RESEARCH ARTICLE

Enhancing Shelf-life and Quality of Tomatoes (*Lycopersicum esculentum* L.) Using UV-C Radiation and Natural Preservatives

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ABSTRACT

The influence of UV-C radiation and garlic extract on the shelf life and storage of tomatoes (*Lycopersicum esculentum* L. cv. Arka Rakshak) was investigated in this study. Fresh tomatoes were subjected to four treatments: control (untreated), UV-C (1.2 kJ/m²), garlic (10% w/v aqueous extract), and UV-C (1.2 kJ/m²) + garlic (10% w/v aqueous extract). The treated tomatoes were preserved at 4°C for 14 days, and their physical, chemical, and microbial properties were analyzed at 0, 3, 7, and 14 days. The combination of UV-C and garlic treatments lowered the loss of firmness, maintained color, and minimized weight loss. The UV-C treatment enhanced the initial lycopene and total phenolic content, while the combination treatment showed the best retention of these bioactive compounds during storage. The garlic treatment contributed to the antimicrobial activity, and the combination treatment significantly ($p < 0.05$) reduced the total plate count and yeast and mold count compared to the control. Pathogenic bacteria were not detected in the samples throughout the storage period. The results demonstrate the potential of UV-C radiation and garlic extract as natural preservatives for improving the shelf life. The combination treatment can be an effective approach to reduce post-harvest losses and ensure the safety and nutritional value of the produce.

Keywords: UV-C radiation, Natural preservatives, Garlic, Shelf life, Lycopene

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INTRODUCTION

Tomatoes (Lycopersicum esculentum L.) are one of the popular vegetables globally, valued for their versatility, taste, and nutritional profile[1]. However, their high perishability leads to significant post-harvest losses and limited year-round availability[2]. This challenge has prompted researchers to explore novel preservation techniques that can extend tomato shelf life while maintaining quality and safety. Tomatoes are rich in essential nutrients, including vitamins C and A, potassium, and folate [3,4]. They are particularly notable for their high content of lycopene, a potent antioxidant carotenoid for combating various diseases [1]. The antioxidant and anti-inflammatory properties of lycopene contribute significantly to the health benefits of tomatoes[2,3]. Despite their nutritional value, the high moisture content and delicate nature of tomatoes make them susceptible to rapid deterioration and microbial growth[5]. UV-C radiation [6] (200 and 280 nm) effectively inactivates a wide range of microorganisms by damaging their DNA, preventing replication and leading to cell death [7,8]. Importantly, UV-C treatment does not leave harmful residues or compromise the nutritional quality of treated produce. Additionally, it stimulates the production of bioactive constituents in various fruits and vegetables, potentially enhancing their nutritional value and antioxidant capacity [9]. Concurrent with technological approaches, there is growing interest in natural preservatives as consumers demand more sustainable food preservation methods. Garlic (Allium sativum L.) has shown potential as a natural antimicrobial agent [10]. Its bioactive compounds, particularly allicin, exhibit strong antimicrobial activity [11,12]. The antimicrobial mechanism of garlic involves disruption of microbial cell membranes, enzyme inhibition, and interference with DNA replication [13]. Incorporating garlic as a natural preservative in tomatoes could enhance their shelf life and microbial safety while appealing to consumers seeking clean label products. The preservation of tomatoes is crucial not only from nutritional and economic perspectives but also for food security and sustainability. Extending tomato shelf life can reduce food waste, improve food availability, and potentially decrease the environmental impact of food production and distribution. Moreover, improved preservation techniques could enable wider distribution of tomatoes, increasing accessibility to this nutritious vegetable in areas with limited fresh produce availability. Given these considerations, there is a clear need for innovative approaches to tomato preservation that can effectively extend shelf life while maintaining nutritional quality and safety. The primary aim of this work is to

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Table 1: Changes in physical properties of tomatoes during storage for each treatment group

Treatment Group	Storage Duration (days)	Firmness (N)	L*	a*	b*	Weight Loss (%)
Control	0	12.34 ± 0.56	45.23 ± 1.12	18.45 ± 0.87	23.67 ± 0.92	0.00 ± 0.00
	3	10.21 ± 0.48	43.56 ± 1.08	19.23 ± 0.91	22.34 ± 0.88	1.23 ± 0.12
	7	8.56 ± 0.41	41.23 ± 1.02	20.12 ± 0.94	20.56 ± 0.81	2.89 ± 0.21
	14	5.67 ± 0.32	38.45 ± 0.96	21.34 ± 1.01	18.23 ± 0.72	5.12 ± 0.27
UV-C	0	12.45 ± 0.58	45.34 ± 1.14	18.56 ± 0.89	23.78 ± 0.94	0.00 ± 0.00
	3	11.23 ± 0.52	44.23 ± 1.11	18.89 ± 0.92	22.89 ± 0.91	0.89 ± 0.09
	7	9.89 ± 0.47	42.56 ± 1.06	19.45 ± 0.95	21.67 ± 0.86	1.78 ± 0.16
	14	7.56 ± 0.39	40.23 ± 1.01	20.12 ± 0.98	20.12 ± 0.79	2.89 ± 0.21
Garlic	0	12.56 ± 0.59	45.45 ± 1.15	18.67 ± 0.90	23.89 ± 0.95	0.00 ± 0.00
	3	11.45 ± 0.54	44.56 ± 1.12	19.12 ± 0.93	23.12 ± 0.92	0.78 ± 0.08
	7	10.12 ± 0.49	43.12 ± 1.08	19.78 ± 0.96	22.23 ± 0.88	1.56 ± 0.14
	14	8.45 ± 0.43	41.23 ± 1.04	20.45 ± 1.00	20.89 ± 0.83	2.45 ± 0.19
UV-C + Garlic	0	12.67 ± 0.61	45.56 ± 1.16	18.78 ± 0.91	23.99 ± 0.96	0.00 ± 0.00
	3	11.89 ± 0.57	44.89 ± 1.14	19.01 ± 0.93	23.45 ± 0.94	0.56 ± 0.06
	7	10.67 ± 0.52	43.78 ± 1.10	19.34 ± 0.95	22.78 ± 0.91	1.23 ± 0.12
	14	8.23 ± 0.45	42.12 ± 1.06	19.89 ± 0.98	21.67 ± 0.86	2.12 ± 0.18

mean ± standard deviations

investigate the effects of UV-C radiation on the physicochemical properties, microbial growth, and shelf life of tomatoes.

MATERIALS AND METHODS

Plant Material

Fresh, ripe tomatoes (*Lycopersicum esculentum* L. cv. Arka Rakshak) were procured from a nearby farms in Tirupati, Andhra Pradesh. The tomatoes were chosen based according to the uniformity in size, color, and absence of visual defects. They were then transported to the laboratory

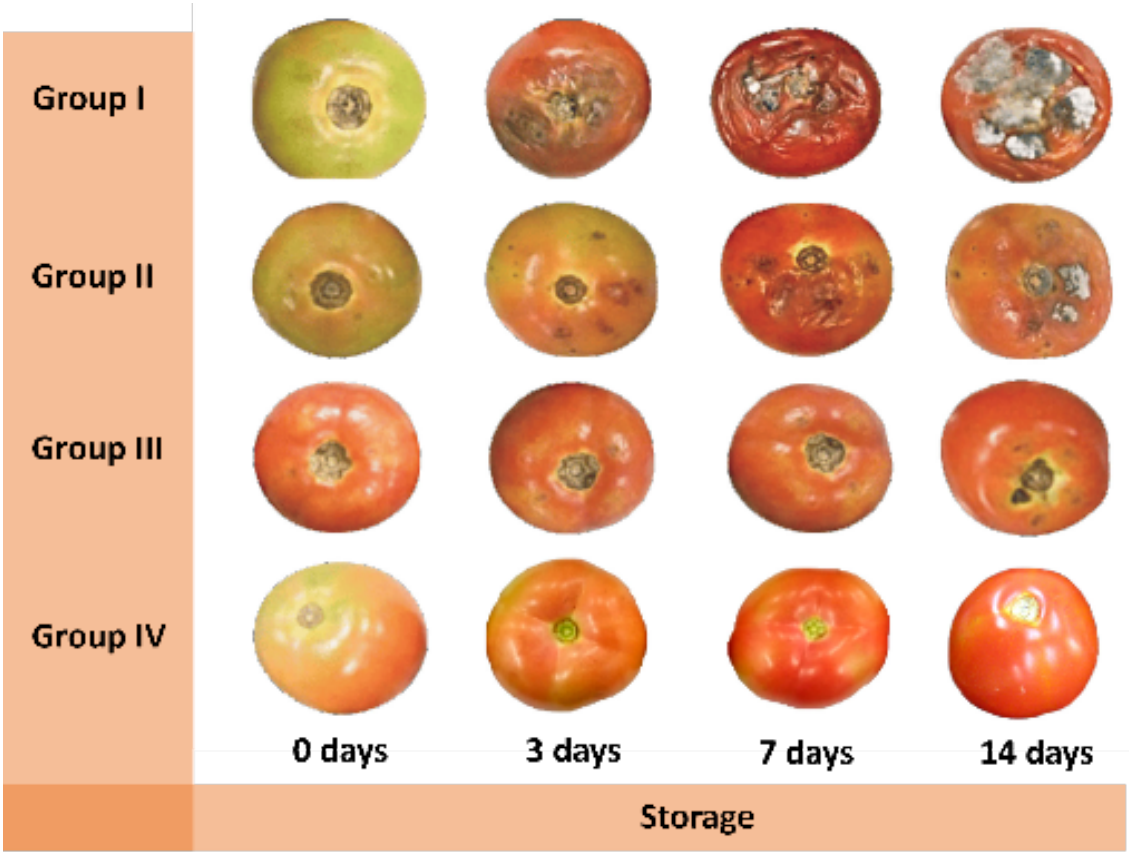

Figure 1. Changes in physical properties of tomatoes during storage for each treatment group

Table 2: Changes in microbial properties of tomatoes during storage for each treatment group

Treatment Group	Storage Duration (days)	TPC (log CFU/g)	Yeast and Mold Count (log CFU/g)
Control	0	2.34 ± 0.09	1.23 ± 0.06
	3	3.56 ± 0.12	2.45 ± 0.09
	7	5.12 ± 0.17	3.89 ± 0.13
	14	6.78 ± 0.21	5.23 ± 0.18
UV-C	0	1.45 ± 0.07	0.89 ± 0.04
	3	2.23 ± 0.09	1.56 ± 0.07
	7	3.45 ± 0.13	2.45 ± 0.09
	14	4.89 ± 0.16	3.67 ± 0.13
Garlic	0	1.89 ± 0.08	1.12 ± 0.05
	3	2.67 ± 0.11	1.89 ± 0.08
	7	3.89 ± 0.14	2.78 ± 0.11
	14	5.23 ± 0.18	4.12 ± 0.15
UV-C + Garlic	0	1.23 ± 0.06	0.67 ± 0.03
	3	1.89 ± 0.08	1.12 ± 0.05
	7	2.78 ± 0.11	1.89 ± 0.08
	14	4.23 ± 0.15	2.89 ± 0.11

mean ± standard deviations. TPC: Total plate count, CFU: Colony forming unit

within 2 hours of harvest and preserved at 10°C until further processing.

Chemicals and Reagents

Sodium hypochlorite (4% w/v) was purchased from Sisco Research Laboratories Pvt. Ltd. (Mumbai, India). Methanol, acetone, and other organic solvents were procured from Merck Life Science Pvt. Ltd. (Bangalore, India). Plate count agar, potato dextrose agar, and selective media for pathogenic bacteria were purchased from Merck Life Science Pvt. Ltd. (Bangalore, India).

Preparation of Garlic Extract

Garlic (*Allium sativum* L.) bulbs were procured from a nearby market in Bangalore, Karnataka, India. The cloves were peeled, and a 10% (w/v) aqueous garlic extract was prepared[14,15] by blending 100 g of garlic cloves with 900 mL of sterile distilled water using a kitchen blender (Philips

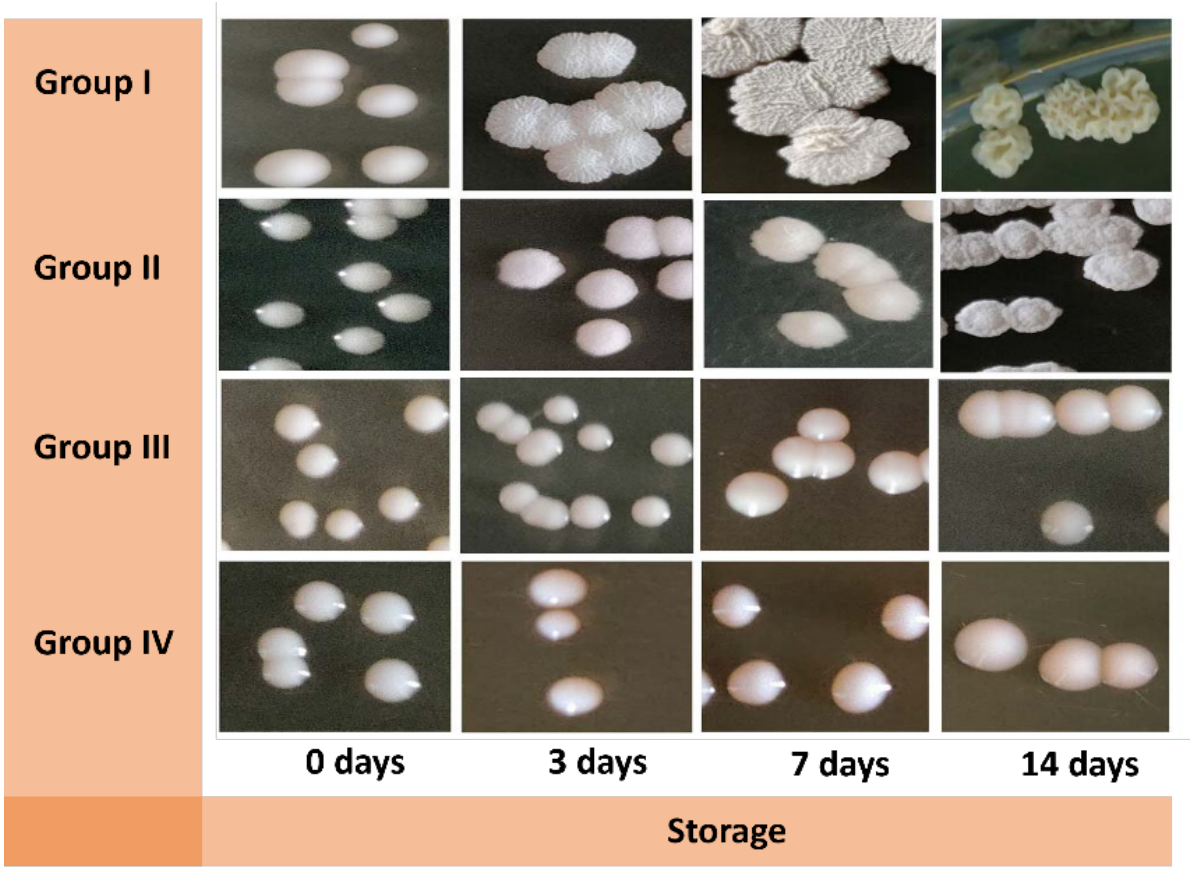

Figure 2. Changes in microbial properties of tomatoes during storage for each treatment group

HL7756/00, Bangalore, India). The mixture was then screened through a sterile cheesecloth, and the filtrate was collected as the garlic extract. The extract was prepared fresh before each treatment application.

UV-C Radiation

Tomates were irradiated using a custom-built UV-C chamber (Alphatech Systems, Coimbatore, India) equipped with low-pressure mercury lamps (254 nm, 30 W, Philips, Bangalore, India). The tomatoes were placed on a sterile stainless steel tray at a length of 30 cm from the UV-C lamps [16]. The tomatoes were irradiated at 1.2 kJ/m² on each side to ensure uniform treatment. The UV-C intensity was calculated using a UV-C radiometer (Lutron, UVC-254, Taipei, Taiwan).

Treatment Application

The fresh tomatoes were washed thoroughly with tap water, sanitized with a 100 ppm bleaching solution (hypo) for 2 minutes, and cleaned with sterile distilled water. The tomatoes were then cut into 1 cm thick slices using a sterile stainless steel knife. The tomatoes were divided into four treatment groups[17, 18]:

a) Control (untreated)
b) UV-C (1.2 kJ/m²)
c) Garlic (10% w/v aqueous extract)
d) UV-C (1.2 kJ/m²) + Garlic (10% w/v aqueous extract)

For the garlic treatment, the tomatoes were dipped in the 10% (w/v) aqueous garlic extract for 2 minutes and then drained of excess liquid using a sterile stainless steel sieve. For the combination treatment, the tomatoes were first exposed to UV-C radiation (1.2 kJ/m²) and then dipped in the 10% (w/v) aqueous garlic extract for 2 minutes. After the treatments, the tomatoes were packaged in sterile polypropylene containers (200 g capacity) and preserved at 4°C for 14 days [19].

Physical Analysis

Firmness

The firmness of the tomatoes was estimated using a texture analyzer (Godalming, UK) equipped with a 5 mm dia cylindrical probe. The probe was set to penetrate 5mm into the tomato slices. The maximum force (N) required to penetrate the tomato tissue was recorded as an indicator of firmness[20]. The analysis was performed on 10 slices per treatment at each sampling point.

Color

The color of the tomatoes was determined using a portable colorimeter (CR-400, Konica Minolta, Tokyo, Japan). The L*, a*, and b* values were recorded at three different locations on each tomato slice, and the average values were calculated[20, 21]. The analysis was performed on 10 slices per treatment at each sampling point.

Weight Loss

The weight of the tomatoes was measured using a digital balance (Shimadzu BL-220H, Kyoto, Japan) at each sampling point. The analysis was performed on three containers per treatment at each sampling point[22].

Chemical Analysis

Total Soluble Solids (TSS)

The TSS content of the tomatoes was determined using a digital refractometer (PAL-1, Atago, Tokyo, Japan). The tomato slices were homogenized using a kitchen blender (Philips HL7756/00, Bangalore, India), and the juice was filtered through a sterile cheesecloth. The TSS content was recorded in °Brix. The analysis was performed thrice for each treatment [23].

pH

The pH of the tomato juice was determined using a digital pH meter (Orion Star A211, Thermo Fisher Scientific, Mumbai, India) [24].

Lycopene Content

The lycopene content of the tomatoes was estimated using the spectrophotometric method described by Ranganna (1986) [1]. Briefly, 5 g of homogenized tomato tissue was stirred with 50 mL of acetone and hexane (4:6 v/v) and agitated for 1 hour using a magnetic stirrer. The lycopene content was obtained using the following formula:

Lycopene (mg/100g) = [A503 × 31.2] / [W × (1 / 3450)][25].

Total Phenolic Content

The Folin-Ciocalteu method, as outlined by Bellette and colleagues (2008), was employed to quantify the total phenolic content in tomato samples [26]. The procedure involved homogenizing 5 g of tomato tissue and mixing it with 50 mL of 80% methanol. This mixture was then stirred for 60 minutes using a magnetic stirrer. After filtration through Whatman No. 1 filter paper, 0.5 mL of the resulting filtrate was combined with 2.5 mL of Folin-Ciocalteu reagent (diluted tenfold) and 2 mL of sodium carbonate solution (7.5%). The mixture was then left to incubate in darkness for half an hour. Subsequently, absorbance readings were taken at 765 nm using a Shimadzu UV-1800 UV-visible spectrophotometer (Kyoto, Japan).

Microbial Analysis

Total Plate Count (TPC)

The standard plate count method was employed to assess the Total Plate Count (TPC) of the tomato samples. The process involved homogenizing 10 g of sliced tomatoes with 90 mL of sterilized 0.1% peptone water. This homogenization was performed using an Interscience BagMixer 400 stomacher (Saint-Nom-la-Bretèche, France) for a duration of 2 minutes. Following this, a series of dilutions were prepared. Aliquots of 1 mL from appropriate dilutions were then plated in duplicate on plate count agar, utilizing the pour plate technique. These plates were subsequently incubated at a temperature of 37°C for a period of 48 hours. After incubation, the resulting colonies were enumerated using a Labtronics Digital Colony Counter (Haryana, India). The final results of the TPC analysis were presented as logarithmic values of colony forming units (CFU) per gram of fresh tomato weight[27].

Yeast and Mold Count

To determine the presence of yeast and mold in the tomato samples, a spread plate technique was utilized. The growth medium employed was potato dextrose agar, which was acidified using 10% tartaric acid. Following the plating process, the prepared dishes were subjected to incubation at a temperature of 25°C. This incubation period lasted for a total of 5 days. Upon completion of the incubation, the resulting colonies were enumerated with the aid of a colony counting device. The final data from this analysis were expressed in logarithmic form, representing the number of

colony forming units (CFU) per gram of fresh tomato weight[28].

Pathogenic Bacteria

The growth of Escherichia coli O157:H7, Salmonella spp., and Listeria monocytogenes in the tomatoes was estimated using selective media and confirmation tests according to the methods described by the Food Safety and Standards Authority of India (FSSAI, 2012). The analysis was performed on 25 g of tomato slices at each sampling point [29, 30].

RESULTS AND DISCUSSION

Physical Properties

UV-C radiation and garlic-based preservatives effect on the physical properties of tomatoes during storage are presented in Table 1. The firmness of the tomatoes during storage for all treatment groups. The combination of UV-C and garlic showed the best retention of firmness, with a final value of 8.23 ± 0.45 N after 14 days of storage, compared to 5.67 ± 0.32 N for the control. The color of the tomatoes, expressed as L*, a*, and b* values, showed changes during storage. The L* value decreased, indicating a loss of lightness, while the a* value increased, indicating an increase in redness. The b* value decreased, indicating a loss of yellowness. The UV-C and garlic treatments reduced the changes in color compared to the control, with the combination treatment showing the best color retention (Figure 1). The weight loss of the tomatoes increased during storage for all treatment groups [31]. The combination treatment showed the lowest weight loss, with a final value of 2.45 ± 0.18% after 14 days of storage, compared to 5.12 ± 0.27% for the control.

Chemical Properties

The TSS content decreased during shelf life for all treatment groups. However, the UV-C and garlic treatments reduced the loss of TSS compared to the control. The combination treatment showed the best retention of TSS, with a final value of 4.23 ± 0.12 °Brix after 14 days of storage, compared to 3.45 ± 0.09 °Brix for the control. The pH of the tomatoes increased during storage, indicating a loss of acidity. The UV-C and garlic treatments reduced the increase in pH compared to the control, with the combination treatment showing the best retention of acidity. The lycopene content of the tomatoes decreased during storage for all treatment groups. However, the UV-C treatment increased the initial lycopene content, indicating a potential hormetic effect. The garlic treatment did not significantly affect the lycopene content [32]. The combination treatment showed the best retention of lycopene, with a final value of 8.23 ± 0.28 mg/100g after 14 days of storage, compared to 6.12 ± 0.19 mg/100g for the control. The total phenolic content of the tomatoes decreased during storage for all treatment groups. The UV-C treatment increased the initial total phenolic content compared to the control, while the garlic treatment did not impact total phenols. The combination treatment showed the best retention of total phenolic content, with a final value of 24.56 ± 0.62 mg GAE/100g after 14 days of storage, compared to 18.23 ± 0.45 mg GAE/100g for the control.

Microbial Properties

The TPC increased during storage for all treatment groups (Table 2). However, the UV-C and garlic treatments reduced the TPC compared to the control. The combination treatment showed the lowest TPC, with a final value of 4.23 ± 0.15 log CFU/g after 14 days of storage, compared to 6.78 ± 0.21 log CFU/g for the control. The yeast and mold count increased during storage for all treatment groups. The UV-C and garlic treatments reduced the yeast and mold count compared to the control, with the combination treatment showing the lowest count [19, 20]. Pathogenic bacteria are absent in all of the samples throughout the storage period, indicating that the tomatoes were microbiologically safe.

CONCLUSION

The results of this study show the potential of UV-C radiation and garlic-based preservatives in improving the storage life and preserving the quality of tomatoes. The combination of UV-C and garlic treatments showed the best retention of physical, chemical, and microbial properties, indicating a synergistic effect between these preservation methods. The UV-C treatment -improved the initial lycopene and total phenolic content of the tomatoes, suggesting a hormetic effect that could enhance the nutritional value of the produce. The garlic treatment did not significantly affect the bioactive compounds but contributed to the antimicrobial activity and the preservation of quality attributes. The combination of UV-C and garlic treatments effectively reduced the microbial growth and extended the shelf life of tomatoes by up to 7 days compared to the control. The absence of pathogenic bacteria throughout the storage period indicates that the preservation methods did not compromise the safety of the produce. Further research is needed to optimize the treatment parameters and evaluate the sensory quality and consumer acceptance of the preserved tomatoes. The economic feasibility and scale-up potential of these preservation methods should also be assessed to determine their commercial viability

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