Effect of combining UV-C irradiation and vacuum sealing on the shelf life of fresh strawberries and tomatoes

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Abstract: This research presents the effect of combining UV-C irradiation and vacuum sealing on the shelf life of strawberries and quartered tomatoes and compares it with the effect of the sole use of UV-C irradiation or vacuum sealing. A constant UV-C dose of 360 J/m² was used for the samples’ irradiation, and all the vacuum-sealed samples were stored at a reduced pressure of 40 kPa. Organoleptic analysis, microbial population quantification of yeast and mold, Pseudomonas sp., weight loss, and pH measurements were obtained to identify the spoilage occurrence, monitor the samples’ quality, and quantify the shelf life. Sensory evaluation was conducted by 12 consumer panelists to evaluate the aroma, taste, color, texture, and the overall acceptance of the samples. The results revealed that the combination of UV-C irradiation and vacuum sealing prolongs the shelf life of perishables more than the sole use of UV-C irradiation or vacuum sealing. The achieved shelf-life increase using this combination was 124.41% and 54.41% for strawberries and quartered tomatoes, respectively, while acceptable sensory characteristics were maintained throughout the storage period. Hence, this food preservation method can be further improved and integrated in the daily life of modern consumers and the operations of fresh produce retailers, as it could effectively reduce the spoilage rates of fresh produce and help achieve the UN SDG 12.3, which aims to reduce food loss and waste by 50% by 2030 at the consumer and retail levels.

KEYWORDS
food waste, shelf life, strawberry preservation, tomato preservation, UV-C irradiation, vacuum packaging

Practical Application: The system can be further developed and introduced to the market as a kitchen appliance for households or as a predistribution step for fresh produce distribution centers. The shelf-life extension capability of this system, which does not involve any use of chemical substances, would make it an attractive solution for households and food retailers.

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1 | INTRODUCTION

Food loss and waste are among the most pressing global issues. They are commonly regarded as a significant obstacle to global sustainability, and they significantly affect the global economy; according to the Food and Agriculture Organization (FAO), worldwide food waste cost is estimated at $750 billion (McGuire, 2015; Xue et al., 2017). The United Nations estimated that food waste produces over 3 million tonnes$^2$ of greenhouse gases (GHGs), representing 11% of all GHGs (FAO, 2019; Scherhaufer et al., 2018). Food loss and waste occur for various reasons across the supply chain, some occurs due to microbial infection, which can cost up to 30% of a crop’s overall yield, while in the other hand farmers, sellers, and processors would discard food that they expect to be undesirable due to consumers’ perceptions of product quality (Papargyropoulou et al., 2014). The quality deterioration of fresh produce can occur in a variety of ways during the growing, handling, harvesting, and transportation processes, and even after purchase by consumers or service providers. Nevertheless, the main causes of loss and waste are microbial infections, improper handling and packaging, ineffective storage systems, insufficient on-farm storage facilities, and harsh weather conditions (Joardder & Masud, 2019; Saeed et al., 2021). Globally, numerous food items are increasingly being sold in regions that are geographically far from their origins; therefore, there is a growing demand for a longer food shelf life and advanced food preservation methods that can be used during storage and transportation (Rawat, 2015).

Fragile produce such as tomatoes and strawberries are more prone to postharvest deterioration in comparison to other produce due to their delicate textures and high moisture content. Tomatoes and strawberries are among the most consumed produce globally (Saeed et al., 2021; Xue et al., 2021). However, they generate high loss and waste volumes across various points in the supply chain due to their high perishability. The postharvest tomato wastage in Europe is estimated at 3 million metric tons per year. In Australia, yearly tomato crop losses were estimated to be between 27% and 36% (Løvdal et al., 2019). Similarly, in-field food loss statistics for tomatoes in Florida showed an average loss of 40% of the crop (Thorsen et al., 2021). On the other hand, fresh strawberries are one of the most popular fruits in the world and are in great demand due to their flavor, high nutritional content, and range of health advantages, including anti-inflammatory, anticancer, and antioxidant properties (Shahbazi et al., 2021). However, fresh strawberries are highly perishable with short postharvest life mainly due to high respiration rate, excessive soft texture, sensitivity to temperature, water loss, microbiological decay, and mechanical injury and vibrations, which makes their marketing a challenge (Shahbazi, 2018). Strawberry waste happens at every stage of the life cycle, including production, distribution, retail, and household handling. This amounts to an estimated 640 million pounds of strawberries lost, with a market value of $1.4 billion (Kessler, 2020).

Several food preservation methods have been developed in the recent years to extend the shelf life of perishables and reduce the waste. Edible coatings have been extensively studied as a natural means of controlling the growth of microorganisms and extending the shelf life of fresh produce. For instance, gum arabic (a polysaccharide) and mango kernel starch have been used as edible coatings for extending the shelf life of tomatoes, where both coating materials increased the shelf life of tomato by up to 20 days at a storage temperature of 20°C (Ali et al., 2010; Nawab et al., 2017). Several edible coating materials have also shown positive results and improved the shelf life of strawberries under cold storage (Pinzon et al., 2020; Saleem et al., 2021). However, although edible coatings can enhance the shelf life of produce, their poor barrier properties and the unappealing flavor are among the main disadvantages of this method (Duguma, 2022). Ultraviolet irradiation is considered a highly effective method for prolonging the shelf life of perishables (Delorme et al., 2020). The wavelength region of UV-C light (200–280 nm) is known for its germicidal effects, as it damages the DNA of pathogenetic microorganisms, affecting their metabolism and reproduction and ultimately resulting in cell death (Brem et al., 2017; Gayán et al., 2011). Various researchers have demonstrated the positive effect of UV-C radiation in limiting microbial growth and increasing the shelf life of perishables (Allende et al., 2006; Gogo et al., 2017; González-Aguilar et al., 2007; Khan & Kanesamkandi, 2013; Liu et al., 2012; Manzocco et al., 2011; Pinheiro et al., 2015; Rabelo et al., 2020; Rodoni et al., 2012). A recent study (Araque et al., 2022) reported that a UV-C irradiation dose of 4 KJ/cm$^2$ can be useful to extend the shelf life of fresh-cut strawberries (stored at 4°C) for up to 7 days. Furthermore, fresh strawberries were subjected to UV-C irradiation at lower doses of 0.8–4 KJ/m$^2$, and results revealed that the treatment increased the shelf life of strawberry samples for up to 13 days while storing them at 0°C (Araque et al., 2018).

The shelf life of tomatoes can also be increased through UV-C treatment. Pataro et al. (2015) found that the shelf life of fresh tomatoes can be increased for up to 21 days when a UV-C irradiation of 1–8 J/cm$^2$ is applied at a storage temperature of 20°C. Similarly, another study (Pinheiro et al., 2015) reported that the shelf life of tomatoes could be increased by up to 15 days after the treatment of fruit with UV-C light (0.32–4.83 KJ/m$^2$ at 254 nm). However, despite the spoilage delay after UV-C irradiation, the long
storage time can affect the sensory characteristics of food and cause tissue softening, browning, aroma deterioration, and weight loss (Allende et al., 2006; Rodoni et al., 2012).

Vacuum sealing is another widely used method for food preservation due to its ability to extend the shelf life of perishables, decreasing the weight loss and browning index of fresh produce while retaining its firmness (Moradinezhad & Dorostkar, 2021; Moradinezhad et al., 2019; Othman et al., 2021). Vacuum packaging can increase the shelf life of strawberries by 1–3 days (Putri et al., 2021). It has also been reported to increase the shelf life of tomatoes up to 21 days at a storage temperature of 4°C while maintaining the fruit's quality (phenolic and carotenoid content) and vitamin C content (Odriozola-Serrano et al., 2009).

The sole use of UV-C irradiation or vacuum sealing has been widely studied and applied in various food industries; however, the effect of the combination of both preservation methods has not been studied yet. Therefore, this paper investigates the effectiveness of combining UV-C irradiation and vacuum sealing in extending the shelf life of fruits in comparison to the sole use of UV-C irradiation or vacuum sealing. Tomatoes and strawberries were chosen for this research due to their high market demand, high monetary value, and high perishability.

2 MATERIALS AND METHODS

2.1 Sample preparations

Whole tomatoes and strawberries that are free from external defects were purchased from a local supermarket (Thuwal, Saudi Arabia). The strawberries were supplied by Driscoll’s Inc. (Watsonville, CA, USA), and the tomatoes were supplied by Mahasil Agriculture Company Co. (Unayzah, Saudi Arabia). All samples were washed using tap water and dried using napkins. Whole strawberries were used for the shelf-life experiments, whereas the tomatoes were cut into four equal quarters.

2.2 Experimental setups

Every experiment consisted of eight samples: four strawberry samples, each weighing 100 g, and four quartered tomato samples, each weighing 200 g. All the samples were stored in 1.4-L plastic containers made of Eastman Tritan PCTG TX1001 at a temperature of 4°C and a relative humidity level of 60%. To investigate the effectiveness of the combination of the UV-C irradiation and vacuum sealing in extending the shelf life of the whole strawberry and quartered tomato samples, the physicochemical characteristics of the fruits were examined while storing the samples under four different conditions:

1. An anaerobic and sterilized environment created by UV-C irradiation and vacuum sealing (UV-C and vacuum);
2. An aerobic sterilized environment created by UV-C irradiation (UV-C only);
3. An anaerobic environment created by vacuum sealing the storage container (vacuum only);
4. A normal aerobic environment (control).

Four UV-C lamps (253.7 nm, 2G11, 18 W; Philips, Shanghai, China) were mounted on movable racks from the right, left, top, and bottom sides of the storage container. Each lamp was turned on for 10 min prior to exposure to stabilize the wavelength at 253.7 nm. The distance between the samples and each lamp was 2 cm, and the exposure time was 30 s. The samples received a UV-C light dose of 360 J/m², with the UV-C light intensity measured using an ultraviolet meter (Zenith, Atlantic Ultraviolet Corporation, New York, USA). The vacuum-sealed samples were maintained at a reduced pressure of 40 kPa using a 12-V oxygen vacuum pump (JP1). As determined by the AR8100 oxygen sensor, the oxygen levels in the vacuumed containers range from 1.7% to 1.8%, whereas those in the unvacuumed containers range from 20.7% to 21%. The strawberry and tomato shelf-life experiments were repeated three times using different samples that were harvested at different times to increase the accuracy of the shelf-life estimation.

2.3 Shelf life and quality examination

2.3.1 Organoleptic analysis

Color and appearance, flavor (taste and aroma), and texture are the main distinguishing sensory characteristics of fruits and vegetables that influence the consumers’ purchase and consumption decisions (Barrett et al., 2010). Therefore, these characteristics of all experimental samples were examined daily to monitor the changes in color, wilting, smell, texture, and appearance to identify spoilage. A group of 12 untrained panelists that consist of six females and six males with an age range of 21–41 years have evaluated the sensory characteristic of the samples every 3 days during the experiment period. The panelists examined the qualitative traits of strawberries and tomatoes, which are the color, texture, taste, aroma, and overall acceptance. The evaluation was provided on a scale from 1 to 9, where 1 is the lowest score that indicates undesirable sensory traits and 9 is the highest score that indicates attractive sensory traits. For instance, the score of 9 for strawberry and tomato implies an attractive red shell color, firm pulp texture (as resistance to finger pressure), extremely fresh flavor, and very fresh aroma, while the score of 1 implies very soft pulp,
very dark or brownish shell color, soft shell, slimy texture, off-taste, and off-aroma.

2.3.2 Weight loss

The weight loss of each sample compares the weight at the first day of storage and the last day prior to spoilage. The weight loss percentages were calculated as follows (Hosseini et al., 2019):

\[
\text{Weight loss(\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100.
\]

2.3.3 Microbial analysis

Aerobic mesophilic bacteria and Enterobacteriaceae, Pseudomonas sp., and lactic acid bacteria were counted for every sample by applying Plate Count Agar (PCA) and Violet Red Bile Glucose agar (VRBG), Pseudomonas CFC Agar Base, and De Man, Rogosa and Sharpe agar (MRS), respectively. Dichloran Rose-Bengal Chloramphenicol agar (DRBC) was used to enumerate yeast and mold. The work area and tools were cleaned with 70% alcohol. Thereafter, 5 g from each sample was taken for the serial dilutions and placed in stomacher bags, and 45 ml of sterile physiological solution was then added and homogenized in the stomacher for 1 min to obtain the initial suspension (10⁻¹ dilution). For the second dilution (10⁻²), a sterile pipette was used to take 1 ml from the first dilution and added to 9 ml of the physiological solution, and the same process was repeated for additional dilutions. The microbial loads were enumerated by spread-plating 100 µl of each dilution into the PCA, DRBC, and CFC and pour-plating 1 ml of each dilution into VRBG and MRS. The Petri dishes of the aerobic mesophilic bacteria, Enterobacteriaceae, Pseudomonas sp., and lactic acid bacteria were incubated for 24 h at 37°C, while the yeast and mold Petri dishes were incubated for 5 days at 25°C. The microbial populations were detected on separate days during the experimental period, and the results were captured in the form of log of colony-forming units per gram (log CFU/g) (Hosseini et al., 2019).

2.3.4 PH measurements

The pH levels were measured by taking 2.5g from each sample and mixing it with an equal amount of distilled water as stated in the ISO 1842:1991 standards. Thermo Scientific Orion 5 Star Benchtop Multiparameter Meters was used for measuring the pH.

3 RESULTS AND DISCUSSION

3.1 Weight loss and sensory characteristics evaluation

The weight loss is an indication of dehydration, decomposition, and overall quality decay, which directly contribute to the shelf-life deterioration of fresh produce. All experimental samples in this study decayed throughout the storage period as shown in Figure 1a,b; however, the weight loss percentages were influenced by the storage condition.

As shown in the figure, the samples that were stored in the UV-C and vacuum condition lost less weight in comparison to other samples that were either irradiated with UV-C light only or only vacuum sealed in all the experimental iterations. The vacuum storage condition came second in terms of decay, followed by the UV-C condition, while the control samples experienced a relatively larger decay. The weight loss is associated with a higher polyphenol oxidase (PPO) enzyme reaction, which stimulates the oxidation of phenolic compounds in fresh produce and consequently affects the firmness and color of the produce (Xu et al., 2022; Yoon et al., 2022). The low oxygen levels in the vacuumed samples limited the PPO activity and resulted in reduced weight loss. For the UV-C-irradiated samples, the weight loss reduction is attributed to the effect of the UV-C irradiation on the inactivation of microorganisms, as limiting their growth reduces damage to the walls and tissues, maintains the firmness, and limits the weight reduction of the produce (Hosseini et al., 2019).

In general, the weight loss in fresh produce is a result of the transpiration (moisture loss) and respiration (carbon loss) processes. Hence, prolonging the shelf life of perishables can be achieved by limiting the transpiration and respiration rates, which are associated with various factors including storage temperature and humidity levels, postharvest handling processes, and transportation conditions. However, since moisture passes through the skin of the fruits and vegetables before it evaporates, the transpiration rate is directly proportional to skin permeability. Skin permeability is a function of the skin mass transfer coefficient—an indicator of the skin’s porosity level, which defines its resistance to the moisture passage (Becker & Fricke, 1996). Chau et al. (1987) and Gan and Woods (1989) have experimentally defined the skin mass transfer coefficients of various fresh produce: the mean coefficients of strawberries and tomatoes are 13.6 and 10.1, respectively, which justifies the higher weight loss values of the strawberry samples in comparison to the tomato samples in the present study.
3.2 | Microbial analysis

The microbial populations were quantified for all the strawberry and tomato samples on different days to study the effect of each storage condition on the microbial growth rate, which influences the alteration of the sensory characteristics of the samples. The population growth of *Pseudomonas* sp. and yeast and mold is shown in Figure 2 for the strawberry samples and in Figure 3 for the tomato samples.

The growth of *Pseudomonas* sp. was very slow in the first days for all samples, but it abruptly increased during the last few days. It was observed that the growth rates of *Pseudomonas* sp. were affected by the storage environment and the chemistry of each fruit. For instance, it was noticed that the growth of *Pseudomonas* sp. in the strawberry samples that were stored in aerobic environments (control and UV-C) is higher than the growth in the samples stored in anaerobic environments (Vacuum and UV-C & Vacuum) as shown in Figure 2d–f. In contrast, the *Pseudomonas* growth in the quartered tomato samples was higher in the anaerobic storage environments and lower in the aerobic storage environments (Vacuum and UV-C & Vacuum) as shown in Figure 3d–f. This difference in the growth rates between the storage conditions is attributed to the characteristics of *Pseudomonas*.

The majority of *Pseudomonas* sp. are obligate aerobes, where oxygen is used as a terminal electron acceptor (Robinson, 2014). Yet, some *Pseudomonas* sp. species can grow anaerobically upon the availability of nitrate that can be also used as a terminal electron acceptor (Robinson, 2014; Schaechter, 2009). In fresh tomato fruits, the nitrate levels range between 0.93 and 66.54 with an average of 12.55 ± 0.002 (mg/kg FW ± SE) (MirMohammad-Makki & Ziarati, 2015). Therefore, the high growth of *Pseudomonas* sp. in the tomato samples that were stored in anaerobic environments was stimulated by the high nitrite content in the fruit itself.

As for the yeast and mold populations, a reduction in the growth rates was observed in all the tomato and strawberry samples that were irradiated using UV-C light, whereas the slowest growth rate was observed in the UV-C and vacuum storage condition, as presented in Figures 2a–c and 3a–c. A different growth behavior was observed in the strawberry samples of run 3, where the UV-C-irradiated sample expired before the vacuumed sample, which could be attributed to the potential difference in the initial microbial content of each sample.

The growth rates of yeast and mold, and *Pseudomonas* sp. were compared to the changes in the sensory evaluation of the samples during their shelf life. Noticeable increases in the microbial populations were observed on the days when organoleptic spoilage was identified as shown in Figures 2 and 3. The population of yeast and mold that indicates the spoilage of strawberries and tomatoes ranged from $21 \times 10^4$ to $25 \times 10^4$ log CFU/g and from $21 \times 10^4$ to $24 \times 10^4$ log CFU/g, respectively. Since these microbial population levels were reached on later days for all the UV-C and vacuum samples, this storage condition proved its positive effect on maximizing the shelf life of strawberries and tomatoes in comparison to the other storage conditions. This positive effect is mainly due to the combined effect of the (1) UV-C irradiation, which damages the DNA of microorganisms and affects their metabolism and reproduction, ultimately resulting in cell death (Brem et al., 2017; Gayán et al., 2011), in addition to the (2) vacuum sealing that limits the oxygen level necessary for the metabolism and growth of microorganisms (Shajil et al., 2018). The oxygen levels in the storage containers after the vacuum sealing range between 1.7% and 1.8%, while the oxygen levels in the unvacuumed containers range between 20.7% and 21%. Since the oxygen level plays a pivotal role in microbial growth, it is important to study the packaging parameters that can influence the oxygen level, such as the Oxygen Transmission Rate (OTR), the Carbon Dioxide Transmission Rate (CTR), the Water Vapor...
Transmission Rate (WVTR), and the oxygen and water permeabilities. Hence, our future research can focus on studying the transmission rates, the permeabilities, and their correlation with the shelf life of food. In general, eliminating oxygen from the containers creates oxygen and vapor barriers, which impede the undesirable oxidative reactions in the food during storage. Yet, the anaerobic storage condition is a favorable environment for some bacteria, such as *Clostridium botulinum*, which thrives in the low-oxygen conditions and produces harmful toxins. But since the ideal temperature range for *Clostridium botulinum* growth is 20–37°C, its growth will be limited as the samples were stored at 4°C (Fields et al., 1977; Tanner & Oglesby, 1936).

Aside from the yeast and mold counts, the populations of aerobic bacteria, lactic acid bacteria, and *Enterobacteriaceae* were examined and found to be too few to count in all the tomato and strawberry samples. This low count is due to the natural acidity (low pH) of tomatoes and strawberries, which creates an unfavorable environment for the growth of many spoilage microorganisms, especially bacteria (Barth et al., 2009). However, the low pH environment is suitable for the growth of yeast and mold (Petruzzi et al., 2017). Therefore, the increase in the yeast and mold
colonies has been inferred to be the main cause of the degradation in the sensory characteristics of strawberries and tomatoes.

3.3 PH measurements

The pH levels of tomato and strawberry samples increased during the storage period, where the slowest increase rate was observed in the UV-C & Vacuum samples as shown in Figure 4. The pH levels in the UV-C and vacuum samples of strawberry ranged between 0.25 and 0.29 as shown in Figure 4a–c, while pH levels of the tomato samples ranged between 0.20 and 0.24 on the last days as indicated in Figure 4d–f. On the other side, the fastest rate of pH increase was observed in the control samples, which implies the reduction of acidity level in the fruits (Mgaya-Kilima et al., 2014). These results are on agreement with other research that showed as increase in the pH levels throughout the storage period of strawberry and tomatoes (Caner et al., 2008; García et al., 2014).

3.4 Organoleptic examination

Spoilage is indicated by a variety of sensory cues, such as off-colors, off-odors, and the softening of vegetables and
F I G U R E 4  The pH levels of the strawberry samples (a–c) and tomato samples (d–f) throughout the experimental period

For the strawberry samples, the spoilage was determined based on the color change to dark red, the appearance of soft brown spots, wilting, seed disappearance (softness), and the appearance of white fungal growth. The spoilage was observed between day 8 and 10 for the control samples, between day 13 and 15 for the vacuum-sealed samples, and between day 13 and 17 for the UV-C-irradiated samples. The samples that were vacuum sealed and irradiated with UV-C light remained intact for a longer period of time and spoiled between day 19 and 20, as illustrated in Figure 5a. On the other hand, the spoilage of the quartered tomato samples was determined based on the appearance of black spots, small green and white mold growth, a mushy texture, fluid leakage, or a foul odor. Generally, the odor of UV-C & Vacuum samples was the strongest followed by the Vacuum samples. The color alteration was slight in the UV-C & Vacuum samples and Vacuum samples, while it was more noticed in UV-C samples. These changes were observed in the control samples between days 13 and 15, in the vacuum-sealed sample between days 15 and 17, and in the UV-C-irradiated samples between day 17 and 20. The UV-C and vacuum samples remained intact for a longer time; small black spots and fluid leakage were noticed between day 20 and 23, as indicated in Figure 5b. The shelf-life results that were determined through the organoleptic analysis align with those determined via the microbial population quantification of yeast and mold and Pseudomonas sp. that are illustrated in Figures 2 and 3.

3.5 | Sensory evaluation

The consumer acceptance of perishables is greatly influenced by the sensory qualities. The effects of UV-C irradiation and vacuum sealing on the sensory characteristics, such as the color, texture, taste, aroma of fresh fruit, and general acceptance, of the strawberries and tomatoes samples were evaluated by 12 panelists. Figures 6 and 7 illustrate the average scores reported by the panelists for the strawberry and tomato samples throughout the full
FIGURE 5  The shelf life of the (a) strawberry samples and (b) quartered tomato samples (days)

FIGURE 6  The sensory evaluation of the strawberry samples: (a) aroma, (b) color, (c) texture, and (d) taste
FIGURE 7 The sensory evaluation of the tomato samples: (a) aroma, (b) color, (c) texture, and (d) taste

experimental period. As shown in the figures, there are notable differences in the sensory traits and the shelf life of the samples based on the storage condition, where the positive effects of the UV-C irradiation and the anaerobic storage are noteworthy. Although the shelf life of the UV-C-irradiated samples is longer than the shelf life of the control samples, the sensory evaluation scores of the UV-C samples at the end of the shelf life are less than that of control samples. This is attributed to the effect of the aerobic storage environment that results in higher weight loss percentages (Figure 1), dehydration, and an overall quality decay throughout the long storage period. In contrast, the scores of the Vacuum samples are within the excellent limits, despite a slight decrease in the texture and taste scores at the end of the shelf life. It has been observed that UV-C & Vacuum samples received a higher acceptance rate in comparison to the other storage conditions. The sensory evaluation scores (Figures 6 and 7) and the overall acceptability (Figure 8) of the UV-C & Vacuum samples are greater than those of the UV-C samples, Vacuum samples, and Control samples, despite a minor decline in taste and texture scores by the end of the shelf life.

To visualize the overall effectiveness of each storage condition in extending the shelf life of strawberries and quartered tomatoes, the average shelf-life values of the three experimental runs are plotted in Figure 9. As shown in the figure, the maximum shelf life was achieved in the UV-C and vacuum storage condition, where the average shelf life exceeded the normal (control) storage condition by 124.41% for strawberries and by 54.41% for quartered
FIGURE 8 The overall acceptance of the (a) strawberry samples and the (b) tomato samples

FIGURE 9 The average increase in the shelf life of all experimental samples. The standard deviation of the three shelf-life measurement runs under the four storage conditions has been calculated and used to derive error bars.

tomatoes. Although the shelf life of the samples varied between the iterations due to the potential differences in the growing practices, harvest times, handling, and transportation, the standard deviation between the iterations is fairly low (<1.63), which indicates the possibility of using the average shelf-life values of quartered tomatoes and whole strawberries as a reference. Since the UV-C & Vacuum samples attained high sensory evaluation scores despite the long storage period, this storage method can be applicable in the real-world settings and would have a significant impact on the economy and the environment. However, further study is required to examine the unit economics, usage scenarios, and practical designs.

4 | CONCLUSION

The effectiveness of the combination of UV-C irradiation and vacuum sealing in extending the shelf life of whole strawberries and quartered tomatoes stored at 4°C was examined and compared with the effect on shelf life under the normal storage condition, the sole UV-C irradiation condition, and the sole vacuum sealing storage. The shelf life and quality of the samples were evaluated through organoleptic quality examination, weight loss measurement, pH analysis, and the microbial population quantification of yeast and mold and Pseudomonas sp. The combination of UV-C irradiation and vacuum sealing increased the average shelf life of the strawberries and tomatoes by 124.41% and 54.41%, respectively. The results suggest that this storage condition is more effective for fresh produce preservation than the sole use of UV-C irradiation or vacuum sealing, and it could significantly reduce the spoilage rate of fresh produce.

AUTHOR CONTRIBUTIONS

Asrar Damdam: Conceptualization; Investigation; Funding acquisition; Writing – original draft; Formal analysis; Writing – review & editing; Methodology; Visualization; Data curation. Ashwaq Al-Zahrani: Methodology; Validation; Writing – original draft; Writing – review & editing; Investigation. Lama Salah: Data curation; Validation; Visualization; Writing – review & editing; Methodology. Khaled Nabil Salama: Funding acquisition; Writing – review & editing; Supervision; Resources.
CONFLICT OF INTEREST
The authors declare no conflict of interest.

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