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Evaluating the Impact of Natural and Synthetic Preservatives on Quality and Shelf Life of Solar Dehydrated Tomatoes (*Solanum Lycopersicum* L.)

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Abstract

This study investigated the effects of natural and synthetic preservatives on the quality and shelf life of solar-dried tomatoes (Solanum lycopersicum L.) during storage at room temperature. Fresh, ripe tomatoes were washed, cut into uniform slices, and treated with sodium benzoate (2% w/v), potassium metabisulfite (2% w/v), vinegar (10% acetic acid), or lemon juice (10% citric acid). Untreated tomatoes served as the control. After treatment, the samples were blanched, drained, and dried in a passive solar dryer for five consecutive days until a stable moisture content was reached. The dried tomatoes were packed in clean, sterile plastic bags and stored at ambient temperature for 40 days. Physicochemical and microbiological analyses were performed on days 1, 5, 10, 20, and 40. The parameters examined included weight loss, moisture content, water activity, pH, titratable acidity, vitamin C, total phenolic content, total viable count, and fungal load. Among the treatments, potassium metabisulfite showed the best preservation performance, as the treated tomatoes exhibited comparatively stable physicochemical properties and limited microbial growth during storage. Vinegar and lemon juice also helped maintain product quality, although their effects were less pronounced than those of potassium metabisulfite. Overall, potassium metabisulfite was more effective than the tested natural preservatives in maintaining the quality and extending the shelf life of solar-dried tomatoes under ambient conditions. These findings may help improve preservation practices for solar-dried tomatoes and reduce postharvest losses.

1. Introduction

Tomatoes, scientifically known as *Solanum lycopersicum* L., belong to the family Solanaceae and are extensively cultivated worldwide (Ray *et al.,* 2016). The crop is well adapted to tropical and subtropical climates where it performs very well at temperature between 15 and 30˚C with moderate rainfall of about 1000 mm (Naika *et al.,* 2005). The pre-dominant hue of a tomato is often red, although it can also be found in yellow, purple, and green variations. They can also be found in various color combinations or striped designs.

The approximate world output of tomatoes was 200 million tons, and the revenue would be US$ 190 billion per year. Out of total production 7.3 million tons were

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exported. Mexico is the top exporter of tomato whereas United States is the top importer (Nabnean*et al*., 2020). China contributes 52 percent of the world's total tomato production and Pakistan ranks at the 33rd position in the tomato production in the world (Owureku-Asare *et al*., 2018). In addition, the statistics reveal that Pakistan has 1.3 per cent share of world's tomato area, 0.33 per cent of production and 0.06 per cent of export. Pakistan has a relatively low export-production ratio, export price and yield of tomato per ha in the international production. It grew from US$0.33 million in 2001 to US$114.9 million in 2016, before falling to US$32.4 million in 2017. From 2001 to 2017 the country's trade surplus with tomatoes increased on average by 49 percent per year. (Ladi *et al.,* 2017).

Tomatoes are valued for their taste and attractive look and their significant contribution to our diet as rich providers of different nutrients (Paul & Pandey *et al.,* 2013). Tomato is a rich source of lycopene (60-90 mg/kg), vitamin C (160-240 mg/kg), polyphenols (10-50 mg/kg) and small quantities of vitamin E (5-20 mg/kg) (Oliveira*et al.,* 2016) and also excellent source of minerals and vitamins.

Tomatoes generally have a shelf life of 4 to 8 days at room temperature. Perishability significantly contributes to the seasonal variation in availability. The lack of an effective preservation method for tomatoes, other than processing them into a paste, has led to a decline in quality and other socio-economic deficiencies (Arah *et al.,* 2015). The mitigation of losses is a significant priority, particularly in situations where there is an uneven distribution between supply and demand during both the production and off seasons (Adeyeye *et al.,* 2017). It is necessary to develop a method for processing and preserving tomatoes to minimize spoilage and waste, thus addressing the issue of over production and scarcity during the off-season (Varghese *et al.,* 2022). The preservation of tomatoes is crucial due to the seasonal nature of their production, whereas consumption occurs throughout the year (Owureku-Asare *et al.,* 2017)

Solar Drying is a method of preservation that is commonly used on a modest scale. Solar drying, also called solar dehydration, is a food preservation technique that uses solar energy to evaporate the moisture content from fruits and vegetables through a system or setup called Solar dryer or solar dehydrator. Solar dryers can be of different shape, size and design, however Gable type solar dryer installed at Nuclear Institute of Food and Agriculture (NIFA) Peshawar consists of electric source, water tank, electric motor, pipes, glass, exhaust fan, electric heaters and chamber (Mahmood, Z. *et al.,* 2005). The primary objective of this research was to investigate the effects of selected preservative-based pre-treatments specifically sodium benzoate, potassium metabisulfite, vinegar, and lemon juice on the physicochemical, microbial, and sensory quality parameters of solar-dehydrated tomatoes

2. Materials and Methods

All experiments were conducted at the Nuclear Institute of Food and Agriculture (NIFA) Tarnab, Peshawar. The region experiences two primary climatic periods, namely summer and winter season. The drying process started in the last week of February and concluded in early March 2025.

2.1 Collection of tomatoes

6 kg of fresh tomatoes (*Solanum lycopersicum* L.) were purchased from Tarnab Fruits and Vegetables Market Peshawar, Khyber Pakhtunkhwa, Pakistan as the raw material for the study.

2.2 Sorting and cleaning

A study by Sohai *et al*. (2011) investigated the effect of pretreatment of the tomatoes before drying on the antioxidant properties and color of a few tomato varieties. They said that the chemical treatments (sodium metabisulfite and calcium chloride) play a significant role in the retention of the TPC of dried tomatoes by the oven method. An important aspect of this study was the importance of pretreatments in reducing the degradation of the phenolics during drying.

In each case 20g KMS and 20g Na Benzoate were dissolved in 1000mL of distilled water taken. For preparation of lemon juice solution, 10% lemon juice was prepared by squeezing and filtering the fresh lemons from local market manually through muslin cloth. Lemon juice solution (10%)

Table 1. Atmospheric temperature and temperature of solar dryer

Parameters	Day 1	Day 2	Day 3	Day 4	Day 5
Atmospheric temperature	23˚C	22˚C	21˚C	22˚C	23˚C
Average temperature inside solar dryer	42˚C	40˚C	35.23˚C	41.73˚C	43.9˚C

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was prepared using the fresh lemon which were squeezed manually from the local market and filtered using muslin cloth. Lemon juice solution (10%) was prepared using the fresh lemon which were squeezed manually from the local market and filtered using muslin cloth. The filtered juice was then pipetted into a volumetric flask and this was then made up to 1000 mL in a beaker with distilled water, creating a 10% solution. Similarly, 100mL of the commercial vinegar was diluted with 1000mL of water to make the 10% vinegar solution. Distilled water to make 10% vinegar solution. No one of the above preservative treatments was applied to the control sample.

2.3 Weighting and trimming

An additional 1 kg of tomatoes was taken for each treatment with different tomato preservation methods, and an untreated control group was also considered as above. In this study, total 5 kg of tomatoes were used. Each fruit was bisected after weighing and brought into the Center for further processing using a sterilized stainless-steel knife and dividing lengthwise.

2.4 Preparation of treatment solutions

A 2% solution of potassium metabisulfite (KMS) and 2% solution of sodium benzoate were prepared by dissolving 20g of each of these compounds in 1000mL of distilled water respectively. For the 10% lemon juice solution, fresh lemons sourced from the local market were manually squeezed, and the juice was filtered through muslin cloth. A volume of 100 mL of this filtered juice was pipetted into a volumetric flask and diluted with 1000 mL of distilled water to achieve a 10% concentration. Similarly, the 10% vinegar solution was prepared by adding 100 mL of commercially available vinegar to 1000 mL of distilled water to make 10% vinegar solution. The control sample did not receive any of the preservative treatments.

2.5 Blanching

Five 1 kg portions of tomatoes were wrapped in muslin cloth and blanched for 3 minutes in boiling distilled water with the following treatments: T0 (plain water), T1 (10% lemon juice, v/v), T2 (10% vinegar v/v), T3 (2% sodium benzoate, w/v) and T4 (2% potassium metabisulfite, w/v). After blanching samples were drained on a sanitized surface for 1 minute.

2.6 Loading trays of solar dryer

Drying was done in a solar dryer with rectangular trays made of 1″ (2.5 cm) x 2″ (5.0 cm) furring strip. The frame was covered with high quality plastic mesh screen and securely fastened by staples for air circulation when drying. To ensure cross-contamination was avoided and treatment integrity was ensured, each batch of sliced tomato fruits was carefully stored in separate trays. The trays, measuring 50 cm × 35 cm, were then loaded into the dehydrator, where the tomatoes were subjected to solar drying.

2.7 Daily observation

The weight of the trays kept in the solar dryer was recorded daily. The ambient temperature in the dryer was monitored frequently to maintain a uniformity in drying condition. The physical condition of tomato slices was daily investigated, and the extent of drying of tomato slice was observed until the moisture contents reached 9–15%. It was found that it took 5 days to dry tomatoes to the desired moisture content. The temperature recorded during those days is given in Table 1.

2.8 Quality and shelf-life assessment of fresh and dried tomatoes

Representative samples were taken from each treatment and the untreated control, to assess the quality and shelf life of the fresh tomatoes. The physicochemical and microbiological tests such as moisture content, water activity (aw), pH, titratable acidity, vitamin C, total phenolics, total bacterial and total fungal count were done.

Weight Loss

The weight of tomato samples was measured before and after drying using a digital electronic balance. The fresh weight of each tomato sample was first measured before any pre-treatment was applied. After the solar dehydration process, and when the targeted moisture content level (9–15%) was reached, the final weight of the dried samples was measured on the same balance. The weight loss was then determined by subtracting the weight of the sample after drying, from the original fresh sample weight (Azumah et al., 2024).

2.8.1 Moisture content

Moisture content is an important aspect of shelf life and stability of food products. The moisture content of both fresh and solar-dehydrated tomatoes was determined gravimetrically by an Ohaus moisture analyzer (MB23, Ohaus Corporation, Parsippany, NJ, USA) which is based on the principle of rapid heating of sample by an infrared heating element, not of glass, by which the moisture content

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is measured by the weight loss, readable with 0.1 % accuracy.

2.8.2 Water activity

Water activity (aw) is an important parameter which plays a significant role in the microbial stability and shelf life of food products and also plays a critical role in product quality. The water activity in fresh and solar-dried tomato samples was measured with a water activity meter Novasina LabSwift-aw (Novasina AG, Lachen, Switzerland). The device is specifically developed for fast and accurate measurement of (aw) using a high precision humidity sensor, which is based on resistive electrolytic measurement technology, and is suitable for the assessment of food quality.

2.8.3 pH Determination

The fresh and solar-dehydrated tomato sample pH was measured by using a digital pH meter (Adwa AD1020 pH/mV/ISE & Temperature Meter, Adwa Instruments, Romania). Standard buffer solutions (pH 4.0, pH 7.0 and pH 10.0) were used for calibration before measurement. The pH reading was obtained by dipping the electrode in a homogenised tomato sample to better understand the acidity level which directly affects the stability, safety from microbiological contamination and organoleptic characteristics of the product.

2.8.4 Titratable acidity

The titratable acidity was measured according to the standard acid base titration procedure (AOAC, 2016). 10 g of fresh tomato sample was taken and placed in a conical flask of 250 mL. Distilled water was used to make up to 150 mL. This mixture was then blended in the laboratory and again poured into the conical flask. The sample was left to settle for 15 minutes. The clarified solution was used to take two 5 mL samples and place them in individual small conical flasks. Each aliquot then was treated with two to three drops of phenolphthalein indicator solution. Then the samples were titrated with titration solution of 0.01 N sodium hydroxide (NaOH) until a faint light pink endpoint was obtained, which means that the acid content is neutralized. The titratable acidity was then determined and expressed as % citric acid equivalent.

$$\text{Titratable acidity}(\%)=\frac{\text{N}\times 0.064\times \text{Titer}\times \text{Dilution}\times 100}{\text{Wt. of Sample}\times \text{Aliquot of sample}}$$

The same procedure should be followed for determination of titratable acidity in dried tomatoes except a weight of 0.5 g should be taken from dried tomatoes instead of 10g.

2.8.5 Vitamin C

Quantification of ascorbic acid in fresh samples of tomato was done by using the titration method with dye 2, 6-dichlorophenolindophenol (DCPIP) (Toyin, 2010). 10 g of the fresh tomato sample was placed in a 250 mL conical flask, and 0.4% oxalic acid was added to make the total volume of the mixture 150 mL. Return the mixture to the flask and mix with a laboratory blender. It was then left to stand still for 15 minutes to settle out the suspended particles. This mixture was then filtered through Whatman filter, and a clear extract was obtained. Two samples of 10 mL of filtered extract were taken and added to smaller conical flasks and each of these smaller flasks receiving the filtered extract was diluted to about 10–15 mL with 0.4% oxalate. The diluted samples were titrated with a standard DCPIP dye solution till a permanent light pink endpoint was reached, indicating the complete reaction with ascorbic acid. The concentration of ascorbic acid was determined and reported as ascorbic acid mg/100g of sample material.

$$Ascorbic\ \text{acid}\left(\frac{\text{mg}}{100\text{g}}\right)=\frac{\text{Dye factor}\times \text{Titer}\times \text{Dilution}\times 100}{\text{Wt. of sample}\times \text{Aliquot of sample}}$$

The same procedure should be followed for determination of vitamin C in dried tomatoes except a weight of 0.5 g should be taken from dried tomatoes instead of 10g.

2.8.6 Total phenolic content

Total phenol content (TPC) of the tomato samples was measured by the Folin – Ciocalteu colorimetric method as described by (Wambugu, 2022). In this method a definite quantity of the tomato extract (Fresh Tomato and Dried tomato) (2g and 0.5g respectively) was reacted with Folin–Ciocalteu reagent (1 ml) for a few minutes. Later, sodium carbonate solution (20%) was added to the mixture, and it was incubated in the dark at room temperature for 30 minutes to facilitate the development of color. The complex obtained was analyzed spectrophotometrically at 765nm using UV-Visible spectrophotometer (Hitachi U-5100, Japan). The calibration curve was created using Gallic acid, and the TPC was reported as the amount in milligrams of gallic acid equivalents (mg GAE) for each 100 grams of sample.

2.9 Total bacterial count

10g of the tomato sample was aseptically placed in the sterile stomacher bag with 90 mL of the sterile peptone water, thoroughly homogenized resulting in 10^{-1} dilution. These were then serially diluted up to 10^{-6} with 1 mL of each dilution transferred to 9 mL of sterile diluent.

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Table 2. Effect of treatments on the pH, Titratable acidity (TA), Vitamin C and Total Phenolic content (TPC)

Treatments	pH	Titratable acidity (%)	Vitamin C (mg/100g)	TPC (mg GAE /100g)
T_0	4.89±0.77a	0.4548±0.0717bc	7.71±5.86d	61.12±26.47c
T_1	4.53±0.30bc	0.5301±0.0526a	11.23±5.80c	82.29±30.68a
T_2	4.43±0.26cd	0.4883±0.0483b	10.33±4.88cd	70.25±28.00b
T_3	4.83±0.26ab	0.4325±0.0531c	13.81±4.39b	77.72±26.35ab
T_4	4.30±0.23d	0.4548±0.0717bc	14.20±4.54a	83.01±25.86a

Table 3. Effect of storage on the pH, Titratable acidity (TA), Vitamin C and Total Phenolic content (TPC)

Storage (Days)	pH	Titratable acidity (%)	Vitamin C (mg/100g)	TPC (mg GAE /100g)
Day 1	4.058±0.16d	0.37±0.05e	26.95±3.24a	108.24±5.17a
Day 5	4.192±0.18c	0.40±0.06d	18.88±3.32b	88.92±10.59b
Day 10	4.312±0.22c	0.43±0.04c	15.64±2.99c	73.05±12.39c
Day 20	4.526±0.17b	0.47±0.03b	11.24±3.63d	55.17±8.42d
Day 40	4.972±0.47a	0.52±0.05a	7.26±4.13e	37.13±8.54e

Appropriate dilutions were made and 1 mL of the sample was pipetted onto the sterile Petri dishes, followed by pouring of 15–20 mL of sterile, molten Plate Count Agar (PCA) cooled to 45 ± 1°C. The plates swirled slightly to distribute the material evenly and then the plates were left to cool. After the incubation, number of colonies that could be observed were scored and results expressed as colony forming units per gram (CFU/g).

2.10 Total fungal count

10 grams of tomato sample was homogenized in 90 mL sterile peptone water in stomacher bag to prepare 10^{-1} sample for total fungal count (TFC). 1 mL of each was then further diluted with sterile diluent to 10-6. The appropriate dilutions were plated with 1 mL on a sterile Petri dish and 15–20 mL of molten Potato Dextrose Agar (PDA) to which chloramphenicol (Cm) was added was poured and stirred to inhibit the growth of bacteria. These plates were then solidified and inverted and grown for 5-7 days at 25°C. These fungi colonies were counted after incubation period, and the results were presented as the number of colonies formed per gram of the sample (CFU/g).

3. Results and Discussion

3.1 Weight loss

Weight loss during drying is an important parameter of moisture removal and dehydration efficiency. The values show constant and high weight loss which confirms that the sun drying process has taken off most of the moisture for all the treatments.

Tomatoes treated with T_2 (vinegar-treated) experienced the highest weight loss among all the treatments, which could be due to the softening of the cell wall due to the action of acid, allowing moisture to migrate. By contrast, T_1 (lemon juice) exhibited the least weight loss, which may be related to the positive effect of the pectin stabilization caused by acid conditions or a tightening of the structure.

The same results were obtained in a relevant study titled "Effect of Solar Drying on Physico-chemical Characteristics of Tomato" (Slimestad & Verheul., 2018) where it was reported that solar drying process always gave 90-94% weight loss of tomato varieties. The study also reported slight variation among preservatives, favoring the belief that drying method, rather than preservative, is the more important factor on final weight loss. The percentage weight loss is illustrated in Figure1.

3.2 Moisture content

The effect of different preservatives on the loss of moisture during solar drying of tomatoes was evaluated. Moisture content of fresh tomato samples ranged from 92.8% to 95.2%, and the moisture content of dried tomato sample ranged from 9.4% to 11.6% after drying. The sample with 2% potassium metabisulfite (T_4) had the maximum moisture loss (89.87%), followed by the sodium benzoate (T_3) and the untreated control (T_0). Lemon juice treatment (T_1) had the lowest rate of moisture loss (87.81%). The results suggest that use of chemical preservatives, especially potassium metabisulfite and

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sodium benzoate, favors drying efficiency which could be mediated by an altering effect on cell-wall permeability or by a decrease in microbial activity during the drying process. A study titled "Performance of Two Terms Exponential Model on the Drying Kinetics of Solar-Dried Tomatoes Treated with and without Chemical Preservatives"(Ullah *et al*., 2022) investigated importance of selecting appropriate preservatives and drying conditions to optimize the drying process and product quality. The results for moisture content are presented in tables 2 and 3, while the percentage moisture loss is illustrated in figure 1.

3.3 Water activity

The high-water activity values in fresh tomato samples (range between 0.87 and 0.93) significantly reduced to between 0.39 and 0.50 after the drying process. The samples treated with 2% potassium metabisulfite (T_4) had a water activity value of 0.39, the lowest of all the treatments, and this resulted in the most effective reduction of water activity that indicated free water. While the sample treated with 10% lemon juice (T_1) has the highest water activity (0.50).

The outcome of this study corroborates with the research study "The Potential of Exploiting Economical Solar Dryer in Food Preservation: Storability, Physicochemical Properties, and Antioxidant Capacity of Solar-Dried Tomato (*Solanum lycopersicum*) Fruits" (Al Maiman *et al*., 2021). The results for water activity are presented in tables 2 and 3, while the percentage water activity is illustrated in figure 1.

3.4 pH

The pH of solar-dried tomatoes showed a general increasing trend across storage time from Day 1 to Day 40 in all treatments. On Day 40, T0 (control) had the highest pH (5.73), while T_4 (treated with 2% potassium metabisulfite) had the lowest pH (4.53). T_3 (2% sodium benzoate) had moderately high pH (5.10) whereas T_1 (10% lemon juice) and T_2 (10% vinegar) had pH of 4.82 and 4.68 respectively when the samples were treated.

During storage, pH increased in all samples, particularly in the Control (T_0), suggesting that the sample underwent microbial and enzymatic degradation over time, as there were no preservatives. The pH stability was greater in the preservative treated samples (T_1-T_4) indicating the inhibitory effect of organic acids and chemical preservatives on microbial activity. Sodium benzoate and potassium metabisulfite were more effective in controlling pH rise compared to natural preservatives (lemon juice and vinegar).

A study titled "Effect of Different Drying Methods on the Physico-Chemical Properties of Tomato Variety 'Rio Grande'" (Mechlouch, R. F. *et al*.,2012) investigated the impact of various drying techniques, including direct solar drying, on the pH of tomatoes. The research found that different drying methods significantly affected the physico-chemical properties of tomatoes, with minimal effects on pH. The results for pH are presented in tables 2 and 3, while the percentage change in pH is illustrated in figure 1.

3.5 Titratable acidity

The titratable acidity (%) of tomato samples was measured across five different treatments over a 40-day storage period. The pH values increased steadily in T_0 (control) and increased in all treated samples (T_1–T_4) but with different trends.

The highest acidity was observed in the treatment T_1 (10% lemon juice) which consistently showed the highest values on Day 40 up to 0.5801%. T_2 (10% vinegar) was followed closely by T_3 (2% sodium benzoate) and T_4 (2% potassium metabisulfite). The use of organic acid preservatives (lemon juice and vinegar) had a more pronounced effect on titratable acidity compared to chemical preservatives.

A study, "Physicochemical and Nutritional Characteristics of Solar and Sun-dried Tomato Powder"(Owureku-Asare *et al*., 2018), examined the effects of different drying methods and pre-treatments on tomato quality. The results showed that the tomatoes dried in the sun and preserved with the preservatives had significantly higher titratable acidity than that of untreated tomatoes. This acidification was blamed on the effect of the preservative during the drying process to preserve the quality and to extend the shelf life of the dried tomatoes. The results for titratable acidity are presented in tables 2 and 3, while percentage increase in titratable acidity is illustrated in figure 1.

3.6 Vitamin C

The vitamin C content was found to vary from 24.01 mg/100g to 31.67 mg/100g between the different treatments. All samples had a decrease in vitamin C content over the 41 day period because of factors such as thermal degradation and oxidation, common in the drying process.

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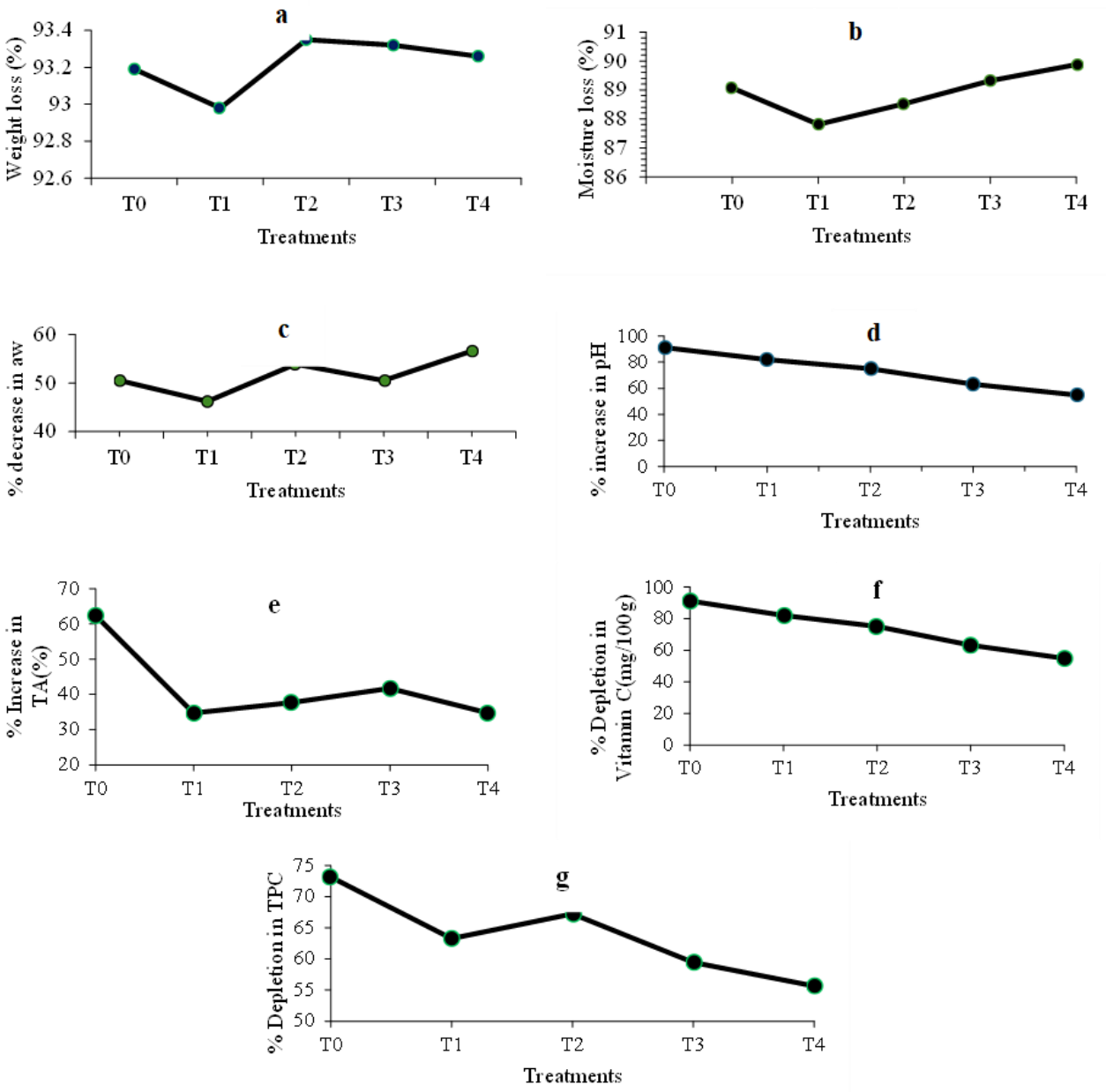


Figure 1. Impact of pretreatments and solar drying on (a) weight loss, (b) moisture loss, (c) % decrease in a_w, (d) % increase in pH, (e) % increase in TA, (f) % depletion in vitamin C and (g) % depletion in TPC

Specifically, T_4 (Potassium metabisulfite) resulted in the highest retention for vitamin C, where it retained 12.97 mg/100g of vitamin C to Day 40, which suggests its effectiveness in retaining vitamin C during drying and storage. Also, the commendable retention of T_3 (Sodium benzoate) was observed as 9.56 mg/100g. In contrast, the preservative effect was observed in the control (T_0) which had the lowest retention (2.13 mg/100g).

In a study by Al Maiman *et al*. (2021), the influence of solar drying on physicochemical properties of tomato has been studied. They observed that vitamin C content of the fresh tomatoes decreased to 3.12 mg/100g after solar

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Table 4. Impact of pretreatments and solar drying on total bacterial count (CFU/g)

Treatments	Fresh tomatoes	Solar dried tomatoes				Mean±S.D
	Day 1	Day 5	Day 10	Day 20	Day 40	
T_0	3010	1840	2960	3530	4180	3304±938a
T_1	2680	40	90	150	270	164±99c
T_2	4580	80	160	370	750	340±290b
T_3	750	20	70	130	410	158±173c
T_4	ND	ND	ND	30	80	55±35d

preservative pretreatments showed a statistically significant inhibition of bacterial growth during storage($p<0.001$). ND stands for Not Detected and TNTC stands for Too Numerous to Count

Table 5. Impact of pretreatments and solar drying on total fungal count (CFU/g)

Treatments	Fresh tomatoes	Solar dried tomatoes				Mean±S.D
	Day 1	Day 5	Day 10	Day 20	Day 40	
T_0	TNTC	30	190	360	850	358±353a
T_1	130	10	110	280	590	248±253b
T_2	3100	20	160	300	740	305±311ab
T_3	TNTC	ND	90	170	320	193±117bc
T_4	ND	ND	ND	ND	40	40±0d

The reduction of fungal load across storage was statistically significant with T4 demonstrating superior antifungal efficacy($p<0.001$). ND stands for Not Detected and TNTC stands for too numerous to count

drying, as compared to 4.19 mg/100g. This loss highlights the need for protection, for example in the form of preservatives, to reduce nutrient loss during the drying operation. The results for vitamin C are presented in tables 2 and 3, while percentage depletion in vitamin C is illustrated in figure 1.

3.7 Total phenol content

Initial TPC values (Day 1) ranged from 129.76 to 141.33 mg GAE/100g across treatments. Over the 40-day period, a decline in TPC was observed in all samples, attributed to oxidative degradation and enzymatic activity during drying and storage.

By Day 40, T_4 (Potassium metabisulfite) exhibited the highest TPC retention at 58.09 mg GAE/100g, followed by T_3 (Sodium benzoate) at 53.75 mg GAE/100g, T_1 (Lemon juice) at 51.89 mg GAE/100g and T_2 (Vinegar) at

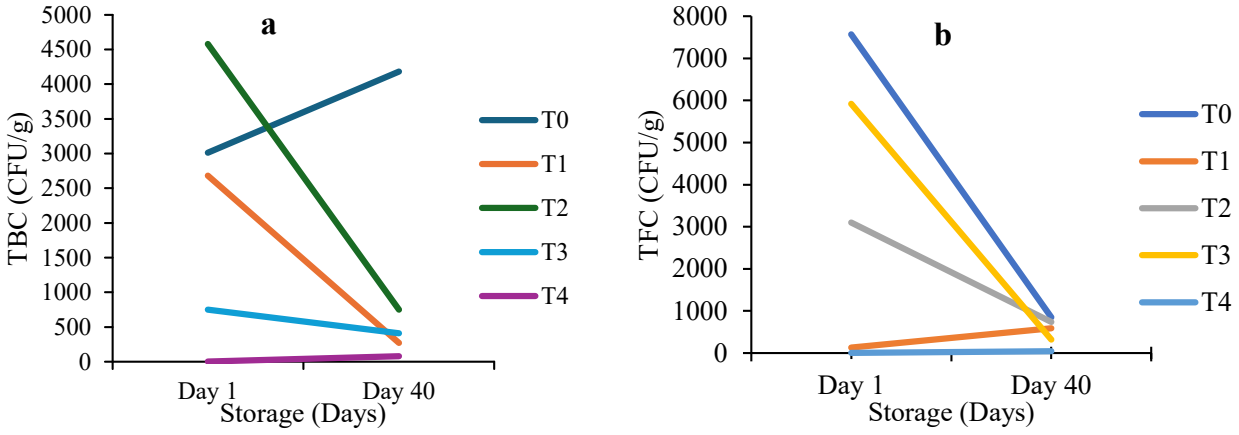


Figure 2. Impact of pretreatments and solar drying on (a) total bacterial count (CFU/g) and (b) total fungal count (CFU/g)

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45.12 mg GAE/100g. The control (T_0) showed the lowest retention, decreasing to 34.87 mg GAE/100g.

The impacts of pretreatment prior to drying on the antioxidant activity and color of some tomato cultivars were investigated by Owureku-Asare *et al*. (2017). They found that chemical pretreatments (sodium metabisulfite and calcium chloride) greatly enhanced the retention of total phenolic content in oven-dried tomatoes. The study highlighted the importance of pretreatment in reducing the degradation of phenolics during drying. The results for total phenolic content are presented in tables 2 and 3, while percentage depletion in total phenolic content is illustrated in figure 1.

3.8 Total bacterial count

A total bacterial count was performed on the microbial analysis of solar dried tomatoes and there were significant differences among the tomato preservative treatments. The untreated control (T_0) exhibited a gradual rise in microbial population from 3010CFU/g on Day 1 to 4180CFU/g on Day 40, which reflects the development of spoilage bacteria because no preservative measures were taken.

Among treated samples: The results showed that T_4 (Potassium metabisulfite) was the most effective, showing no bacteria until Day 20 and 80CFU/g by Day 40, and was outstanding in the preservation power. T_3 (Na benzoate) also showed significant inhibition of bacterial growth, resulting in a low level of bacterial growth of 410 CFU/g at Day 40. T_1 (Lemon juice) and T_2 (Vinegar) had intermediate effectiveness, but vinegar-treated tomatoes had a higher initial microbial load.

Al Maiman *et al*. (2021) studied the effect of solar drying on the storability and physicochemical properties of tomatoes. The study showed that microbial reduction and low water activity levels were achieved by solar drying which led to longer shelf life. The use of other products such as preservative (citric acid) also improved the quality and safety of dried tomatoes throughout the storage period up to 180 days, noted the study. Total bacterial count is presented in Table 4 and illustrated in Figure 2.

3.9 Total fungal count

The purpose of the study was to assess the effectiveness of different preservative treatments in synergist combination with Solar drying on the shelf life of tomato. T_0 (Control) showed a gradual accumulation of fungi; 850 CFU/g was obtained after Day 40, which was a rapid spoilage with no preservative action. T_1 (10% Lemon Juice) and T_2 (10% Vinegar): Showed initial reductions in fungal counts due to increase in temperature and pretreatment with preservatives however, a gradual increase was observed over time, suggesting limited efficacy in long-term preservation. T_3 (2% Sodium Benzoate): Maintained relatively low fungal counts throughout the storage period, demonstrating effective antimicrobial properties. T_4 (2% Potassium Metabisulfite): Showed the most significant reduction in fungal load, with no detectable fungi until Day 20 and only 40 CFU/g by Day 40, highlighting its superior preservative effect along with solar drying.

This result agrees with the work of Al Maiman *et al.* (2021) who investigated the effect of solar drying on the storability and physicochemical properties of tomatoes. Total fungal count is presented in Table 5 and illustrated in Figure 2.

Conclusion

The results of this study point to the importance of preservative pre-treatment using both natural and synthetic methods to impact the quality attributes and stability of solar dehydrated tomatoes. Generally, the moisture content, pH stability, titratable acidity, vitamin C, and total phenolic content were retained, and microbial growth was effectively suppressed by synthetic preservatives like potassium metabisulfite and sodium benzoate. However, other natural preservatives such as vinegar and lemon juice proved to be effective in the case of bioactive compounds such as total phenolics and acceptable sensory attributes. Lemon juice was the most promising natural preservative as it exhibited good effect on the inhibition of microbial growth without compromising the antioxidant activity and sensory qualities. Overall, although synthetic preservatives showed better preservative ability, natural preservatives, particularly lemon juice, can be a good alternative for small-scale or organic solar drying units that cannot use chemical preservatives due to consumer acceptance. The focus of this study is that suitable preservatives can be chosen depending on the priority of the shelf life, nutritional quality and consumer preference.

Author's Contribution

Muhammad Shariq: Conceptualization, methodology, investigation, and writing-original draft. Majid Suhail Hashmi: Supervision, methodology, and critical revision of the manuscript. Farzana Fatima: Data curation, formal analysis, and interpretation of results. Laila Bashir: Investigation, literature review, and data collection.

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Rahmat Ali: Methodology, validation, and data analysis. Waqas Ahmad: Investigation, visualization, and manuscript editing. Alishba: Data curation, literature review, and manuscript preparation. Muhammad Sadat: Supervision, validation, and final review of the manuscript. All authors reviewed and approved the final version of the manuscript.

Conflict of Interest

Authors declared that there were no conflicts of interest.

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