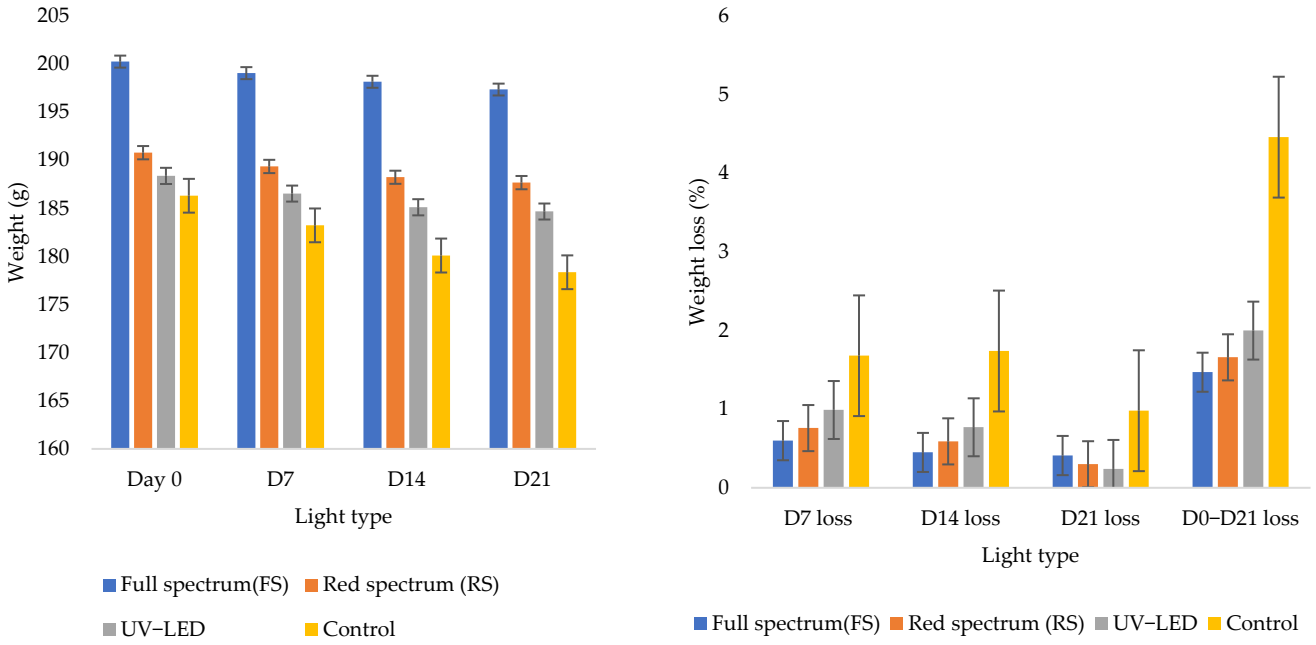
related to one another. A high correlation, according to the indices, typically meant that two or more variables were tightly related to one another. The variables were not significantly associated if there was a minimal connection between them. Ratings for the correlation included "poor," "moderate," "strong," and "extremely strong" (0.3–0.49, 0.5–0.69, and 0.7–1, respectively) [37]. The statistical significance of the changes in the analyzed parameters was also evaluated in this study using a single-factor Analysis of Variance (ANOVA). The method evaluates the degree of variance in the data from the researched parameters within each group using samples from each group. The discrepancy between the *p*-values and alpha (0.05) values was used to assess the significance level. It is also critical to keep in mind that, even if the null hypothesis is true, the alpha number represents your chances of rejecting it. The null hypothesis is accepted if the *p*-value exceeds the alpha value. The *p*-value, on the other hand, shows the chance of obtaining a result that is more extreme than the one you received from the experiment [38]. Tukey's Honest Significance Test was also utilized in the study. It was used to determine whether the means of the parameters under investigation had any statistically significant deviations. All statistical procedures were carried out with the aid of Microsoft Excel 2019.

## 3. Results

### *3.1. Weight Characterization*

Figure 2 shows that, when compared to the samples preserved using various UV light spectra, the control (non-preserved sample) exhibited the highest weight loss (4.46%). It is also obvious that the full spectrum preservation approach produced the lowest weight. That is to say, compared to the other preservation systems, the full spectrum preservation system was more effective at preserving the fruits in terms of weight loss. A similar phenomenon can also be observed in Figure 2. It is also important to note that fruit and vegetable quality is greatly impacted by post-harvest water loss, which is a significant contributor to degradation. If the commodity is sold by weight, significant water loss could lead to a significant decrease in fresh weight, which would result in a financial loss. When the essential moisture loss threshold is achieved, more noticeable detrimental changes in turgidity, firmness, discoloration, flavor, and nutritional value might happen. Slight moisture loss can create subtle quality changes in color and texture. Weight loss has been linked to accelerated senescence, increased pathogen invasion, and greater vulnerability to chilling injury [39]. Generally, fruit spoiling and destruction during storage are typically brought on by microbial contamination of the food and oxidation brought on by active oxygen species (ROS). This deterioration and rotting during storage affect the food sector, the environment, and both. Using preservation technologies in fruits is crucial to the prevention of contamination and food deterioration [40].

It is noteworthy that tomatoes, one of the more fragile fruits, keep evolving even after being picked. Depending on the humidity and temperature, they ripen quickly, which ultimately leads to poor quality as the fruit grows soft and tastes awful [41]. Because an overripe tomato is more likely to incur bodily harm than a ripe or pink one, it must be harvested at the right moment. After being harvested, tomatoes continue to ripen, and they can soon become overripe. Tomatoes are climacteric fruits, and the ripening stage is when they breathe the most. Because tomatoes are a climacteric and perishable product, their shelf life is usually only 2 to 3 weeks [42]. The post-harvest (post-production) and marketing system is a collection of interconnected activities that take place between the time of the harvest and the delivery of the food to the customer. The outcomes of the weight loss monitoring in grams are summarized in Figure 3. From Figure 3 it can be seen that the control sample presented the highest weight loss compared to the preserved samples using the different techniques. UV-LED presented the lowest weight loss after 21 days of the monitoring process.




(**a**) (**b**)

**Figure 2.** Fruits weight monitoring results. (**a**) Weight in grams. (**b**) Weight loss in percentage.

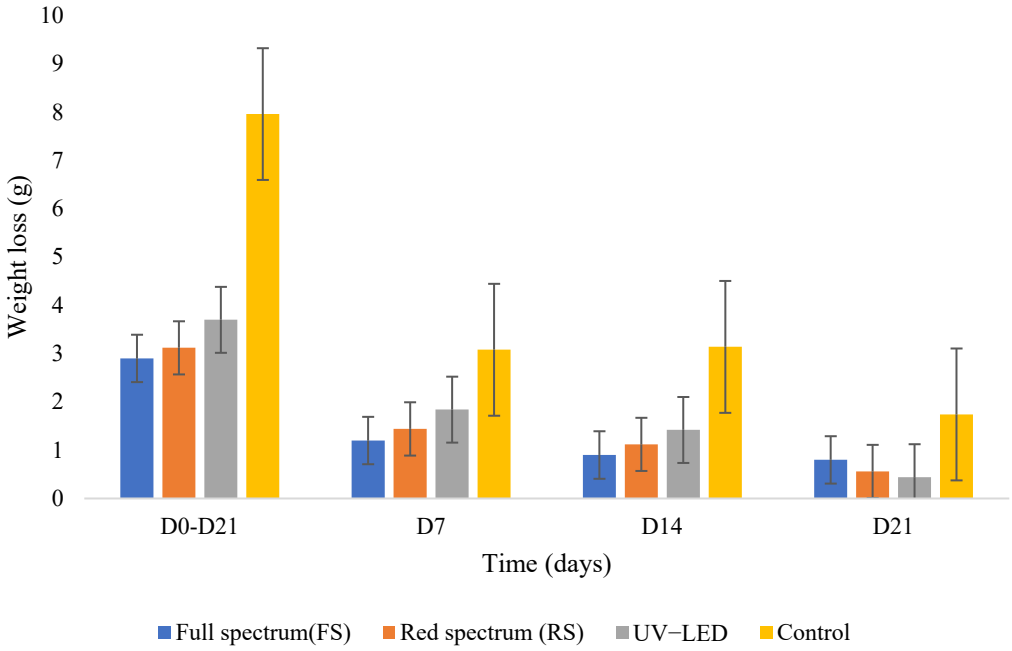



**Figure 3.** Weight loss monitoring results.

A tomato fruit's fresh weight is 90% water, and the size of the fruit is influenced by the water supply to the plant. Due to the quantity of water, the fruit is perishable. The quality of most fruits and vegetables is also impacted by water loss during storage, which is affected by ambient temperature and relative humidity levels [43]. Fruits should be properly preserved for a short time, say 4 to 7 days, to prevent quality loss in order to reduce post-harvest losses and improve fruit quality and marketability [44]. Low soluble solid content, delayed fruit lycopene, and low acidity all contribute to maintaining the flesh's firmness. Apart from the preservation techniques investigated in this study, the

use of plastic film is becoming more and more significant among the different strategies developed to extend fruit post-harvest life since it is practical in a range of scenarios along the handling chain from producer to consumer [45].

ANOVA was employed in this study, as described earlier, to examine the significant degree of differences between the parameters under investigation. The ANOVA was applied to the full spectrum preservation system, red spectrum, UV-LED, and control datasets. The ANOVA results from the fruit weight monitoring are summarized in Table S1. When the datasets were put through the ANOVA, a $p$-value of $1.02 \times 10^{-6}$ was found, as can be shown. Given that the obtained $p$-value was less than 0.05 (alpha value), it may be concluded that the differences between the examined parameters' effects on the datasets were statistically significant. By employing statistical testing, a statistically significant difference reveals if the datasets of one group are significantly different from the datasets of another group.

To further explore the significance levels in the differences from the researched parameters, the study additionally used Tukey's honest significance test in addition to the ANOVA. Tukey's honest significance test also used the datasets from the full spectrum preservation system, red spectrum, UV-LED, and control. Table 3 shows that a $p$-value of 0.001005 was obtained when the full spectrum fruit weight data were compared to the red spectrum results. The obtained $p$-value was less than 0.01 (alpha value) and indicated that the differences were statistically significant. A similar phenomenon can be observed when full spectrum results were compared with UV-LED results, full-spectrum results vs. control, as well as when the red spectrum results were compared with the control results. However, $p$-values larger than 0.01 were found when the UV-LED findings were compared to the red spectrum results, and when the UV-LED results were compared to the control data, rendering the differences statistically insignificant.

**Table 3.** Tukey's honest significance test results from weight results.

| Treatments Pair | Tukey's HSD Q Statistic | Tukey's HSD $p$-Value | Tukey's HSD Inference |
|---|---|---|---|
| Full spectrum (FS) vs. red spectrum (RS) | 8.992 | 0.001005 | ** $p < 0.01$ |
| Full spectrum (FS) vs. UV-LED | 11.6275 | 0.001005 | ** $p < 0.01$ |
| Full spectrum (FS) vs. Control | 15.5018 | 0.001005 | ** $p < 0.01$ |
| Red spectrum (RS) vs. UV-LED | 2.6354 | 0.293234 | insignificant |
| Red spectrum (RS) vs. Control | 6.5097 | 0.002944 | ** $p < 0.01$ |
| UV-LED vs. Control | 3.8743 | 0.074133 | insignificant |

### *3.2. Fruit Size Characterization*

Figure 4 and Table 4 reveal that the control sample experienced the greatest reduction in tomato size over time. However, across all of the examined preservation techniques, the size variations were often very small. Another important aspect to note is that, after being harvested, tomatoes begin to lose quality because they are a perishable food. When shipping tomatoes across long distances, it is crucial to choose the finest fruit sizes in order to preserve their quality. The size of the tomato, which can affect the nutritional content, is a key element in consumer decision-making. The sizes of fruits and vegetables serve as a crucial gauge for a number of characteristics. The highest quality food is packaged and marketed both domestically and internationally, while smaller fruit is frequently shifted to local markets or processing facilities. The size of tomatoes can vary depending on a variety of circumstances. The first effect of low ambient light is smaller tomatoes with less vitamin C content. Second, too much salt and/or chloride (caused by salinity) can cause fruit to become smaller and/or heavier while also containing more soluble particles. Finally, it has been demonstrated that fruit size may decrease in response to water stress, which may have an impact on the amount of soluble solids, acidity, and ascorbic acid present in the fruit. Fruit size may be influenced by cultivar, salinity, and mineral imbalances. It is possible for small fruit to be lighter, less firm, have a shorter shelf life, and have less marketability. The market value of tomatoes decreases as a result of all of these factors.

Fruit size may also be affected by nutritional and organoleptic characteristics. Low light levels or salinity can change the intrinsic fruit composition, making this effect troublesome. Polygenic quantitative inheritance accounts for variation in fruit size and form. Segregation of offspring from cultivated species and crosses with wild relatives can result in a small fruit size, which is regulated by genetic locus mutations. By characterizing and identifying the gene mutations that can arise in grown fruit, one can use Mendelian techniques to prevent the variation of the quantitative nature of fruit size. During storage, fruit microbe activity often rises [46].

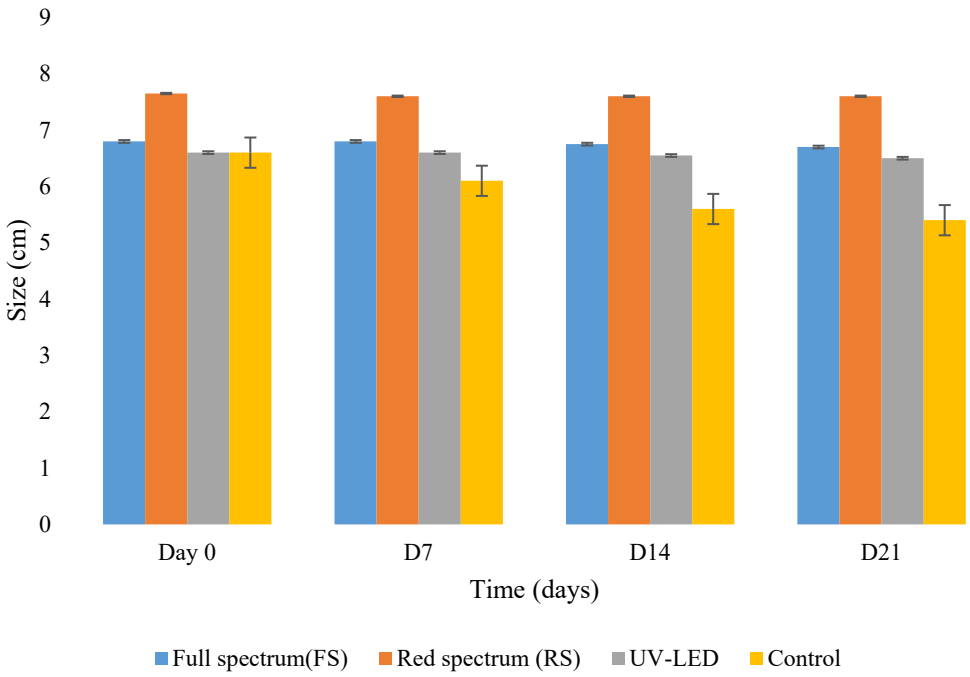



**Figure 4.** Fruit size monitoring results.

**Table 4.** Fruits size change monitoring results.

| Light Type | Size Changes (cm) | | | |
|---|---|---|---|---|
| | **D0–D21** | **D7** | **D14** | **D21** |
| Full spectrum (FS) | 6.8 | 0 | 0.05 | 0.05 |
| Red spectrum (RS) | 0.05 | 0.05 | 0 | 0 |
| UV-LED | 0.1 | 0 | 0.05 | 0.05 |
| Control | 1.2 | 0.5 | 0.5 | 0.2 |

Table S2 provides a summary of the ANOVA results from fruit size monitoring. It can be seen that a *p*-value of $1.44 \times 10^{-5}$ was retrieved when the datasets were subjected to the ANOVA. The computed *p*-value was less than 0.05 (alpha value) indicating that the differences in the datasets from the investigated parameters were statistically significant. In other words, a statistically significant difference was seen between the datasets when comparing the fruit size findings from the full spectrum preservation system, red spectrum, UV-LED, and control.

Table 5 shows that a *p*-value less than 0.01 was obtained when the full spectrum fruit size data were compared to the red spectrum results. Moreover, when the full spectrum results were compared against the control results a *p*-value higher than 0.01 was retrieved, making the difference statistically significant. A similar phenomenon can be seen from the comparison between red spectrum vs. UV-LED as well as red spectrum vs. control results. The obtained *p*-values were less than 0.01 and indicated that the differences were statistically significant. A similar phenomenon was observed when full spectrum results

were compared with UV-LED results, full-spectrum results vs. control, as well as when the red spectrum results were compared with the control results. However, a *p*-value larger than 0.01 was found when the full spectrum findings were compared to the UV-LED results, rendering the differences statistically insignificant.

**Table 5.** Tukey's honest significance test results from size monitoring results.

| Treatments Pair | Tukey's HSD Q Statistic | Tukey's HSD *p*-Value | Tukey's HSD Inference |
|---|---|---|---|
| Full spectrum (FS) vs. red spectrum (RS) | 6.2665 | 0.003938 | ** $p < 0.01$ |
| Full spectrum (FS) vs. UV-LED | 1.4745 | 0.711969 | insignificant |
| Full spectrum (FS) vs. control | 6.1744 | 0.004398 | ** $p < 0.01$ |
| Red spectrum (RS) vs. UV-LED | 7.741 | 0.001005 | ** $p < 0.01$ |
| Red spectrum (RS) vs. control | 12.4409 | 0.001005 | ** $p < 0.01$ |
| UV-LED vs. control | 4.6999 | 0.026979 | * $p < 0.05$ |

### 3.3. Ascorbic Acid

According to Figure 5, the control sample had the lowest ascorbic acid level after 21 days. The phenomenon underlines once more how important it is to preserve fruits using practical techniques. To be more specific, the ascorbic acid concentration in the red spectrum was discovered to be significantly greater after 21 days than in the other two spectra and control samples, measuring at roughly 1.8 mg/100 mL as opposed to 1.0 mg/100 mL for the control samples. Ascorbic acid is mostly found in fruit juices, which have seen rapid increases in consumption in recent years. However, ascorbic acid in fruit juices is easily oxidized and lost while the juices are in storage at rates that depend on the storage circumstances. It follows that the content and rate of loss after remaining determine the quality of any fruit juice and its worth as a source of vitamin C. Increasing ascorbate content has not been a major breeding priority, despite the fact that fruits and vegetables are the principal sources of ascorbate in the human diet and that there is significant inter- and intraspecific variation in ascorbate content in fruit crops [47]. Ascorbate content is being increased more and more these days, not just to enhance fruit quality but also to produce crops that can withstand more stress [48]. Several initiatives to enhance ascorbate in fruits have had some success, but occasionally negative effects on fruit growth have also appeared. This is probably because of the interplay between ascorbate production and elements of the cell wall [49].

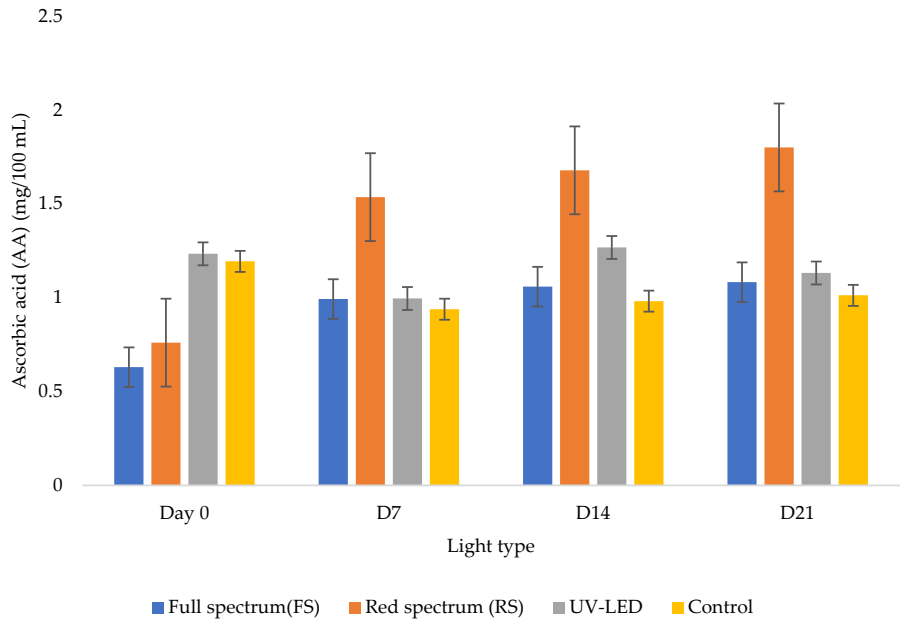



**Figure 5.** Ascorbic acid monitoring results.

ANOVA findings from the fruit size monitoring are summarized in Table S3. It is evident that an ANOVA analysis of the datasets yielded a *p*-value of 0.097458. Given that the obtained *p*-value was greater than 0.05 (alpha value), the differences between the datasets based on the studied parameters were statistically insignificant.

However, when the ascorbic acid monitoring results from the full spectrum vs. red spectrum, full spectrum vs. UV-LED, full spectrum vs. control red spectrum vs. UV-LED, red spectrum vs. control as well as UV-LED vs. control results were subjected to the Tukey's honest significance test, *p*-values higher than 0.01 were retrieved, making the differences statistically insignificant (Table 6).

**Table 6.** Tukey's honest significance test results from ascorbic acid monitoring results.

| Treatments Pair | Tukey's HSD Q Statistic | Tukey's HSD *p*-Value | Tukey's HSD Inference |
|---|---|---|---|
| Full spectrum (FS) vs. red spectrum (RS) | 3.7283 | 0.088083 | insignificant |
| Full spectrum (FS) vs. UV-LED | 1.6029 | 0.663574 | insignificant |
| Full spectrum (FS) vs. control | 0.6726 | 0.899995 | insignificant |
| Red spectrum (RS) vs. UV-LED | 2.1254 | 0.466654 | insignificant |
| Red spectrum (RS) vs. control | 3.0556 | 0.189558 | insignificant |
| UV-LED vs. control | 0.9302 | 0.899995 | insignificant |

### *3.4. Lycopene*

Additionally, it was noted in the study that the full spectra were somewhat observed to preserve the samples' lycopene concentrations with time (Figure 6). The fact that the lycopene concentration of fruit keeps increasing as the fruit ripens is related to the overall increase in lycopene content. It should be mentioned that lycopene is an antioxidant-rich plant nutrient; it is the pigment responsible for the distinctive colors in fruits. Lycopene has been associated with health advantages ranging from heart health to defense against skin cancer and sunburn. In red, pink, and orange fruit and vegetables such as tomatoes and cranberries, lycopene, a lipophilic carotenoid hydrocarbon pigment, can be found. A food-grade source of carotenoid may be obtained via lycopene extraction [50].

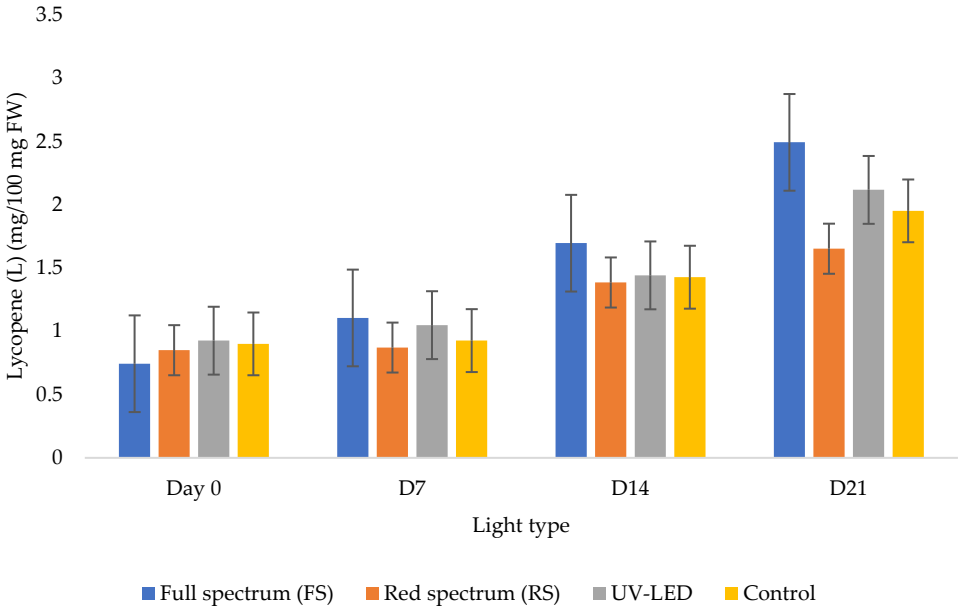



**Figure 6.** Lycopene monitoring results.

According to [51], about 23 mg of lycopene are present in one cup (240 mL) of tomato juice. The natural lycopene in raw tomatoes is changed into a form that is more readily absorbed by the body when they are heated during processing (such as when preparing

tomato juice, tomato paste, or ketchup). Lycopene supplements are used to prevent cardiovascular disease as well as cancers of the pancreatic, prostate, breast, lung, bladder, and ovaries. Because of their outstanding antioxidant capabilities, lycopene and lycopene supplements can reduce the risk of coronary artery disease [52].

Table S4 summarizes the lycopene monitoring ANOVA results, whereby the ANOVA produced a *p*-value of 0.925602. The discrepancies between the datasets based on the investigated parameters were statistically insignificant because the obtained *p*-value was more than 0.05 (alpha value).

Similarly, when the lycopene monitoring results from full spectrum vs. red spectrum, full spectrum vs. UV-LED, full spectrum vs. control red spectrum vs. UV-LED, red spectrum vs. control as well as UV-LED vs. control results were subjected to the Tukey's honest significance test, *p*-values higher than 0.01 were retrieved, making the differences statistically insignificant (Table 7).

**Table 7.** Tukey's honest significance test results from lycopene monitoring results.

| Treatments Pair | Tukey's HSD Q Statistic | Tukey's HSD *p*-Value | Tukey's HSD Inference |
|---|---|---|---|
| Full spectrum (FS) vs. red spectrum (RS) | 0.8829 | 0.899995 | insignificant |
| Full spectrum (FS) vs. UV-LED | 0.4554 | 0.899995 | insignificant |
| Full spectrum (FS) vs. control | 0.7512 | 0.899995 | insignificant |
| Red spectrum (RS) vs. UV-LED | 0.4275 | 0.899995 | insignificant |
| Red spectrum (RS) vs. control | 0.1317 | 0.899995 | insignificant |
| UV-LED vs. control | 0.2958 | 0.899995 | insignificant |

### *3.5. Total Soluble Solids*

The full spectra were also observed to be highly effective in terms of preserving total soluble solids in samples (Figure 7), with the lowest TSS concentration observed from the control sample. To be more precise, after 21 days of preservation, the total soluble solids concentration was 3.9 °Brix in the control samples and around 7.3 °Brix in the full spectrum-preserved samples. Total soluble solids are a crucial indicator of fruit quality. TSS gives the liquid soluble solids content [53]. Because it might reveal the fruit's level of sweetness, the TSS value has an impact on the flavor of the fruit. The typical method for determining a fruit's TSS concentration is to measure its Brix level [54]. However, one drawback of utilizing Brix as a maturity indicator is that, in the case of climacteric fruits, TSS upon harvest is not a reliable predictor of TSS after a lengthy period of storage. It is substantially more accurate to predict TSS after storage based on dry matter content at harvest. Dry matter is entirely composed of solids, including soluble sugars and insoluble starches. Therefore, the starch that would eventually transform into sugar is taken into account, making the dry matter a good indication of flavor in all fruits. The fruit's carbohydrates, organic acids, proteins, lipids, and minerals are all measured by the TSS, or sugar content. It makes up a significant amount of the fruit's fresh weight and grows as the fruit ripens to produce a sweeter, less acidic fruit. A desirable balance of TSS and fruit acidity must be produced by the farmer.

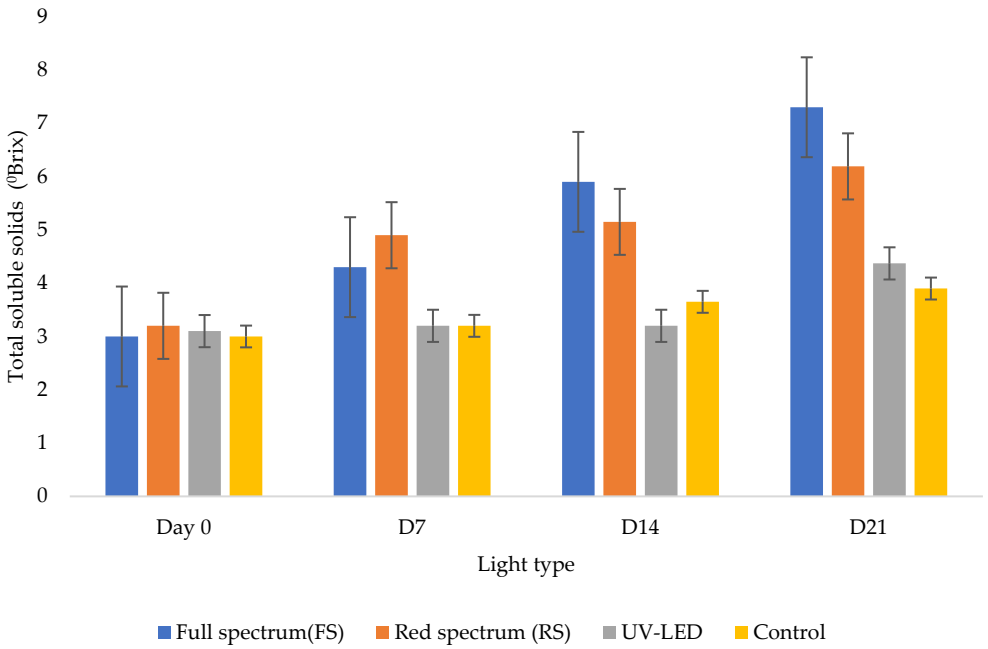



**Figure 7.** Total soluble solids.

The findings of the ANOVA monitoring of the total soluble solids are summarized in Table S5, with a *p*-value of 0.056578. Because the obtained *p*-value was greater than 0.05, the differences between the datasets based on the studied parameters were statistically insignificant (alpha value).

In the same way, *p*-values higher than 0.01 were obtained when the monitoring results of the total soluble solids from the full spectrum vs. red spectrum, full spectrum vs. UV-LED, full spectrum vs. control, red spectrum vs. UV-LED, as well as UV-LED vs. control results, were subjected to the Tukey's honest significance test making the differences statistically insignificant (Table 8).

**Table 8.** Tukey's honest significance test results from total soluble solids monitoring results.

| Treatments Pair | Tukey's HSD Q Statistic | Tukey's HSD *p*-Value | Tukey's HSD Inference |
|---|---|---|---|
| Full spectrum (FS) vs. red spectrum (RS) | 1.0422 | 0.874909 | insignificant |
| Full spectrum (FS) vs. UV-LED | 3.5647 | 0.106839 | insignificant |
| Full spectrum (FS) vs. control | 3.62 | 0.10012 | insignificant |
| Red spectrum (RS) vs. UV-LED | 2.5225 | 0.327052 | insignificant |
| Red spectrum (RS) vs. control | 2.5778 | 0.310183 | insignificant |
| UV-LED vs. control | 0.0553 | 0.899995 | insignificant |

### *3.6. pH Monitoring Results*

Figure 8 presents the summary of the pH results from the study. Along with sugars and flavor volatiles, acidity plays a significant role in determining the flavor and quality of most fruits. However, the molecular genetic control of plant acid levels is still poorly understood. The majority of eatable fruits have acidic pH values between 3–5. Even in major fruit crops such as grape, citrus, tomato, peach, and apple, which have drawn significant attention in genomic, biochemical, and physiological research, the genes responsible have not yet been definitively identified. Genetic variation for fruit acidity has been identified in many fruit crops but the genes responsible have yet to be definitively identified [55].

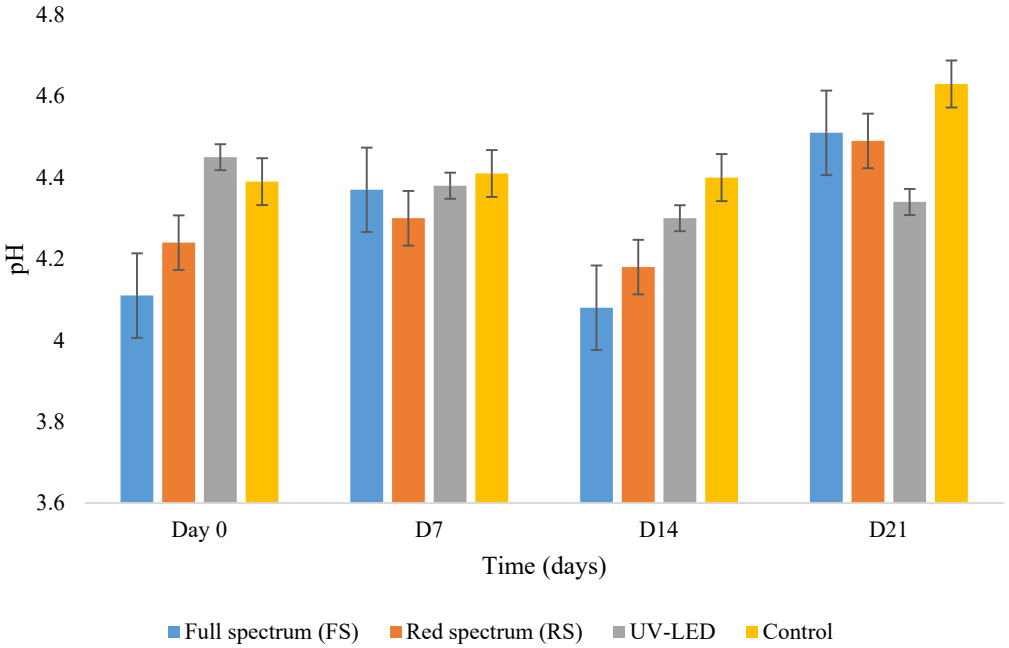



**Figure 8.** pH monitoring results.

Table S6 provides a summary of the pH monitoring ANOVA results with a *p*-value of 0.284881. The discrepancies between the datasets based on the investigated parameters were statistically insignificant because the obtained *p*-value was more than 0.05 (alpha value).

Furthermore, the differences were found to be statistically insignificant when the pH monitoring results from full spectrum vs. red spectrum, full spectrum vs. UV-LED, full spectrum vs. control, red spectrum vs. UV-LED, and UV-LED vs. control results were subjected to Tukey's honest significance test (Table 9).

**Table 9.** Tukey's honest significance test results from pH monitoring results.

| Treatments Pair | Tukey's HSD Q Statistic | Tukey's HSD *p*-Value | Tukey's HSD Inference |
|---|---|---|---|
| Full spectrum (FS) vs. red spectrum (RS) | 0.4997 | 0.899995 | insignificant |
| Full spectrum (FS) vs. UV-LED | 1.4277 | 0.729618 | insignificant |
| Full spectrum (FS) vs. control | 2.7126 | 0.271535 | insignificant |
| Red spectrum (RS) vs. UV-LED | 0.928 | 0.899995 | insignificant |
| Red spectrum (RS) vs. control | 2.2129 | 0.434068 | insignificant |
| UV-LED vs. control | 1.2849 | 0.783428 | insignificant |

### *3.7. Moisture Content Monitoring Results*

The findings from the moisture content investigations based on the samples preserved using various preservation techniques are summarized in Figure 9. When compared to the other preservation systems studied in the study, the full spectrum preservation method was typically quite effective in preserving the moisture content in the samples, as seen by the control sample's lowest moisture content. Approximately 66.2% of the moisture content from the 14-day samples and 59.2% of the moisture content from the 21-day samples were both obtained from the full spectrum system. Furthermore, the control sample had roughly 50.4% of moisture content from the 14-day samples and roughly 32.3% from the 21-day samples.

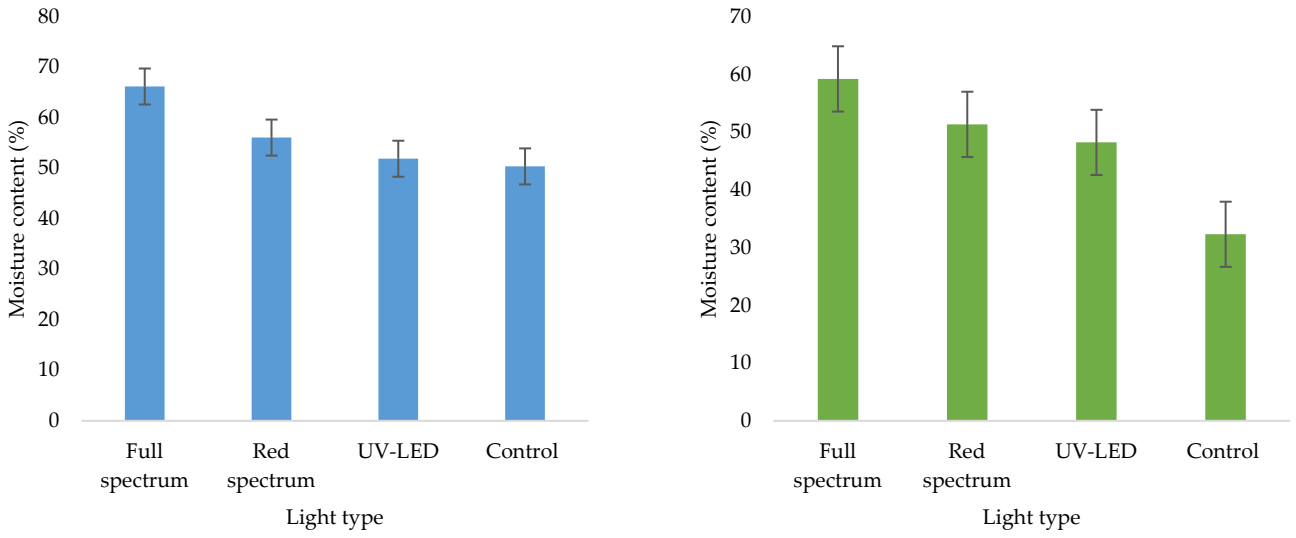



**Figure 9.** Moisture content monitoring results (**a**) day 14 (**b**) day 15.

### *3.8. Correlation Analysis*

The degree of change in one variable as a result of the other's change was determined using correlation analysis. You can infer that the other variable or metric is also being impacted in a similar way if there is evidence of a high connection between the two and one of them is acting in a certain way. A common thread, or an underlying cause of events that, on the surface, may appear unrelated and unexplained, can be found through relating unrelated events and patterns. A high correlation indicates a significant link between the two measurements, whereas a low correlation indicates a poor association between the two metrics. A positive correlation indicates that both measurements grow in tandem, whereas a negative correlation indicates that as one metric grows, the other one shrinks. Table 10 demonstrates that there was a very strong positive correlation between tomato sample size and weight, with a correlation coefficient of 0.998498. With a correlation coefficient of 0.947123, it was also possible to discern a very strong positive correlation between lycopene and TSS (Table 10).

**Table 10.** Relationship among different parameters.

| | Weight | Size | Ascorbic Acid | Lycopene | TSS | pH |
|---|---|---|---|---|---|---|
| Weight | 1 | | | | | |
| Size | 0.998498 | 1 | | | | |
| Ascorbic acid | 0.632944 | 0.659211 | 1 | | | |
| Lycopene | −0.91723 | −0.89688 | −0.29162 | 1 | | |
| TSS | −0.99585 | −0.99124 | −0.5599 | 0.947123 | 1 | |
| pH | −0.71498 | −0.67612 | −0.17835 | 0.871942 | 0.743132 | 1 |

TSS = total soluble solids.

## 4. Discussion

Based on various criteria for fruit quality, the potential utility of various UV light spectra for the preservation of tomatoes was examined. The tomato was an ideal fruit for this study because it is one of the most perishable types of fruit and is widely consumed worldwide. It ripens quickly depending on the humidity and temperature, which finally led to poor quality as the fruit turned soft and unpalatable. It must therefore be harvested at the proper time because an overripe tomato is more vulnerable to physical harm than a ripe or pink one. After harvest, ripening continues, and tomatoes can quickly become overripe. Because tomatoes are climacteric fruits, their respiratory activity peaks as they

ripen. Tomatoes have an extremely short shelf life because they are a climacteric and perishable produce, often within 2 to 3 weeks [56]. The control sample, which was not preserved, showed the greatest weight loss (4.46%) when compared to the samples that were preserved using various UV radiation spectra. It is also evident that the full spectrum had the lowest weight loss. The full spectrum preservation system was more effective at preserving the fruits in terms of weight loss than the other preservation methods. It is also evident that the full spectrum had the lowest weight loss. In other words, the full spectrum preservation approach was more effective in preserving the fruits in terms of weight loss than the other preservation methods. UV-C is increasingly being used as an alternative to post-harvest sanitation of both fruits and vegetables. According to research, sanitizing our fruit and vegetables with UV light can prevent the growth of microorganisms without degrading the quality of the produce. Compared to regularly used chemicals such as chlorine, hydrogen peroxide, or ozone, which can leave residues and eventually lower quality, UV radiation has the potential to be more successful at reducing microbial growth [57].

Moreover, according to the Food and Agriculture Organization of the United Nations [58], the majority of tomato fruit is water, and once it is harvested, it can no longer replenish the water lost. High temperatures and low relative humidity cause water to evaporate, reducing the amount of marketable weight. An ANOVA analysis of the weight monitoring datasets revealed a $p$-value of $1.02 \times 10^{-6}$. It can be stated that the differences between the analyzed parameters' impacts on the datasets were statistically significant because the resulting $p$-value is less than 0.05 (alpha value). It is also significant to point out that ANOVA is a commonly used method for univariate data and is a fundamental tool in many research domains [59]. It establishes and quantifies the influence of various experimental parameters on the observable experiment result. The first step in an ANOVA is to estimate these effects for each factor and any potential interactions. The significance of these effects is inferred as the second step in an ANOVA. The well-known F-test is employed under the presumption that the measurements are normally distributed with equal variance under the various experimental settings [60].

The control sample, according to the results, had the highest reduction in tomato size over time. The size changes were, however, frequently extremely slight when compared to all of the tested preservation techniques. As was previously mentioned, tomato fruits are primarily made up of water, and once picked, they are unable to replenish the water lost. Low relative humidity and high temperatures cause water to evaporate, reducing the amount of marketable weight. Shriveling also results from the fruit losing water.

The control sample, according to the results, had the lowest ascorbic acid level after 21 days. The phenomenon highlights once more how critical it is to use sensible methods to preserve tomatoes. Tomato juices for instance, which have seen sharp increases in consumption in recent years, are the main source of ascorbic acid. However, ascorbic acid in fruit juices is easily oxidized and lost while the juices are in storage, at rates that depend on the storage circumstances. It follows that the content and rate of loss after remaining determine the quality of any fruit juice and its worth as a source of vitamin C. However, in general, it is anticipated that the ascorbic acid in tomatoes would start to decline over time. For instance, in the study of Yahia et al. [60], ascorbic acid in tomato fruit was found to gradually grow, peaking at 94.9 mg/100 g after 74 days, before slowly declining. As evidenced by a color change, the ascorbic acid level dropped at the same time that ripening began, and ascorbate oxidase activity increased.

The study also found that the lycopene concentrations in the samples were highly preserved over time by the full spectra. However, it was generally shown that the lycopene levels in the samples under study were rising over time. The overall increase in lycopene content is a phenomenon that is related to the fact that the fruit's lycopene concentration keeps rising as the fruit ripens. Lycopene, the principal chemical responsible for the vivid red hue of ripe tomatoes and tomato-based products, is most commonly found in tomatoes. Watermelon, pink grapefruit, apricots, pink guava, and papaya are other foods from plants

that contain lycopene, although tomato-based foods like ketchup, tomato paste, pizza sauce, spaghetti sauce, and tomato soup continue to be the main sources. Lycopene has largely been studied in vitro and in animal models to demonstrate its possible health benefits, including a decreased risk of malignancies of the prostate, breast, lung, and digestive tract [61]. Moreover, in the literature, a potential correlation between lycopene and tomato firmness has been reported. For instance, in the study conducted by Buccheri and Cantwell on fruit ripening conditions affecting the quality of sliced red tomatoes, it was observed that tomatoes ripened at a lower temperature (15 °C) had higher fruit firmness, while tomatoes kept at 25 °C had a lower lycopene content and lower firmness [62].

Additionally, the *p*-value for the ANOVA using lycopene findings obtained using various preservation techniques was 0.925602. The findings show that because the obtained *p*-value was greater than 0.05, the differences between the datasets based on the analyzed parameters were statistically insignificant (alpha value). When the lycopene monitoring results from full spectrum vs. red spectrum, full spectrum vs. UV-LED, full spectrum vs. control, red spectrum vs. UV-LED, red spectrum vs. control, as well as UV-LED vs. control were subjected to the Tukey's honest significance test, *p*-values higher than 0.01 were retrieved, making the differences statistically insignificant.

As already mentioned, it was shown that the full spectrum was also quite successful at keeping total soluble solids in the tomato samples. with the control sample having the lowest TSS concentration found. The typical method for determining a fruit's TSS concentration is to measure its Brix level. The fruit's carbohydrates, organic acids, proteins, lipids, and minerals are all measured by the TSS, or sugar content. It makes up between 10 and 20 percent of the fruit's fresh weight and grows as the fruit ripens to produce a sweeter, less acidic fruit. It is crucial that the producer makes an effort to establish a TSS and fruit acidity balance that is deemed acceptable.

With a correlation coefficient of 0.998498, the findings showed that there was a very high positive association between tomato sample size and weight. The findings also reveal a very strong positive link between lycopene and TSS, with a correlation coefficient of 0.947123. Other parameters, including pH versus lycopene and pH versus TSS, were also shown to be substantially correlated, with correlation coefficients of 0.871942 and 0.743132, respectively. Similarly, lycopene was shown to be positively correlated with TSS in the study by Panthee et al. [63] on the degree of genotype and environment interactions on tomato fruit quality. Total soluble solids (TSS) and pH, lycopene content, and vitamin C were found to be positively and highly significantly correlated with TSS, while moisture content and titrable acidity had negatively and highly significantly correlated with TSS, according to a study by Shobo et al. [64], on correlation and path coefficient analysis for TSS in tomato (Lycopersicon esculentum Mill) fruit. Fruit hardness, moisture content, titratable acidity, and lycopene content had a direct but detrimental effect on TSS, but vitamin C content and pH had beneficial and direct effects on TSS. The direct influence of vitamin C on TSS was greatest. The authors also came to the conclusion that screening tomato genotypes using a combination of these qualities as selection indices is advised for tomato fruits' total soluble solids rather than focusing on any one trait with a direct effect on TSS in an effective selection for high TSS in tomato fruit. The pigments (such as chlorophyll, carotenoids, anthocyanins, etc.) that give fruits their color are significantly influenced by pH. Additionally, pH has a significant effect on water-holding capacity and softness, which may have an impact on the firmness of the fruit [65]. Furthermore, Jia et al. [66], looked at the pattern in changes in TSS along with fruit growth and ripening to see whether variations in TSS might be correlated to the changes in fruit water relationship. It was shown that increases in TSS were closely linked with changes in fruit hardness, indicating a close relationship with the start of fruit ripening.

Moreover, it should be noted that, when a tomato is damaged, biological processes such as respiration and ethylene production move very quickly, causing the fruit to quickly deteriorate. It is possible that the damage won't be apparent during the green stage, but it might become apparent later on during the sale as compression and discoloration in the

flesh. Insects and other creatures that cause decay can attack tomatoes, which could hasten the process of degradation. Handling anything roughly may result in wounds that act as entryways for organisms that cause deterioration. Additionally, wounds can cause water loss and hasten ripening [67]. Additionally, it is important to note that, when done correctly, UV therapy can be a competitive process when applied to meals, where the huge surface area for UV rays reaches the entire volume of the item. Food composition may change if UV treatment is administered incorrectly. Both free-radical and photochemical reactions can break down proteins, harm antioxidants, oxidize lipids, modify color and composition, and produce flavorings and odors that are not desired. Some vitamins are more vulnerable to UV radiation, and as a result, losses can even approach 50%. Vitamins C, B12, B6, B2, and folic acid are photosensitive water-soluble vitamins, whereas vitamins A, K, and E are photosensitive fat-soluble vitamins; carotene is the only provitamin with such qualities. On the other hand, due to the photosensitivity of fungal toxins, UV therapy can be a beneficial technique for general food safety [68].

## 5. Conclusions

As a result, compared to the control samples of tomatoes, tomato fruits exposed to three different spectra of LED lights displayed improved qualities in terms of lycopene content, ascorbic acid, firmness and size, fruit mass, total soluble solids, and moisture content. Even while the lycopene concentration in control samples was quite high for the first five days of storage, the increase in lycopene concentrations in samples was not as good as the ones from the preserved samples. The red spectrum preservation system, in contrast to full spectrum and UV-LED systems, was shown to significantly improve the lycopene concentrations, which was an intriguing phenomenon. The concentration of ascorbic acid in the full-spectrum samples was substantially higher than in the red spectrum and UV-LED samples. However, the concentrations of ascorbic acid in the samples were noticeably higher in the preserved samples compared to the control samples. Total soluble solids improved noticeably after preservation, particularly in samples exposed to UV-LED lights. Overall, the study's findings demonstrated that tomato preservation utilizing the investigated technologies has a significant potential to enhance the status of the quality parameters in tomatoes. Moreover, the findings of this study offer a wealth of knowledge in the area of post-harvest preservation towards devising and developing highly efficient and effective preservation technologies.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15021111/s1, Table S1: ANOVA results from fruit weight monitoring; Table S2: ANOVA results from size monitoring results; Table S3: ANOVA results from ascorbic acid monitoring results; Table S4: ANOVA results from lycopene monitoring results; Table S5: ANOVA results from total soluble solids monitoring results; Table S6: ANOVA results from pH monitoring results.

**Author Contributions:** Conceptualization, Z.A. and K.M.; methodology, Z.A.; investigation, Z.A., T.M. and K.M.; data curation, T.M. and D.D.; writing—original draft preparation, Z.A. and T.M.; writing—review and editing, T.M. and Z.A.; formal analysis, Z.A. and T.M.; resources, A.K., S.Z. and R.U.; software, A.T.; validation, G.A. and D.D.; visualization, Z.A. and T.M.; supervision, K.M.; project administration, K.M.; funding acquisition, K.M. and Z.A. All authors have read and agreed to the published version of the manuscript.

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