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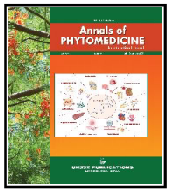

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Optimizing tomato powder shelf-life: The role of pretreatments and drying methods

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Abstract

Processing of excessive short lived and deteriorating commodities, like tomatoes represents a strategic approach to preservation, particularly during periods of oversupply. Preliminary treatment is frequently applied in advance of dehydrating agricultural products to deactivate enzymatic activity, accelerate the dehydration process to enhance the standard of the desiccated goods. In this experiment, tomato fruits were subjected to pretreatments of citrus oil, honey, and vinegar before subjecting to dehydration methods (freeze and oven drying). The physical attributes and polyphenolic content (including total flavonoids, total phenolic content, lycopene, Total carotenoids and ascorbic acid) of tomato powder were evaluated over a 180-days period, with assessments taken at 45-days intervals. Additionally, the microbial quality of the powder was evaluated. The findings revealed that the measured parameters (total flavonoid content, total phenolic compounds lycopene, total carotenoids and ascorbic acid) were significantly (p=0.05) impacted by the different preliminary approach and dehydrated methods used. Tomato powder prepared after treating with vinegar, freeze dried and packed in laminated aluminium pack showed higher values of total phenolic compounds (198.73 mg GAE/100 g), total flavonoids (104.80 mg/100 g), total carotenoids (13.21 mg/100 g), lycopene (28.63 mg/100 g) and ascorbic acid (8.46 mg/100 g) and retained its quality up to 180 days under ambient storage conditions.

1. Introduction

The tomato is a consumable fruit from *Solanum lycopersicum* L. emerged from Western and Central America. Numerous tomato plant varieties are widely grown across temperate regions worldwide. It is consumed as either cooked or raw, in the form of abundant dishes, sauces, salads, and drinks. Tomatoes are an exceptional source of essential nutrients, including the potent antioxidant lycopene, which has been associated with numerous health advantages, such as a lower risk of heart disease and cancer. Additionally, they are rich in vital vitamins and minerals like vitamin C, potassium, folate, and vitamin K, making them a nutritious addition to a healthy diet. Senescence and moisture losses are crucial factors to postharvest losses which include softening of these fruits with afterward loss of cellular turgidity and fruit quality. Minimizing losses is a crucial concern, especially when imbalance exists amidst demand and supply while both peak fabrication and off-peak periods (Adeyeye, 2017). Additionally, the availability of fresh tomatoes varies across different regions of the country, and their prices fluctuate throughout the year. However, growing market demand has necessitated the availability of tomatoes in alternative, more convenient formats. As a result, it is crucial to devise effective transformation and protection methods to facilitate the marketability of tomatoes, especially during non-peak stages. Preservation technology involves transforming produce into a longer-lasting form through various processes. In India, preserving tomatoes is particularly important due to their seasonal production, despite year-round consumption (Owureku-Asare *et al*., 2017). Processing superfluity amounts of such highly perishable crop is especially vital during periods of market oversupply. Transforming spoilable and fragile goods like tomato into shelf-stable products is often recommended for certain primary reasons, *e.g*., managing excess supply during peak seasons enhancing the secondary processing chain by increasing the worth of final product. Implementing suitable micro postharvest techniques can decrease crop losses in fruits and vegetables, potentially increasing earnings for smallholder farmers and vendors by as much as 30% (Hailu and Derbew, 2015). Cold storage helps prolong freshness, but other methods like use of chemicals (potassium carbonate, sodium metabisulfite, ascorbic acid) as pre-treatment for tomato drying has been explored. Drying is a commonly used preservation technique, particularly on a small scale. Tomato powder is a valuable component used to augment taste and palatability of a range of dishes, including flatbreads, broths greens and starters. Their distinctive taste comes from their high acid content. Consequently, developing effective methods for transforming tomato into shelf-steady products is crucial to reduce spoilage and waste, thereby tackling the challenges of excessive production coupled with shortages during the slump period (Varghese *et al*., 2022). Most common method for drying vegetables is convective hot air, utilizing temperatures around 55°C to achieve the final amount of moisture content, *i.e*., 4-8% on a wet weight basis. Microwave drying, employing electromagnetic waves to generate heat and expedite the drying process, is also gaining popularity. A research investigation was administered to examine

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effects of varied preliminary treatment techniques (citrus oil, honey, vinegar) and dehydrating techniques (freeze and oven) with drying characteristics and biochemical properties of tomatoes that had been pre-treated.

2. Material and Methods

2.1 Raw material preparation

Ripe-stage tomato fruits *L. esculentum*, homogenous in size, red in color, free from visible defects were sourced from the Division of Olericulture, SKUAST-K Shalimar. The tomatoes were manually rinsed with tap water to eliminate contaminants and soil and then positioned on a plastic mesh to facilitate drainage of surplus water. They were subsequently sliced into 4-7 mm thick pieces employing a fruit chopped before undergoing pre-treatment. The tomato slices were categorized into four distinct groups for the purpose of pre-drying treatments. The first group was immersed in a citrus oil solution for 5 min, the second group in a honey solution for 5 min, the third group in a vinegar for 5 min and the fourth group remained untreated as a control (C). After pre-treatment, the slices were drained on a sieve for 3-4 min. Freeze and oven drying and were then employed for development of tomato powder. For oven drying, the tomato slices were distributed in a single layer across trays and subjected to drying at 55°C for duration of 8 h. In case of freeze drying, tomato slices were placed in trays and frozen at – 40 ± 5°C and then dried under a vacuum of – 600 mmHg with the desired moisture content being accomplished in about 20 h. Dried tomato slices were milled in a grinder to powder form (101-108 mesh) and then packed in aluminium laminates for a period of 6 months and were evaluated at an interval of 45 days. The plant is authenticated by Dr. Nazeer Ahmad, Ex. Head of the Division, Division of Vegetable Science, SKUAST-K. The herbarium No. is SH-FMS-IX SH-T-11.

2.2 Analytical methods

Standard procedures were employed for different qualitative and quantitative parameters for the current study.

2.2.1 Total flavonoid content (mg/100 g)

The total flavonoid quantity was measured by incorporated $AlCl_3$ colorimetric approaches. To do this, 10 ml of $AlCl_3$ and 10 ml of potassium acetate solution were combined with the 20 ml solution mixture, and was diluted to a total measurement of 200 ml with the addition of 160 ml of purified water. After 30 min incubation at 37°C, absorbance was recorded at 415 nm. Quercetin served as the benchmark standard, with results reported as quercetin equivalents (QE mg/g) (Vishwakarma *et al*., 2014).

2.2.2 Total phenolics (mg GAE/100 g)

The amount of total phenolic content (TPC) was assessed using the Folin-Ciocalteu (FC) reagent method. To 20 ml of the sample solution, 90 ml of Folin-Ciocalteu reagent and 90 ml of 6% Na_2CO_3 were added. The mixture was incubated at 25°C for 60 min, and the optical density was measured at 760 nm. Gallic acid served as the positive control. The TPC was reported as gallic acid equivalents (GAE) in mg/100 g of the extract (Vishwakarma *et al*., 2014).

2.2.3 Ascorbic acid (mg/100 g)

Following Ranganna (1986) protocol, ascorbic acid was quantified using the 2,6-dichlorophenol indophenol dye. Ascorbic acid was measured using the method outlined by Ranganna (1986), involving the 2,6-dichlorophenol indophenol dye. The dye factor was established by titrating a 5 ml mixture of standard ascorbic acid and 5 ml of 3% metaphosphoric acid with the 2,6-dichlorophenol indophenol dye until a pink color appeared, with the volume of dye consumed being noted. The ascorbic acid content was expressed in mg per 100 g and determined using the following formula:

$$\text{Ascorbic acid (mg/ 100 g)} = \frac{\text{Titre}}{\text{Weight or Volume of sample} \times \text{Aliquot of extract taken for estimation}}$$

2.2.4 Total carotenoid (mg/100 g)

Total carotenoids, expressed as equivalents to beta-carotene, were quantified following protocol outlined by Rodriguez-Amaya and Kimura (2004). 2 g of the homogenized samples were subjected to extraction using cold acetone, until the remnant achieved a colorless appearance. The extract was subsequently passed *via* cellulose based filter sheet. Twenty-five milliliters of the filtered acetone extract were transferred to an isolating container, where 20 ml of petroleum ether was then added. The solution was left to settle for 15 min, resulting in distinct phases. The sheets were divided, and the organic fraction was kept for further analysis. To eliminate leftover water, petroleum ether was poured using a funnel lined with anhydrous sodium sulfate into a 100 ml volumetric flask. The volume makeup 100 ml was done with additional pet ether, and the optical density was recorded, with pet ether serving as the blank. Total carotene was subsequently quantified as milligrams of beta-carotene equivalents per 100 g of analyte using the following equation:

$$\text{Total carotenoids (mg/100 g)} = \frac{\delta A}{E1} \times MW \times D \times \frac{V}{G}$$

where delta "A" is the absorbance, "e" is the molar extinction coefficient of beta-carotene (2590), "l" is the path length of the cell (1cm), "D" is the dilution factor, "MW" represents molar mass of beta-carotene, "V" represents end volume (in ml), and "G" acts as sample weight (in g).

2.2.5 Lycopene (mg/100 g)

The concentration of lycopene in tomato powder was evaluated utilizing approaches mentioned in research conducted by Srivastava and Kumar (2004). The extraction process started with 5-10 g of the analyte, using acetone as the extraction solvent. The acetone extract was subsequently poured to an isolated decanter with 10-15 ml of ligroin and a 5% sodium sulfate solution to remove excess moisture. The mixture was repetitively extracted until it was clear. The layer of petroleum ether, containing the lycopene, was collected and volume was adjusted to 50 ml. Furthermore, the lycopene concentration and absorbance was assessed at 472 nm using a UV-Vis-spectro-photometer.

2.2.6 Colour

Color analysis was conducted using a Hunter Lab Colorimeter (Model SN 3001476, Micro accuracy sensors, NY). Calibration involved using black plates provided by the user to set the zero point and white plates from Minolta for white balance calibration. Samples

were placed in hygienic petri dishes with lids and the instrument was positioned on top to collect readings from various points. The color parameters were reported as L*, a*, and b* according to the CIELAB color measurement system. In this system, L* represents brightness, ranging from black (0) to white (100), a* indicates the green-red spectrum with values from green (+100) to red (-100), and b* measures the blue-yellow spectrum, ranging from blue (-100) to yellow (+100) (McGuire, 1992).

2.2.7 Microbial analysis

The overall microbial counts, including bacteria, yeast, and mold were determined in the samples using the standard serial dilution plate count technique with Nutrient Agar and Potato Dextrose Agar, following the procedure described by Martin (1950). For this analysis, 10 g of the sample was mixed with 90 ml of water to create a suspension. After stirring for 5 min, aliquots of the suspension were serially diluted and used for plate counting. One millilitre of each appropriate dilution was transferred to sterile plates, and molten agar media, cooled to 45°C, was poured onto the plates. The plates were gently swirled to evenly distribute the inoculum before the medium solidified. After incubating the plates at 32°C for 3-5 days, the colonies were counted and the results were reported as log cfu/g, representing the logarithm of the number of colony-forming units per gram.

3. Results

3.1 Total flavonoids (mg/100 g)

The total flavonoid content of tomato fruit subjected to pretreatments of citrus oil, honey, and vinegar followed by drying methods (oven and freeze drying) is shown in Table 1. According to Table 1, a statistically significant ($p \leq 0.05$) decrease in total flavonoids was observed as the storage duration increased. Notably, samples treated with vinegar and freeze dried exhibited a slower decline, with initial levels of 241.27 mg/100 g at day 0, gradually decreasing to 104.80 mg/100 g by day 180th. Higher values of total flavonoids, *i.e.,* 104.80 mg/100 g, was observed in tomato powder treated with vinegar and freeze dried tomato powder after180 days of storage, whereas as lower values (26.88 mg/100 g) were observed in control and oven dried samples.

Table 1: Effect of pretreatments and drying methods on total flavonoid content (mg/100 g) of tomato powder during 180 days of storage

Storage	Treatments	0 Day	45 Days	90 Days	135 Days	180 days
Oven drying	T_0	100.94 ± 6.78^{a,5}	77.70 ± 7.21^{a,4}	66.38 ± 6.33^{a,3}	40.13 ± 5.03^{a,2}	26.88 ± 5.05^{a,1}
	T_1	130.82 ± 9.83^{b,5}	109.00 ± 7.08^{b,4}	77.74 ± 5.67^{b,3}	49.81 ± 6.90^{b,2}	40.05 ± 3.90^{b,1}
	T_2	106.37 ± 6.84^{a,5}	79.73 ± 6.34^{a,4}	65.75 ± 4.63^{a,3}	43.27 ± 5.94^{a,2}	36.42 ± 7.96^{b,1}
	T_3	134.00 ± 9.90^{b,5}	119.39 ± 6.81^{c,4}	81.44 ± 8.48^{b,3}	55.24 ± 4.89^{b,2}	50.13 ± 4.24^{c,1}
Freeze drying	T_0	189.46 ± 8.74^{c,5}	166.32 ± 6.80^{e,4}	122.33 ± 7.97^{c,3}	99.12 ± 6.03^{c,2}	69.12 ± 5.16^{d,1}
	T_1	186.49 ± 9.48^{c,5}	146.50 ± 8.63^{d,4}	131.23 ± 8.14^{d,3}	110.81 ± 6.48^{d,2}	91.95 ± 7.48^{e,1}
	T_2	184.13 ± 8.24^{c,5}	150.67 ± 7.98^{d,4}	130.91 ± 7.47^{d,3}	111.44 ± 10.68^{d,2}	91.77 ± 10.56^{e,1}
	T_3	241.27 ± 9.78^{d,5}	195.26 ± 9.88^{f,4}	169.24 ± 8.98^{e,3}	125.83 ± 6.41^{e,2}	104.80 ± 7.07^{f,1}

T_0= Control, T_1= Citrus oil, T_2= Honey, T3= Vinegar; Values are mean ± SD
Values within treatments in a column not sharing a common superscript lowercase letter (a/f) are significantly ($p \leq 0.05$) different.
Values within storage periods in a row not sharing a common superscript numerical (1/5) are significantly ($p \leq 0.05$) different.

Table 2: Effect of pretreatments and drying methods on total phenolic content (mg GAE/100 g) of tomato powder during 180 days of storage

Storage	Treatments	0 Day	45 Days	90 Days	135 Days	180 days
Oven drying	T_0	181.42 ± 8.88^{a,5}	162.09 ± 9.93^{a,4}	123.42 ± 7.41^{a,3}	107.43 ± 6.56^{a,2}	98.83 ± 6.64^{a,1}
	T_1	231.45 ± 9.37^{e,5}	208.93 ± 7.47^{e,4}	192.54 ± 9.64^{e,3}	142.05 ± 5.89^{c,2}	122.03 ± 6.59^{b,1}
	T_2	196.77 ± 7.89^{b,5}	169.85 ± 9.01^{b,4}	141.92 ± 10.25^{b,3}	116.82 ± 6.96^{b,2}	104.69 ± 7.61^{a,1}
	T_3	210.08 ± 6.95^{c,5}	192.73 ± 9.12^{c,4}	164.15 ± 8.86^{c,3}	143.65 ± 6.95^{c,2}	130.07 ± 6.23^{c,1}
Freeze drying	T_0	221.38 ± 9.13^{d,5}	201.32 ± 8.63^{d,4}	183.88 ± 6.37^{d,3}	152.41 ± 6.40^{d,2}	136.74 ± 8.55^{d,1}
	T_1	287.27 ± 9.09^{f,5}	264.42 ± 8.74^{f,4}	203.32 ± 5.80^{f,3}	170.63 ± 9.30^{e,2}	148.91 ± 8.13^{e,1}
	T_2	223.16 ± 6.16^{d,5}	208.30 ± 9.13^{e,4}	199.81 ± 9.25^{f,3}	169.02 ± 8.57^{e,2}	142.19 ± 9.03^{d,1}
	T_3	317.49 ± 7.71^{g,5}	299.33 ± 9.80^{g,4}	267.13 ± 9.55^{g,3}	205.94 ± 6.33^{f,2}	198.73 ± 8.44^{f,1}

T_0= Control, T_1= Citrus oil, T_2= Honey, T3= Vinegar; Values are mean ± SD
Values within treatments in a column not sharing a common superscript lowercase letter (a/f) are significantly ($p \leq 0.05$) different.
Values within storage periods in a row not sharing a common superscript numerical (1/5) are significantly ($p \leq 0.05$) different.

3.2 Total phenolic content (mg GAE/100 g)

The total phenolic content declined, throughout the six-month storage period, across all samples, regardless of the pretreatment methods or drying processes used, as illustrated in Table 2. However, the reduction was notably less in samples treated with vinegar and freeze dried, with a significant difference ($p \leq 0.05$), which was about 317.49 mg GAE/100 g at 0th day of storage and decreased up to 198.73 mg GAE/100 g at the storage of 180th day. The combination of vinegar and freeze-drying resulted in the highest total phenol content, with a value of 198.73 mg GAE/100 g, compared to the control samples, which had a total phenolic content of 98.83 mg GAE/100 g after 180 days of storage

3.3 Ascorbic acid (mg/100 g)

Experimental evidences regarding ascorbic acid content of dried tomato powder have been presented in Table 3. The vitamin C meaningfully diminished ($p \leq 0.05$) over the storage timeframe, with each increase in storage duration. However, decline in ascorbic acid content was observed to be less in sample treated with vinegar and freeze dried. Among the treatments, the highest ascorbic acid content was observed in T_3 (vinegar + freeze dried samples), with a value of 8.46 mg/100 g on the 180th day of storage.

Table 3: Effect of pretreatments and drying methods on ascorbic acid content (mg/100 g) of tomato powder during 180 days of storage

Storage	Treatments	0 Day	45 Days	90 Days	135 Days	180 days
Oven drying	T_0	18.11 ± 0.05$^{a, 4}$	11.36 ± 0.06$^{a, 3}$	7.85 ± 0.03$^{a, 2}$	4.58 ± 0.07$^{a, 1}$	4.27 ± 0.05$^{a, 1}$
	T_1	18.49 ± 0.66$^{b, 4}$	13.36 ± 0.06$^{c, 3}$	8.98 ± 0.04$^{b, 2}$	6.11 ± 0.04$^{c, 1}$	5.99 ± 0.06$^{c, 1}$
	T_2	18.90 ± 1.19$^{c, 4}$	12.80 ± 0.60$^{b, 3}$	8.13 ± 0.06$^{a, 2}$	5.26 ± 0.05$^{b, 1}$	5.10 ± 0.05$^{b, 1}$
	T_3	18.94 ± 1.20$^{c, 5}$	13.88 ± 0.07$^{d, 4}$	9.08 ± 0.05$^{b, 3}$	6.82 ± 0.04$^{d, 2}$	6.26 ± 0.06$^{c, 1}$
Freeze drying	T_0	18.26 ± 0.06$^{a, 4}$	14.11 ± 0.06$^{d, 3}$	9.86 ± 0.05$^{c, 2}$	7.10 ± 0.05$^{d, 1}$	6.96 ± 0.05$^{e, 1}$
	T_1	18.86 ± 1.26$^{c, 5}$	14.73 ± 0.07$^{e, 4}$	10.29 ± 0.06$^{d, 2}$	10.57 ± 0.05$^{f, 3}$	8.27 ± 0.07$^{f, 1}$
	T_2	18.36 ± 0.05$^{a, 5}$	14.57 ± 0.07$^{e, 4}$	10.00 ± 0.07$^{c, 3}$	7.36 ± 0.04$^{e, 2}$	6.38 ± 0.06$^{d, 1}$
	T_3	18.67 ± 0.64$^{b, 5}$	14.65 ± 0.08$^{e, 4}$	10.33 ± 0.05$^{d, 2}$	10.75 ± 0.08$^{f, 3}$	8.46 ± 0.04$^{f, 1}$

T_0= Control, T_1= Citrus oil, T_2= Honey, T3= Vinegar; Values are mean ± SD
Values within treatments in a column not sharing a common superscript lowercase letter (a/f) are significantly ($p \leq 0.05$) different.
Values within storage periods in a row not sharing a common superscript numerical (1/5) are significantly ($p \leq 0.05$) different.

3.4 Total carotenoids (mg/100 g)

The total carotenoid content as presented in Table 4, was significantly influenced by pre-treatments and drying methods during storage over 180 days which decreased with the storage time. Oven-drying without pretreatment led to a more substantial loss of total carotenoid in tomato powder compared to the pretreated and freeze dried method. Among all the treatments, the T3 samples (vinegar + freeze dried) retained the highest total carotenoid content, measured in mg/100 g on the 180th day of storage. Statistical analysis indicated a notable difference in total carotenoid content (p=0.05) across the dried tomato powders during the storage period. Data also revealed that the decline in total carotenoid was less in freeze dried as compared to oven dried samples.

Table 4: Effect of pretreatments and drying methods on total carotenoids (mg/100 g) content of tomato powder during 180 days of storage

Storage	Treatments	0 Day	45 Days	90 Days	135 Days	180 days
Oven drying	T_0	18.29 ± 0.07$^{a, 3}$	8.56 ± 0.06$^{a, 2}$	5.25 ± 0.04$^{a, 1}$	4.90 ± 0.06$^{a, 1}$	4.58 ± 0.04$^{a, 1}$
	T_1	22.13 ± 0.07$^{b, 4}$	18.85 ± 0.60$^{c, 3}$	15.88 ± 0.07c$^{, 2}$	10.86 ± 0.05$^{b, 1}$	10.04 ± 0.04$^{c, 1}$
	T_2	19.79 ± 0.55$^{a, 4}$	15.54 ± 0.07$^{b, 3}$	13.37 ± 0.06$^{b, 2}$	10.55 ± 0.05$^{b, 1}$	9.66 ± 0.05$^{c, 1}$
	T_3	18.72 ± 0.44$^{a, 5}$	15.67 ± 0.07$^{b, 4}$	12.39 ± 0.07$^{b, 3}$	9.36 ± 0.06$^{b, 2}$	7.63 ± 0.05$^{b, 1}$
Freeze drying	T_0	26.53 ± 6.45$^{c, 4}$	19.88 ± 1.64$^{c, 3}$	15.99 ± 0.07$^{c, 2}$	11.09 ±0.07$^{c, 1}$	10.52 ± 0.06$^{c, 1}$
	T_1	36.53 ± 6.72$^{e, 5}$	32.07 ± 6.76$^{e, 4}$	25.96 ± 4.59$^{d, 3}$	20.79 ± 1.56$^{e, 2}$	18.91 ± 0.10$^{e, 1}$
	T_2	27.04 ± 4.26$^{c, 4}$	21.24 ± 2.05$^{d, 3}$	17.36 ± 0.08$^{c, 2}$	12.86 ± 0.06$^{d, 1}$	13.80 ± 0.04$^{d, 1}$
	T_3	29.74 ± 5.52$^{d, 4}$	21.15 ± 4.02$^{d, 3}$	16.55 ± 0.07$^{c, 2}$	12.69 ± 0.06$^{c, 1}$	13.21 ± 0.08$^{d, 1}$

T_0= Control, T_1= Citrus oil, T_2= Honey, T3= Vinegar; Values are mean ± SD
Values within treatments in a column not sharing a common superscript lowercase letter (a/f) are significantly ($p \leq 0.05$) different.
Values within storage periods in a row not sharing a common superscript numerical (1/5) are significantly ($p \leq 0.05$) different.

3.5 Lycopene (mg/100 g)

The lycopene content in freeze dried tomato samples T_0, T_1, T_2, and T_3 samples was recorded as 43.08, 49.17, 47.64, along with 41.79 mg/100 g, respectively, by the start of storage (Day 0), as shown in Table 5. For the samples subjected to oven dried samples, the lycopene concentration values were 24.09, 27.48, 31.10, and 23.31, mg/ 100 g for T_3 , T_2 , T_1 and T_0 samples, respectively, at 0thday of storage. Over the storage period, concentration values for lycopene in both oven dried and freeze dried tomato powder declines significantly ($p \leq 0.05$). However, the results indicated that the lycopene content remained significantly higher ($p \leq 0.05$) in T_3 samples (vinegar + freeze dried samples) compared to T_0, T_1, and T_2 samples, suggesting the least degradation of lycopene in T_3 samples.

Table 5: Effect of pretreatments and drying methods on lycopene content (mg/100 g) of tomato powder during 180 days of storage

Storage	Treatments	0 Day	45 Days	90 Days	135 Days	180 days
Oven drying	T_0	$23.31 \pm 4.05^{a, 4}$	$18.52 \pm 0.07^{a, 3}$	$15.36 \pm 0.07^{a, 2}$	$11.53 \pm 0.04^{a, 1}$	$9.66 \pm 0.04^{a, 1}$
	T_1	$31.10 \pm 4.18^{c, 3}$	$26.76 \pm 4.31^{c, 2}$	$24.31 \pm 5.46^{c, 2}$	$21.10 \pm 2.02^{b, 1}$	$18.99 \pm 0.86^{b, 1}$
	T_2	$27.48 \pm 3.75^{b, 4}$	$22.42 \pm 6.48^{b, 3}$	$19.22 \pm 1.29^{b, 2}$	$14.29 \pm 0.07^{a, 1}$	$12.65 \pm 0.06^{a, 1}$
	T_3	$24.09 \pm 4.98^{a, 4}$	$20.29 \pm 0.07^{a, 3}$	$16.53 \pm 0.05^{a, 2}$	$12.61 \pm 0.07^{a, 1}$	$10.26 \pm 0.05^{a, 1}$
Freeze drying	T_0	$43 \pm .08 \pm 3.96^{d, 5}$	$39.65 \pm 6.09^{e, 4}$	$35.93 \pm 3.51^{d, 3}$	$31.67 \pm 7.05^{c, 2}$	$26.75 \pm 4.29^{c, 1}$
	T_1	$49.17 \pm 6.83^{e, 4}$	$44.02 \pm 5.76^{f, 3}$	$41.24 \pm 5.96^{e, 2}$	$38.50 \pm 3.48^{d, 1}$	$36.90 \pm 5.84^{e, 1}$
	T_2	$47.64 \pm 5.30^{e, 4}$	$40.71 \pm 4.38^{e, 3}$	$39.90 \pm 7.42^{e, 3}$	$36.38 \pm 4.51^{d, 2}$	$31.24 \pm 3.22^{d, 1}$
	T_3	$41.79 \pm 6.78^{d, 4}$	$34.58 \pm 4.58^{d, 2}$	$38.21 \pm 5.73^{d, 3}$	$32.87 \pm 4.24^{c, 2}$	$28.63 \pm 2.57^{c, 1}$

T_0= Control, T_1= Citrus oil, T_2= Honey, T3= Vinegar; Values are mean ± SD
Values within treatments in a column not sharing a common superscript lowercase letter (a/f) are significantly ($p \leq 0.05$) different.
Values within storage periods in a row not sharing a common superscript numerical (1/5) are significantly ($p \leq 0.05$) different.

3.6 Colour

The influence of various pretreatments was examined followed by dehydrating approaches on the instrumental color (L*) of tomato powder throughout the 180-days period of storage and the detail is given in Table 6.1. The data showed a significant decrease ($p \leq 0.05$) in the L* value, indicating a loss of lightness, regardless of the pretreatment or drying method applied. The most pronounced reduction in L* value occurred in the T_0 samples (freeze dried + control), where the initial L* value of 30.93 declined to 16.22 after 180 days of storage. Conversely, the T_3 samples (freeze dried + vinegar) experienced the lowest decline, with the L* value decreasing from 31.00 to 20.07 during the same storage period. The data presented in Table 6.2 illustrated that the a* value, which indicates the red-green color axis, declined over the 180-days storage period across all pretreatments and dehydration approaches, significantly ($p \leq 0.05$). The most substantial decrease was recorded in the T_0 samples (freeze dried + control), where the value declined from 15.18 to 7.19 after 180 days of storage. Similarly, the T_3 samples (freeze dried + vinegar) exhibited the least decline, with the a* value dropping from 15.77 to 9.14 over the same period.

As for the data presented in Table 6.3, b* value followed a significantly ($p \leq 0.05$) decreasing trend irrespective of pretreatments and drying methods. Highest decrease in b* value was recorded in T_0 samples (oven dried + Control) from an initial value of 29.68 to 15.25 after 180 days of storage. However, the lowest decline in the b* value was recorded in T_3 samples (Freeze dried + vinegar) from an initial value of 21.70 to 15.40 throughout the storage period.

Table 6.1: Effect of pretreatments and drying methods on color score (L* value) of tomato powder during 180 days of storage

Storage	Treatments	0 Day	45 Days	90 Days	135 Days	180 days
Oven drying	T_0	$49.58 \pm 7.62^{b, 4}$	$43.66 \pm 6.59^{c, 3}$	$40.23 \pm 5.07^{c, 2}$	$37.65 \pm 6.56^{c, 1}$	$35.84 \pm 4.11^{c, 1}$
	T_1	$50.51 \pm 5.61^{b, 4}$	$47.22 \pm 4.08^{d, 3}$	$42.69 \pm 5.55^{c, 2}$	$41.24 \pm 7.57^{d, 1}$	$39.49 \pm 5.20^{d, 1}$
	T_2	$49.66 \pm 6.13^{b, 4}$	$44.45 \pm 3.64^{c, 3}$	$41.65 \pm 4.62^{c, 2}$	$39.36 \pm 6.05^{c, 1}$	$37.06 \pm 3.53^{c, 1}$
	T_3	$49.57 \pm 6.59^{b, 4}$	$46.32 \pm 4.08^{c, 3}$	$42.60 \pm 5.60^{c, 2}$	$40.65 \pm 7.57^{c, 2}$	$37.96 \pm 3.54^{c, 1}$
Freeze drying	T_0	$30.93 \pm 4.59^{a, 4}$	$24.85 \pm 3.55^{a, 3}$	$20.95 \pm 1.56^{a, 2}$	$18.67 \pm 0.62^{a, 1}$	$16.22 \pm 0.07^{a, 1}$
	T_1	$31.67 \pm 3.65^{a, 4}$	$28.73 \pm 3.59^{b, 3}$	$25.53 \pm 1.04^{b, 2}$	$22.72 \pm 1.56^{b, 1}$	$20.30 \pm 0.08^{b, 1}$
	T_2	$31.12 \pm 3.09^{a, 4}$	$25.49 \pm 2.15^{a, 3}$	$22.39 \pm 0.66^{a, 2}$	$20.11 \pm 0.08^{a, 1}$	$18.13 \pm 0.06^{a, 1}$
	T_3	$31.00 \pm 5.13^{a, 4}$	$26.85 \pm 2.58^{a, 3}$	$24.74 \pm 4.14^{b, 2}$	$23.08 \pm 2.69^{b, 2}$	$20.07 \pm 0.08^{b, 1}$

T_0= Control, T_1= Citrus oil, T_2= Honey, T3= Vinegar; Values are mean ± SD
Values within treatments in a column not sharing a common superscript lowercase letter (a/f) are significantly ($p \leq 0.05$) different.
Values within storage periods in a row not sharing a common superscript numerical (1/5) are significantly ($p \leq 0.05$) different.

Table 6.2: Effect of pretreatments and drying methods on color score (a* value) of tomato powder during 180 days of storage

Storage	Treatments	0 Day	45 Days	90 Days	135 Days	180 days
Oven drying	T_0	$17.32 \pm 0.07^{e,5}$	$16.90 \pm 0.63^{d,4}$	$15.32 \pm 0.07^{d,3}$	$13.07 \pm 0.06^{d,2}$	$10.91 \pm 0.06^{d,1}$
	T_1	$21.62 \pm 1.19^{e,5}$	$19.84 \pm 0.62^{f,4}$	$18.57 \pm 0.07^{f,3}$	$16.42 \pm 0.07^{f,2}$	$14.33 \pm 0.06^{f,1}$
	T_2	$20.45 \pm 1.19^{d,5}$	$18.40 \pm 0.60^{e,4}$	$17.51 \pm 0.07^{e,3}$	$15.55 \pm 0.06^{e,2}$	$13.58 \pm 0.07^{e,1}$
	T_3	$20.88 \pm 1.55^{d,3}$	$25.31 \pm 2.54^{g,5}$	$22.37 \pm 0.63^{g,4}$	$20.13 \pm 0.08^{g,2}$	$18.11 \pm 0.07^{g,1}$
Freeze drying	T_0	$15.18 \pm 0.07^{a,5}$	$13.19 \pm 0.05^{b,4}$	$11.59 \pm 0.04^{a,3}$	$9.35 \pm 0.07^{a,2}$	$7.19 \pm 0.05^{a,1}$
	T_1	$15.91 \pm 0.66^{b,5}$	$14.36 \pm 0.08^{c,4}$	$13.18 \pm 0.06^{c,3}$	$11.02 \pm 0.05^{b,2}$	$8.94 \pm 0.04^{b,1}$
	T_2	$15.52 \pm 0.07^{a,4}$	$12.32 \pm 0.05^{a,3}$	$12.56 \pm 0.08^{b,3}$	$10.61 \pm 0.06^{b,2}$	$8.64 \pm 0.04^{b,1}$
	T_3	$15.77 \pm 0.63^{b,5}$	$14.03 \pm 0.07^{c,4}$	$13.09 \pm 0.06^{c,3}$	$11.15 \pm 0.07^{c,2}$	$9.14 \pm 0.04^{c,1}$

T_0= Control, T_1= Citrus oil, T_2= Honey, T3= Vinegar; Values are mean ± SD
Values within treatments in a column not sharing a common superscript lowercase letter (a/f) are significantly ($p \leq 0.05$) different.
Values within storage periods in a row not sharing a common superscript numerical (1/5) are significantly ($p \leq 0.05$) different.

Table 6.3: Effect of pretreatments and drying methods on color score (b* value) of tomato powder during 180 days of storage

Storage	Treatments	0 Day	45 Days	90 Days	135 Days	180 days
Oven drying	T_0	$29.68 \pm 2.56^{c,5}$	$23.90 \pm 1.55^{d,4}$	$19.66 \pm 0.08^{b,3}$	$17.41 \pm 0.07^{b,2}$	$15.25 \pm 0.06^{b,1}$
	T_1	$30.32 \pm 3.09^{c,5}$	$27.16 \pm 4.57^{f,4}$	$24.58 \pm 1.56^{e,3}$	$22.77 \pm 2.12^{d,2}$	$20.03 \pm 0.08^{d,1}$
	T_2	$29.33 \pm 3.63^{c,5}$	$25.39 \pm 1.55^{e,4}$	$21.65 \pm 3.59^{c,3}$	$19.37 \pm 0.07^{c,2}$	$17.39 \pm 0.07^{c,1}$
	T_3	$29.31 \pm 3.15^{c,5}$	$25.60 \pm 2.15^{e,4}$	$22.42 \pm 1.62^{d,3}$	$20.12 \pm 0.09^{c,2}$	$18.11 \pm 0.07^{c,1}$
Freeze drying	T_0	$20.60 \pm 0.07^{a,5}$	$19.06 \pm 0.06^{a,4}$	$17.96 \pm 0.62^{a,3}$	$15.40 \pm 0.07^{a,2}$	$13.26 \pm 0.05^{a,1}$
	T_1	$22.98 \pm 0.65^{b,5}$	$21.84 \pm 1.61^{c,4}$	$20.69 \pm 0.08^{c,3}$	$18.54 \pm 0.06^{b,2}$	$16.45 \pm 0.06^{c,1}$
	T_2	$22.24 \pm 1.26^{b,4}$	$20.03 \pm 0.08^{a,3}$	$19.32 \pm 0.62^{b,3}$	$18.07 \pm 1.04^{b,2}$	$15.09 \pm 0.07^{b,1}$
	T_3	$21.70 \pm 3.07^{a,4}$	$20.31 \pm 0.08^{b,3}$	$19.64 \pm 1.60^{b,3}$	$17.43 \pm 0.07^{b,2}$	$15.40 \pm 0.07^{b,1}$

T_0= Control, T_1= Citrus oil, T_2= Honey, T3= Vinegar; Values are mean ± SD
Values within treatments in a column not sharing a common superscript lowercase letter (a/f) are significantly ($p \leq 0.05$) different.
Values within storage periods in a row not sharing a common superscript numerical (1/5) are significantly ($p \leq 0.05$) different.

3.7 Yeast and mold count (log cfu/g)

The influence of pretreatments and dehydrating techniques on yeast and mold populations in tomato powder over 180 days of storage is illustrated in Table 7. It signifies evidently that yeast and mold count followed an increasing trend irrespective of pretreatments and drying methods. A remarkable and significant spike in yeast and mold count was observed in T_0 samples (oven dried + control) from an initial value of 3.00 to 6.49 log cfu/g after 180 days of storage. Meanwhile, yeast and mold count experienced the slightest growth recorded in T_3 samples (Freeze dried + vinegar), with an increase from 1.47 to 3.57 log cfu/g over 6 months of storage.

Table 7: Effect of pretreatments and drying methods on yeast and mold count (log cfu/g) of tomato powder during 180 days of storage

Storage	Treatments	0 Day	45 Days	90 Days	135 Days	180 days
Oven drying	T_0	ND	$3.00 \pm 0.07^{g,1}$	$4.36 \pm 0.05^{h,2}$	$5.36 \pm 0.06^{h,3}$	$6.49 \pm 0.03^{g,4}$
	T_1	ND	$2.73 \pm 0.06^{e,1}$	$4.04 \pm 0.04^{f,2}$	$5.00 \pm 0.07^{f,3}$	$5.63 \pm 0.08^{e,4}$
	T_2	ND	$2.86 \pm 0.06^{f,1}$	$4.17 \pm 0.06^{g,2}$	$5.05 \pm 0.04^{g,3}$	$5.96 \pm 0.04^{f,4}$
	T_3	ND	$1.97 \pm 0.06^{b,1}$	$2.66 \pm 0.05^{c,2}$	$4.19 \pm 0.03^{d,3}$	$4.36 \pm 0.05^{c,4}$
Freeze drying	T_0	ND	$2.38 \pm 0.06^{d,1}$	$3.46 \pm 0.06^{e,2}$	$4.90 \pm 0.04^{e,3}$	$5.08 \pm 0.06^{d,4}$
	T_1	ND	$1.96 \pm 0.05^{b,1}$	$2.46 \pm 0.04^{b,2}$	$3.00 \pm 0.08^{b,3}$	$3.97 \pm 0.05^{b,4}$
	T_2	ND	$2.07 \pm 0.05^{c,1}$	$2.99 \pm 0.04^{d,2}$	$3.86 \pm 0.07^{c,3}$	$4.40 \pm 0.05^{c,4}$
	T_3	ND	$1.47 \pm 0.07^{a,1}$	$2.17 \pm 0.05^{a,2}$	$2.66 \pm 0.06^{a,3}$	$3.57 \pm 0.04^{a,4}$

T_0= Control, T_1= Citrus oil, T_2= Honey, T3= Vinegar; Values are mean ± SD
Values within treatments in a column not sharing a common superscript lowercase letter (a/f) are significantly ($p \leq 0.05$) different.
Values within storage periods in a row not sharing a common superscript numerical (1/5) are significantly ($p \leq 0.05$) different.

3.8 Bacterial count (log cfu/g)

Effect of pretreatments and drying methods on microbial load as bacterial count of tomato powder during 6 months storage is presented in Table 8. A substantial pattern in bacterial count emerges from the data ($p \leq 0.05$) increasing trend irrespective of pretreatments and dehydrating methods. The bacterial count showed the most significant surge in T_0 samples (oven dried + control) from an initial value of 2.61 to 5.99 log cfu/g after 180 days of storage. However, an increase in the bacterial count in the lowermost was recorded in T_3 samples (vinegar + freeze dried) with the count rising from 1.60 to 3.27 log cfu/g over the same period.

Table 8: Effect of pretreatments and drying methods on bacterial count (log cfu/g) of tomato powder during 180 days of storage

Storage	Treatments	0 Day	45 Days	90 Days	135 Days	180 days
Oven drying	T_0	ND	$2.61 \pm 0.06^{g,1}$	$3.60 \pm 0.05^{f,2}$	$5.09 \pm 0.04^{h,3}$	$5.99 \pm 0.06^{h,4}$
	T_1	ND	$2.37 \pm 0.04^{e,1}$	$3.30 \pm 0.05^{e,2}$	$4.53 \pm 0.07^{f,3}$	$4.93 \pm 0.02^{f,4}$
	T_2	ND	$2.41 \pm 0.04^{f,1}$	$3.69 \pm 0.05^{g,2}$	$4.97 \pm 0.06^{g,3}$	$5.39 \pm 0.06^{g,4}$
	T_3	ND	$2.06 \pm 0.06^{d,1}$	$3.09 \pm 0.04^{d,2}$	$3.66 \pm 0.06^{d,3}$	$3.99 \pm 0.05^{e,4}$
Freeze drying	T_0	ND	$2.09 \pm 0.04^{d,1}$	$3.02 \pm 0.07^{c,2}$	$3.30 \pm 0.05^{c,3}$	$3.67 \pm 0.05^{c,4}$
	T_1	ND	$1.79 \pm 0.07^{b,1}$	$2.66 \pm 0.04^{b,2}$	$3.19 \pm 0.06^{b,3}$	$3.55 \pm 0.05^{b,4}$
	T_2	ND	$1.97 \pm 0.04^{c,1}$	$2.99 \pm 0.03^{c,2}$	$3.76 \pm 0.06^{e,3}$	$3.90 \pm 0.06^{d,4}$
	T_3	ND	$1.60 \pm 0.05^{a,1}$	$2.39 \pm 0.05^{a,2}$	$3.01 \pm 0.04^{a,3}$	$3.27 \pm 0.05^{a,4}$

T_0= Control, T_1= Citrus oil, T_2= Honey, T3= Vinegar; Values are mean ± SD
Values within treatments in a column not sharing a common superscript lowercase letter (a/f) are significantly ($p \leq 0.05$) different.
Values within storage periods in a row not sharing a common superscript numerical (1/5) are significantly ($p \leq 0.05$) different.

4. Discussion

Vinegar pre-treatment significantly increased total flavonoids in tomato powder, regardless of drying method ($p \leq 0.05$) in Table 1. The higher values of total flavonoids might be because of the ability of vinegar to form a hydrophobic barrier around the tomato slices therefore inhibiting enzymatic oxidation and creating a non-polar environment, which enhances the stability of flavonoids. Additionally, the drying processes induce various biochemical reactions in both the flesh and peels of tomatoes, contributing to elevated total flavonoid levels. The findings of this study are consistent with the conclusions drawn by Bovy *et al*. (2002).

The total phenolic content of tomato fruit irrespective of the pretreatment methods and drying process, decreased significantly ($p \leq 0.05$) during the six months of storage (Table 2). Maximum phenolic content was seen in analytes that were treated with vinegar and subsequently freeze dried measured 198.73 mg GAE/100 g. Similarly, the lowermost phenol content of 98.83 mg GAE/100 g was analyzed in control analytes at 180th day of storage as presented in Table 2. The shift in phenolic content is largely the result of the compounds being freed from the matrix (Saihariniand Padmaja, 2022). Freeze dehydration, however, effectively maintains the structural integrity of phenolic compounds, ensuring their stability and preserving their bioavailability throughout the storage period as was highlighted by Nandhini and Anitha (2021); Thorat *et al*. (2024). The acidic nature of vinegar lowers the pH, creating an environment that stabilizes phenolic compounds and reduces their degradation. Additionally, vinegar inhibits enzymatic actiFnandvity that could otherwise lead to phenol breakdown. The oil forms a protective barrier around the tomato slices, limiting oxygen exposure and thus preventing oxidative degradation of phenols. Similar observations were recorded by Gumusay *et al*. (2015).

As indicated in Table 3, the T3 samples (vinegar + freeze dried) exhibited the highest ascorbic acid concentration (8.46 mg/100 g) after 180 days of storage, which is substantially higher than other samples. The more retention of ascorbic acid content in freeze dried samples compared to oven dried samples was observed, since freeze dried samples experience minimal degradation of ascorbic acid attributable to frigid temperature, the preservation of ascorbic acid is enhanced. A similar observation found, freeze dried tomatoes retained higher levels of ascorbic acid compared to those dried by sun, vacuum, or oven methods. This observation highlights that low-temperature processing, as used in freeze-drying, has a minimal impact on ascorbic acid content, whereas high-temperature treatments resulted in a significant reduction of the ascorbic acid content. The decrease is primarily attributed to the chemical deterioration of ascorbic acid, which undergoes a series of reactions involving oxidation and hydrolysis, ultimately yielding nutritionally inactive compounds. Heat exposure exacerbates this deterioration, leading to considerable losses (Sharma *et al*., 2023). Chang *et al*. (2006) corroborated these findings, showing an 8.2% loss of ascorbic acid in freeze-drying compared to a 57-60% loss in oven drying, which aligns with our findings. Furthermore, it was noted that the concentration of ascorbic acid continued to decrease in both oven and freezedried tomato powder as storage progressed.

Table 4 illustrated that the total carotenoid content in the control oven-dried tomato powder decreased significantly ($p \leq 0.05$) more than in the pretreated and freeze dried tomato powders. The maximum level of total carotene was detected in T_3 samples (vinegar + freeze dried samples), *i.e*., mg/100 g at 180th day of storage. According to Farooq *et al.* (2020), pretreatments effectively prevented heat-induced breakdown and oxidative degradation of carotenoids, acting as inhibitors of pigmented reactions. McInerney *et al*. (2007) also reported that due to processing, phytochemicals in certain vegetables may be more available.

The data presented in Table 5 indicated that T_3 samples (vinegar + freezedried) showed greater lycopene composition compared to other samples, demonstrating least degradation of lycopene. The protective effect of vinegar is responsible for this, which shields lycopene

pigments from heat damage. Additionally, freeze dried samples consistently exhibited higher lycopene levels than ovendried samples, with the difference being significant ($p \leq 0.05$). This parallel observation with findings from Sahin*et al*. (2011), who observed comparable differences in lycopene levels between freezedried and ovendried tomato. Over time, the concentration value of lycopene in both ovendried and freezedried samples reduced, likely due to isomerization from all-trans to cis-forms induced by heat, which increases with temperature and processing duration (Shi and Le Maguer, 2000). The thermal process may also disrupt cell walls and weaken the bonds between lycopene and the tissue matrix, making lycopene content more prone to degradation and facilitating increased cis-isomerization.

The impact of pretreatments and drying methods on instrumental color, as revealed by data analysis (L*, a*, b*)of tomato powder over 180 days of storage, as shown in Tables 6.1, 6.2, and 6.3, revealed that the T_3 samples (freeze dried + vinegar) exhibited significantly ($p \leq 0.05$) higher values for L*, a*, and b* of tomato powder. When tomato slices freeze-dry, the subzero temperatures and vacuum conditions preserve their vibrant red color. The observations align with similar results revealed by Vargas *et al*. (2022); Nallan *et al*. (2021). Since the process involves removing moisture through sublimation under low temperatures, which prevents the heat-induced degradation and browning reactions that can occur with other drying methods. This gentle dehydration approach helps retain the original color of the tomato slices by avoiding excessive oxidation and enzymatic reactions that could alter the color components as was observed by Roshanak *et al*. (2016); Guine and Barroca (2012). Additionally, the low-temperature environment reduces the likelihood of color changes due to thermal stress. As a result, freeze dried tomato slices retain their color attributes L*, a* and b* more effectively than other drying methods, ensuring that they closely resemble the fresh product. Similarly, vinegar's acidity can stabilize color pigments by reducing enzymatic and oxidative reactions that often lead to color changes. Oil forms a protective barrier on the surface of the slices, which can minimize exposure to oxygen and light, both of which can cause color degradation. By limiting oxidation and moisture loss, oil helps in preserving the overall color attributes, including L* and b*. Together, vinegar and oil pretreatment followed by freeze drying, effectively retains the color quality of tomato slices, contributing to a more visually appealing product after processing. Our results are also in agreement with the results obtained by Farooq *et al*. (2020).

From the data presented in Table 7, it is evident that significantly ($p \leq 0.05$) lowest yeast and mold count was recorded in T_3samples (Freeze dried + vinegar) under 180 days of storage. Vinegar, with its acidic nature, lowers the pH of the tomato slices, creating an environment that inhibits microbial growth and proliferation. The acidity of vinegar disrupts the conditions that favor the growth of yeasts and molds. Additionally, the oil forms a protective barrier on the surface of the tomato slices, limiting exposure to airborne contaminants and reducing moisture loss, which further deters microbial colonization. Unlike other methods, freeze-drying has been found to prevent microbial growth and slow down lipid oxidation, as demonstrated by Marques *et al*. (2009); Bunkar*et al*. (2020).

Data depicted in Table 8 clearly indicated significantly ($p \leq 0.05$) lowest bacterial count was observed in T_3 samples (vinegar+ freezedried) during 180 days of storage. Vinegar's antimicrobial properties with oil's protective layer, significantly enhances the shelf life and safety of the tomato slices by disrupting bacterial metabolic processes and thus, reducing their ability to thrive. Also, cryogenic-drying is highly effective in preventing bacterial growth in tomato slices due to its unique dehydration process. The low temperatures used during freeze-drying also inhibit bacterial activity and metabolic processes, reducing their ability to survive. These findings align with the observations made by Marques *et al*. (2009).

5. Conclusion

The study highlights that the pre-treating tomatoes with vinegar followed by freeze drying is highly effective in preserving the quality of tomato powder. This combined approach significantly improved the retention of vital polyphenolic compounds, including, flavonoids, total phenolic compounds, ascorbic acid, lycopene, and â-carotene. Freeze drying, enhanced by vinegar treatment, ensures superior preservation of color, minimizes microbial contamination, and maintains the nutritional integrity of the tomato powder over 180 days of storage. This method offers an optimal solution for extending shelf life and maintaining the high quality of tomato products, making it a valuable strategy for managing surplus tomatoes efficiently.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

References

Adeyeye, S.A. (2017). The role of food processing and appropriate storage technologies in ensuring food security and food availability in Africa. Nutrition and Food Science, **47**(1):122-139.

Bovy, A.; de Vos, R.; Kemper, M.; Schijlen, E.; Almenar Pertejo, M.; Muir, S.; Collins, G.; Robinson, S.; Verhoeyen, M.; Hughes, S. and Santos-Buelga, C. (2002). High-flavonol tomatoes resulting from the heterologous expression of the maize transcription factor genes LC and C1. The Plant Cell, **14**(10):2509-2526.

Bunkar, D. S.; Anand, A.; Kumar, K.; Meena, M.; Goyal, S. K. and Paswan, V. K. (2020). Development of production technology for preparation of beetroot powder using different drying methods. Ann. Phytomed., **9**(2):293-301.

Chang, C. H.; Lin, H. Y.; Chang, C.Y. and Liu, Y. C. (2006). Comparisons on the antioxidant properties of fresh, freeze dried and hot-air-dried tomatoes. Journal of Food Engineering, **77**(3):478-485.

Farooq, S. A.; Rather, S. Gull, A.; Ahmad Ganai, S.; Masoodi, F. A.; MohdWani, S. and Ganaie, T. A. (2020). Physicochemical and nutraceutical properties of tomato powder as affected by pretreatments, drying methods, and storage period. International Journal of Food Properties, **23**(1):797-808.

Guine, R. P. F. and Barroca, M. J. (2012). Effect of drying treatments on texture and colour of vegetables (pumpkin and green pepper). Food and Bioproducts Processing, **90**(1):58-63.

Gumusay, O. A.; Borazan, A. A.; Ercal, N. and Demirkol, O. (2015). Drying effects on the antioxidant properties of tomatoes and ginger. Food Chemistry, **173**:156-162.

Hailu, G. and Derbew, B. (2015). Extent, causes and reduction strategies of postharvest losses of fresh fruits and vegetables-A review. Journal of Biology, Agriculture and Healthcare, **5**(5):49-64.

Marques, L. G.; Prado, M. M. and Freire, J. T. (2009). Rehydration characteristics of freeze dried tropical fruits. Journal of Food Science and Technology, **42**:1232-1237.

Martin, J. P. (1950). Use of acid, rose bengal, and streptomycin in the plate method for estimating soil fungi. Soil Science, **69**(3):215-232.

McGuire, R. G. (1992). Reporting of objective colour measurements. Hort. Science, **27**(12):1254-1255.

McInerney, J. K.; Seccafien, C. A.; Stewart, C. M. and Bird, A. R. (2007). Effects of high-pressure processing on antioxidant activity, and total carotenoid content and availability, in vegetables. Innovative Food Science and Emerging Technologies, **8**(4): 543-548.

Nallan Chakravartula, S. S.; Moscetti, R.; Farinon, B.; Vinciguerra, V.; Merendino, N.; Bedini, G.; Neri, L.; Pittia, P. and Massantini, R. (2021). Stinging nettles as potential food additive: Effect of drying processes on quality characteristics of leaf powders. Foods, **10**(6):1152.

Nandhini,B. and Anitha, S. (2021). In vitro DPPH and AChE inhibitory activity of hydroethonolic extract from *Camellia sinesis* (L.) O. Kuntze. Ann. Phytomed., **10**(2):208-212.

Owureku Asare, M.; Ambrose, R. K.; Oduro, I.; Tortoe, C. and Saalia, F. K. (2017). Consumer knowledge, preference, and perceived quality of dried tomato products in Ghana. Food Science and Nutrition, **5**(3):617-624.

Ranganna, S. (1986). Handbook of Analysis and Quality Control for Fruit and Vegetable Products (second edition). Tata McGraw-Hill. pp: 105-106.

Rodriguez-Amaya, D. B. and Kimura, M. (2004). A Guide to Carotenoid Analysis in Foods. International Life Science Institutes, ILSI Press: Washington Dc, USA.

Roshanak, S.; Rahimmalek, M. and Goli, S. A. H. (2016). Evaluation of seven different drying treatments in respect to total flavonoid, phenolic, vitamin C content, chlorophyll, antioxidant activity and colour of green tea (*Camellia sinensis* or *C. assamica*) leaves. Journal of Food Science and Technology, **53**(1):721-729.

Sahin, F. H.; Aktas, T.; Orak, H.; Ulger, P.; Sahin, H.; Aktas, T. and Ulger, P. (2011). Influence of pretreatments and different drying methods on color parameters and lycopene content of dried tomato. Bulgarian journal of Agricultural Science, **17**(6):867-881.

Saiharini, N. and Padmaja, A. (2022). Studies on nutrient and phytochemical composition and assessment of *in vitro* antioxidant and enzyme inhibitory properties of watermelon fruit by-products. Ann. Phytomed., **11**(1):419-425.

Sharma, K.; Ravi, K. and Wani, A. W. (2023). Evaluation of natural edible coatings for enhancing the post-harvest quality and shelf-life of guava (*Psidium guajava* L.) fruits. Ann. Phytomed., **12**(1):808-815.

Shi, J. and Le Maguer, M. (2000). Lycopene in tomatoes: Chemical and physical properties affected by food processing. Critical Reviews in Food Science and Nutrition **40:**1-42.

Srivastava, R. P. and Kumar, S. (2004). Fruits and Vegetables Preservation Principles and Practices, 3rd ed; New York, USA. Oxford and IBH Publishers, pp:22-135.

Thorat, D.; Johar, V.; Rani, S.; Rawat, V.; Pathak, S. and Khan, S. (2024). Exogenous application of calcium chloride on biochemical characteristics of Dragon fruit (*Selenicereus undatus*). Ann. Phytomed., **13**(1):1084-1093.

Vargas, L.; Kapoor, R.; Nemzer, B. and Feng, H. (2022). Application of different drying methods for evaluation of phytochemical content and physical properties of broccoli, kale, and spinach. LWT-Food Science and Technology, **155**:112892.

Varghese, S. M.; Parisi, S.; Singla, R. K. and Begum, A. A. (2022). Trends in food chemistry, nutrition and technology in Indian sub-continent. Springer Nature. pp:9-10, 109-143.

Vishwakarma, M. K.; Mishra, V. K.; Gupta, P. K.; Yadav, P. S.; Kumar, H. and Joshi, A. K. (2014). Introgression of the high grain protein gene Gpc-B1 in an elite wheat variety of Indo-Gangetic Plains through marker assisted backcross breeding. Current Plant Biology, **1**:60-67.

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