



Response of pre-harvest application of chemicals on physico-chemical properties of ber (*Ziziphus mauritiana* Lamk.) cv. Gola during storage

Alkesh Yadav¹ · Mukesh Kumar² · Sneha Punia Bangar^{3,5} · Anil Kumar Siroha⁴

Received: 19 December 2024 / Accepted: 13 March 2025 / Published online: 5 April 2025
© The Author(s) 2025

Abstract

Ber (*Ziziphus mauritiana* Lamk.) is an important arid fruit tree cultivated in arid regions, valued for its unique taste, appealing texture, and high nutritional content. To minimize quality degradation during storage, the study aimed to investigate the effect of pre-harvest foliar application of different chemicals viz., 0.5%, 1.0%, 1.5% CaCl_2 , 0.5%, 1.0%, 1.5% $\text{Ca}(\text{NO}_3)_2$; 1 mM, 2 mM salicylic acid; 0.25%, 0.5% boric acid and a control treatment (tap water). These treatments were applied 15 days prior to harvest in the experimental orchard CCS Haryana Agricultural University, Regional Research Station, Bawal, which is located at latitude 28.09°N, longitude 76.59°E, and 266 m above mean sea level to analyze their effects on the physico-chemical attributes of the fruit. The data was analyzed using a randomized block design. Among different treatments, the pre-harvest spray of 1.5 percent $\text{Ca}(\text{NO}_3)_2$ (T_6) performed better in terms of average fruit weight (13.24 ± 0.19 and 14.26 ± 0.20 g), TSS (20.70 ± 0.18 and $21.50 \pm 0.22^\circ\text{B}$), total sugars (12.47 ± 0.24 and $12.51 \pm 0.27\%$) while minimum titratable acidity $0.21 \pm 0.01\%$ (T_6), 0.28 ± 0.01 (T_7), TSS/acid ratio 98.6 ± 1.0 (T_6) and 72.1 ± 1.0 (T_3). However, 1 mM salicylic acid was found to be better in terms of ascorbic acid (59.5 ± 1.5 and 73.2 ± 1.4 mg/100 g pulp) and phenol content (239.4 ± 6.3 and 275.4 ± 7.3 mg GAE/ 100 g pulp) observed in ambient and low-temperature storage conditions, respectively. Pre-harvest application of different chemicals reduced physicochemical properties of ber during storage at a very slow rate compared to control. The performance of quality parameters under low-temperature storage was found to be better than that of ambient temperature storage conditions. The fruit weight, titratable acidity, TSS: acid, ascorbic acids, and phenol content decreased with storage up to 10 days of storage; however, TSS and total sugars increased initially and thereafter decreased.

Keywords Ber · Sugars · Storage · Phenol content · Ascorbic acid

Introduction

Ber (*Ziziphus mauritiana* Lamk.) is one of the important fruit trees belonging to the family Rhamnaceae. It is one of the ancient fruit trees, and its origin is said to be from

India to southwestern Asia. Also, India is one of the world's leading producers of ber, with a cultivation area of 52,000 hectares and an annual production of 5.31 lakh metric tonnes [1]. The tree is a resilient and salt-tolerant species capable of thriving in marginal lands [2]. Commonly referred to as the "poor man's fruit" or "Chinese date," it is highly regarded for its substantial economic potential, low cultivation costs, and broad environmental adaptability, particularly its resilience to drought conditions. Often termed the "King of Arid Fruits," it is prized for its ability to withstand challenging growing conditions, making it an essential crop in arid and semi-arid regions. The fruits are medium-sized, ovate to round in shape, with an average weight ranging from 15 to 25 g. It develops a greenish to golden-yellowish tinge at the ripening stage. Fresh jujube fruits are perishable with a short post-harvest life, especially for fully mature fruit, which lasts less than one week when preserved at ambient temperature [3]. Therefore, fruits are available only during

✉ Sneha Punia Bangar
snehpunia69@gmail.com

¹ Department of Horticulture, CCS Haryana Agricultural University, Hisar, Haryana 125004, India

² CCS Haryana Agricultural University, Regional Research Station, Bawal, Rewari, Haryana 123501, India

³ Department of Food, Nutrition, and Packaging Sciences, Clemson University, Clemson, SC 29634, USA

⁴ College of Agriculture, CCS Haryana Agricultural University, Bawal, Rewari, Haryana 123501, India

⁵ Department of Packaging and Graphic Media Science, Rochester Institute of Technology, Rochester, NY, USA

the main season in the local market. During peak harvesting season, there is a glut in the market; hence, the prices go very low, and crops become less remunerative. Different researchers have suggested some chemicals to increase the shelf life of ber fruits, as well as improve their quality.

The ber fruit is composed of protein, ash, fat, fiber, and moisture content 4.44–6.87%, 2.67–3.45%, 1.85–2.84%, 1.29–1.92%, and 15.42–21.35%, respectively for different ber cultivars [4]. Additionally, it provides 0.02–0.038 mg/100 g of riboflavin, 0.7–0.9 mg/100 g of niacin, 0.2–1.1 mg/100 g of citric acid, and 65–76 mg/100 g of ascorbic acid. The fruit also contains around 22 g/100 g of sugars, 0.6 g/100 g of dietary fiber, and a caloric value of 104 kcal/100 g, based on fresh weight [5]. Many researchers claimed that jujube possessed health-beneficial properties such as anti-oxidation, anti-fatigue, immunomodulation, anti-allergy, liver protection, anti-cancer, anti-inflammation, anti-aging, anti-hyperglycemic, etc. [6].

The pre-harvest application of different chemicals, including calcium nitrate, calcium chloride, salicylic acid, and boric acid, may improve the yield, quality, and shelf life of the fruits. It also enhances the availability of fruits for longer periods and increases the income of the orchardist. Pre-harvest calcium treatments stabilize cell walls, ensure permeability, and protect them from enzymatic degradation [7], which results in the expression of genes influencing higher fruit production and quality [8] and delay senescences. The application of calcium decreases the activities of oxidative enzymes, like ascorbate oxidase, oxidase, peroxidase, polyphenol oxidase, and catalase, which slow down the ripening process, rates of color change, softening, and generation of CO₂ and ethylene production. It also helps to decrease TSS and acids at a lower rate than the control [9].

Salicylic acid (SA) treatment slows down the process of ethylene biosynthesis and effectively reduces the transpiration and respiration rate by controlling the degradation of cell wall, eventually increasing the shelf life of the fruits. Pre-harvest foliar application of SA with different concentrations (1.0 mM, 2.0 mM, and 3.0 mM) at 15 and 30 days before harvest improved the quality and shelf life of ber fruits [10]. However, it limits the spread of post-harvest fungal diseases. Pre-harvest treatments with boric acid (0.2–0.6%) were helpful in improving the quality of ber fruits during storage [11].

Ber fruit has a shelf life of 4 to 5 days, and the overall quality of ber fruit depends upon the storage conditions, especially temperature and humidity. During high temperatures and low relative humidity storage, fruit starts spoilage rapidly [12]. Fresh jujube fruits have more transpiration losses, softening, alcohol fermentation, browning, surface pitting, and even decomposition, all of which lead to post-harvest spoilage during the supply chain [13]. To reduce the degradation of ber, different pre and postharvest treatments

are used, such as different foliar treatments, low-temperature storage, coatings, etc. Low-temperature storage decreases spoilage by reducing the respiration process. The appearance of the fruits and their nutritional value decreases during spoilage. Organic acids have great potential to improve the quality of fruits and postharvest products. In recent years, exogenous application of natural organic acids could be applied to manage the postharvest quality of fruit and enhance shelf life [14].

Currently, there is limited information on the impact of pre-harvest and pre-storage treatments on the quality of fruits. Therefore, the present study was conducted to evaluate the effects of various pre-harvest foliar treatments on ber fruit quality. Different chemicals were tested, including calcium chloride (CaCl₂) at concentrations of 0.5%, 1.0%, and 1.5%; calcium nitrate (Ca(NO₃)₂) at 0.5%, 1.0%, and 1.5%; salicylic acid at 1 mM and 2 mM; and boric acid at concentrations of 0.25% and 0.5%. A control treatment consisting of tap water spray was also included for comparison.

Materials and methods

Experimental site

The study was carried out at the Experimental Orchard, Chaudhary Charan Singh Haryana Agricultural University, Regional Research Station (CCSHAU, RRS), Bawal, Rewari (Haryana), India, located at 266 m above the mean sea level with coordinates of 28°09' North latitude and 76°59' East longitudes. All chemicals used in this study were of analytical grade.

Weather and climate

The climate of Bawal is typically arid to semi-arid, with very hot and dry summers and bitterly cold winters. The climatic conditions of Bawal are characterized by dryness, high temperature, and scanty rainfall. During summer months, the temperature reaches around 45 °C accompanied by hot and dry winds; however, the temperature drops to the freezing point, followed by frost during the winter season, *i.e.*, December and January. Bawal received 80–85% of total rainfall (about 647 mm) from July to September (2022) and 15–20% (about 128 mm) received during winter months, *i.e.*, December to February (2022–23) due to western disturbances. Relative humidity increases with the onset of monsoons, which fall with the withdrawal of monsoons. Monthly mean wind speed varies from 3 to 8 km/h.

Treatment details

The experiment was conducted on thirty-three-year-old uniformly grown ber trees planted at 8 m × 8 m spacing, which were selected randomly with three replications in randomized block design. A total of eleven pre-harvest foliar sprays 0.5% CaCl₂ (T₁), 1.0% CaCl₂ (T₂), 1.5% CaCl₂ (T₃), 0.5% Ca(NO₃)₂ (T₄), 1.0% Ca(NO₃)₂ (T₅), 1.5% Ca(NO₃)₂ (T₆), 1 mM Salicylic acid (T₇), 2 mM Salicylic acid (T₈), 0.25% Boric acid (T₉), 0.5% Boric acid (T₁₀), Control – tap water (T₁₁) was done at 15 days before harvest, i.e., in the first week of February when the fruit matured physiologically but green in color on ber (*Ziziphus mauritiana* Lamk.) cv. Gola during 2022–23. The air temperature during spray was 18.0 °C (Max 20.6 °C and Min 8.5 °C). The fruits were harvested at the mature stage (when brown tings appear on the fruit's skin) from the respective treatment. After sorting, these fruits were kept in a perforated polybag for storage study at ambient temperature and low-temperature storage conditions (10 °C). The changes in physicochemical parameters were studied on alternate days up to 10 days after storage.

Average fruit weight (g)

Ten uniform-sized fruits free from insects, pests, and diseases were picked from each quarter of a randomly selected tree. The fruits of each replication were weighed on top pan digital electric balance. It was repeated for each treatment and replication. The average value of fruit weight was calculated and expressed in grams (g).

Total soluble solids (°B)

A hand refractometer (0–32°B) was used to measure the total soluble solids (TSS). The juice extracted from the randomly selected fruit was put on the prism of the hand refractometer, and the value reflected was noted. The refractometer was already set at 20 °C, so a correction factor was not required. The refractometer was calibrated with the help of distilled water after each reading.

Titrateable acidity (%)

Titrateable acidity was estimated by using the method given in AOAC [15]. Five grams of fruit pulp was thoroughly macerated and diluted to a final volume of 50 ml with distilled water. The filtrate of 20 ml was taken, and added a drop of 1% phenolphthalein indicator. It was titrated against N/10 sodium hydroxide. The titration continued until the appearance of a light pink color at least 15 s as the endpoint. The titrateable acidity was calculated using the following formula:

Citric acid (%)

$$= \frac{0.0064 \times \text{vol. of } \frac{N}{10} \text{ NaOH used} \times \text{Vol. made}}{\text{weight of fruit sample} \times \text{vol of sample taken for titration}} \times 100$$

TSS/acid ratio

The ratio of total soluble solids to titrateable acidity was calculated using the formula given below:

$$\text{TSS/acid ratio} = \frac{\text{Total soluble solids}}{\text{Titrateable acidity}}$$

Sugars content

For sugar content, a method of Hulme and Narain [16] was used. 5 mL of the aliquot was taken in a clean test tube, and 4 mL of hydrochloric acid (HCl) was added. The test tube was then covered with aluminum foil and placed in a boiling water bath at 80 °C for 15 min to hydrolyze complex sugars. After hydrolysis, the solution was neutralized by gradually adding anhydrous sodium carbonate (Na₂CO₃) until effervescence ceased completely. The test tubes were then cooled under running tap water. Following this, 5 mL of potassium iodide (KI) and 3 mL of acetic acid were added, which could result in an orange-yellow color due to iodine formation. The solution was then titrated against standard sodium thiosulphate (Na₂S₂O₃) using starch as an indicator, and the titration continued until the solution changed from blue to milky white, indicating the endpoint.

Ascorbic acid (mg/100 g pulp)

Ascorbic acid was estimated using the method mentioned in AOAC [15]. Five grams of pulp were taken and mashed with 3% meta-phosphoric acid, and the volume was made to 25 ml with HPO₃. Two ml of aliquot was titrated against 2,6-dichlorophenol indophenol dye. The appearance of a rose pink color for at least 15 s was the endpoint of the titration; it was followed for standard ascorbic acid also and calculated as per the formula given below:

Ascorbic acid

$$= \frac{\text{Titrate value} \times \text{total volume} \times 100}{\text{Standard ascorbic acid reading} \times \text{ml of sample} \times \text{Wt. of fruit taken}}$$

Phenol content (mg GAE/100 g pulp)

The total phenol content was estimated using the method given by Singleton and Rossi [17] using Folin Ciocalteu

Reagent (FCR) based on the colorimetric oxidation/ reduction reaction of phenols. Results are expressed in mg of Gallic Acid Equivalent (GAE) per 100 g pulp on a fresh weight basis.

Total phenol content

$$= \frac{\text{OD} \times \text{dilution factor} \times \text{Volume made up (ml)} \times 100}{\text{Aliquot (ml)} \times \text{weight of sample taken (g)} \times 1000 \times 0.02}$$

Statistical analysis

Statistical analysis for comparison of data for the significance level between the treatments was analyzed using Excel and python powered software GRAPES, as suggested by Gopinath et al. [18]. The significance level is marked with the alphabet given in each box of the table.

Results and discussion

The results of pre-harvest foliar application of different chemicals on changes in physico-chemical properties of ber cv. Gola during storage at ambient temperature and low temperature (10 °C) conditions are elaborated and discussed in this section (Fig. 5). Pre-harvest chemicals consist of eleven treatments, such as foliar spray applied 15 days before harvest at the physiological maturity of fruit (green mature) during afternoon hours. The fruits from these plants were harvested at a mature stage when brown tings appeared on the skin of the fruit. The sorted fruits were kept in perforated ploy bags under ambient and low-temperature storage conditions to study the changes in physicochemical properties on alternate days for up to 10 days.

Effect of treatments and storage conditions on physicochemical properties of ber

The present investigation exhibited that the average fruit weight decreased in all treatments with an increased storage period. The fruit weight decreased less under low-temperature storage conditions than under ambient temperature storage conditions (Table 1). All the treatments positively influence fruit weight compared to the control. The pre-harvest foliar application of chemical treatments retained higher fruit weight than control. The fruits collected from the pre-harvest application of 1.5% $\text{Ca}(\text{NO}_3)_2$ (T_6) treatment retained more fruit weight, i.e., 13.24 ± 0.19 g and 14.26 ± 0.20 g 10 days after storage under ambient as well as low-temperature storage conditions, respectively (Table 1). At the same time, the lowest fruit weight was (11.13 ± 0.17 and 12.53 ± 0.16 g) retained in the control/ water spray treatment in both the storage conditions.

Table 1 Changes in fruit weight (g) of ber fruits in response to pre-harvest application of chemicals during storage at different conditions

Treatments/ Storage period	Ambient temperature storage					Low temperature storage (10 °C)						
	0 day	2 days	4 days	6 days	8 days	10 days	0	2	4	6	8	10
T ₁	14.70 ± 0.19 ^{ab}	14.29 ± 0.16 ^{fg}	13.86 ± 0.16 ^g	13.29 ± 0.17 ^h	12.66 ± 0.18 ^h	11.99 ± 0.18 ^g	14.70 ± 0.18 ⁱ	14.55 ± 0.18 ⁱ	14.39 ± 0.17 ⁱ	14.07 ± 0.17 ^g	13.61 ± 0.17 ^g	13.14 ± 0.19 ^f
T ₂	15.10 ± 0.22 ^{cde}	14.75 ± 0.18 ^{cd}	14.37 ± 0.18 ^{cd}	13.82 ± 0.18 ^e	13.19 ± 0.17 ^e	12.54 ± 0.15 ^d	15.10 ± 0.17 ^e	14.97 ± 0.20 ^e	14.81 ± 0.17 ^e	14.49 ± 0.19 ^d	14.06 ± 0.17 ^e	13.60 ± 0.15 ^d
T ₃	15.40 ± 0.18 ^{ab}	15.08 ± 0.18 ^b	14.75 ± 0.18 ^b	14.20 ± 0.17 ^c	13.63 ± 0.16 ^c	13.00 ± 0.17 ^b	15.40 ± 0.18 ^b	15.28 ± 0.18 ^b	15.14 ± 0.14 ^b	14.85 ± 0.18 ^b	14.46 ± 0.20 ^b	14.00 ± 0.19 ^b
T ₄	14.90 ± 0.20 ^{efg}	14.49 ± 0.16 ^c	14.09 ± 0.16 ^c	13.54 ± 0.19 ^f	12.92 ± 0.15 ^f	12.27 ± 0.15 ^e	14.90 ± 0.22 ^g	14.76 ± 0.19 ^g	14.61 ± 0.18 ^g	14.28 ± 0.18 ^g	13.84 ± 0.16 ^f	13.37 ± 0.15 ^c
T ₅	15.30 ± 0.22 ^{bc}	14.96 ± 0.38 ^b	14.63 ± 0.18 ^c	14.08 ± 0.18 ^d	13.46 ± 0.17 ^d	12.82 ± 0.19 ^e	15.30 ± 0.18 ^c	15.17 ± 0.18 ^c	15.03 ± 0.15 ^c	14.72 ± 0.16 ^c	14.31 ± 0.17 ^d	13.84 ± 0.15 ^c
T ₆	15.60 ± 0.21 ^a	15.28 ± 0.18 ^a	15.00 ± 0.17 ^a	14.45 ± 0.19 ^a	13.85 ± 0.19 ^a	13.24 ± 0.19 ^a	15.60 ± 0.21 ^a	15.48 ± 0.20 ^a	15.35 ± 0.18 ^a	15.07 ± 0.20 ^a	14.69 ± 0.19 ^a	14.26 ± 0.20 ^a
T ₇	15.20 ± 0.21 ^{bcd}	14.91 ± 0.17 ^{bc}	14.75 ± 0.18 ^b	14.35 ± 0.19 ^b	13.80 ± 0.17 ^b	13.23 ± 0.17 ^a	15.20 ± 0.18 ^d	15.09 ± 0.18 ^d	14.96 ± 0.19 ^d	14.73 ± 0.15 ^c	14.40 ± 0.17 ^c	14.03 ± 0.17 ^b
T ₈	14.80 ± 0.22 ^{fgh}	14.48 ± 0.16 ^{cd}	14.14 ± 0.17 ^e	13.54 ± 0.19 ^f	12.89 ± 0.16 ^f	12.25 ± 0.16 ^e	14.80 ± 0.20 ^h	14.66 ± 0.19 ^h	14.50 ± 0.18 ^h	14.22 ± 0.17 ^f	13.82 ± 0.18 ^f	13.37 ± 0.17 ^e
T ₉	14.60 ± 0.17 ^h	14.16 ± 0.17 ^g	13.74 ± 0.18 ^h	13.14 ± 0.17 ⁱ	12.50 ± 0.18 ⁱ	11.81 ± 0.18 ^h	14.60 ± 0.18 ^j	14.44 ± 0.18 ^j	14.26 ± 0.17 ^j	13.93 ± 0.16 ^h	13.49 ± 0.19 ^h	13.03 ± 0.15 ^g
T ₁₀	15.00 ± 0.17 ^{def}	14.57 ± 0.17 ^{de}	14.11 ± 0.17 ^{ef}	13.48 ± 0.18 ^g	12.80 ± 0.15 ^g	12.10 ± 0.18 ^f	15.00 ± 0.17 ^f	14.85 ± 0.18 ^f	14.66 ± 0.19 ^f	14.31 ± 0.17 ^e	13.83 ± 0.16 ^f	13.33 ± 0.19 ^e
T ₁₁	14.30 ± 0.17 ⁱ	13.81 ± 0.17 ^h	13.34 ± 0.19 ⁱ	12.66 ± 0.16 ⁱ	11.93 ± 0.16 ⁱ	11.13 ± 0.17 ⁱ	14.30 ± 0.17 ^k	14.13 ± 0.18 ^k	13.92 ± 0.17 ^k	13.53 ± 0.18 ⁱ	13.03 ± 0.17 ⁱ	12.53 ± 0.16 ^h

Mean $\pm$ SD (n = 3); the superscript letters with in column are indicating the significant different at $p < 0.05$

Bhat et al. [19] also observed that pre-harvest application of calcium salts increased the fruit weight of the pear. The increase in fruit weight might be because the calcium nitrate provides fast-acting nitrate (nitrogen) along with strength-building calcium. Calcium plays a vital role in changes in cell turgor pressure and cell elongation in fruits, while nitrogen also plays a significant role in cell division. Additionally, calcium is involved in auxin signaling and acidification of the cell wall, allowing cell wall expansion, which increases fruit weight [20]. Soil application of calcium becomes unavailable for plant systems as it is immobile in plant systems. Therefore, the foliar application of calcium helps in the formation of calcium pectate; it increases rigidity in the cell wall and middle portion. The decrease in fruit weight was smaller and slower under low-temperature conditions. The average fruit weight decreases with an increase in storage period, likely due to higher transpiration and respiration losses with the advancement of maturity. Calcium also helps to decrease the weight loss process during storage because it strengthens the cell wall or maintains fruit firmness and tissue rigidity, which reduces the transpiration or respiration process [21]. A similar trend of decrease in average fruit weight in mangoes during storage was observed by Vishwakarma et al. [22].

Total soluble solids (°B)

All the treatments applied 15 days before harvest were effective in retaining TSS. Total soluble solids under ambient temperature storage conditions increased with an increase in storage period up to 8 days after storage in T_3 , T_6 , T_7 , and T_8 . In contrast, in other treatments, it increased up to 6 days after storage, while in control (water spray), it increased up to 4 days after storage (Table 2). Thereafter, TSS decreased in the respective treatment. However, under low-temperature storage conditions, TSS increased up to 10 days after storage, except in control, where it increased up to 8 days after storage. Among different treatments, T_6 retained the highest TSS at 10 days after storage under ambient (20.70 ± 0.18°B) and low temperature (21.50 ± 0.22°B) storage conditions (Table 2). Souza et al. [23] revealed similar results when fruits were treated with 1.0 percent calcium chloride; it showed higher soluble solids just before storage. Mandloi et al. [24] reported the highest TSS (17.15°B) in pomegranate fruits treated with pre-harvest foliar spray of 1.0 percent calcium nitrate. Applying calcium increases the translocation and accumulation of photosynthates and soluble solids in the fruits, thereby increasing the total soluble solids [25]. TSS under ambient temperature storage conditions increased at a fast rate during storage; however, it also increased under low-temperature storage conditions but at a slow rate. Metabolic activities like transpiration losses and

Table 2 Changes in total soluble solids (°B) of ber fruits in response to pre-harvest application of chemicals during storage at different conditions

Treatments/ Storage period	Ambient temperature storage					Low temperature storage (10 °C)									
	0 day	2 days	4 days	6 days	8 days	10 days	0	2	4	6	8	10			
T_1	17.40 ± 0.20 ^g	17.70 ± 0.14 ^g	18.30 ± 0.24 ^d	18.90 ± 0.19 ^f	18.30 ± 0.16 ^h	17.80 ± 0.16 ^g	17.40 ± 0.16 ⁱ	17.50 ± 0.16 ⁱ	17.80 ± 0.16 ^h	18.10 ± 0.16 ^g	18.60 ± 0.20 ^h	19.30 ± 0.18 ⁱ			
T_2	17.90 ± 0.18 ^{de}	18.50 ± 0.17 ^{de}	19.10 ± 0.20 ^b	19.80 ± 0.19 ^c	19.30 ± 0.17 ^f	18.90 ± 0.16 ^e	17.90 ± 0.16 ^e	18.10 ± 0.16 ^e	18.50 ± 0.16 ^e	19.10 ± 0.19 ^e	19.50 ± 0.19 ^d	20.30 ± 0.18 ^d			
T_3	18.40 ± 0.16 ^{ab}	19.00 ± 0.20 ^b	19.60 ± 0.19 ^a	20.20 ± 0.12 ^b	20.80 ± 0.18 ^b	20.40 ± 0.18 ^b	18.40 ± 0.16 ^b	18.60 ± 0.20 ^b	19.00 ± 0.19 ^b	19.60 ± 0.17 ^b	20.20 ± 0.18 ^b	20.90 ± 0.18 ^b			
T_4	17.70 ± 0.25 ^{ef}	18.20 ± 0.19 ^f	18.80 ± 0.14 ^c	19.50 ± 0.19 ^d	19.00 ± 0.16 ^g	18.60 ± 0.20 ^f	17.70 ± 0.16 ^g	17.80 ± 0.16 ^g	18.20 ± 0.16 ^f	18.50 ± 0.16 ^d	19.30 ± 0.18 ^c	20.00 ± 0.17 ^c			
T_5	18.20 ± 0.17 ^{bc}	18.80 ± 0.16 ^{de}	19.60 ± 0.20 ^a	20.40 ± 0.18 ^a	20.00 ± 0.17 ^c	19.70 ± 0.17 ^c	18.20 ± 0.16 ^c	18.40 ± 0.16 ^c	18.90 ± 0.17 ^c	19.60 ± 0.21 ^b	20.10 ± 0.17 ^c	20.90 ± 0.20 ^b			
T_6	18.60 ± 0.12 ^a	19.30 ± 0.17 ^a	19.80 ± 0.19 ^a	20.50 ± 0.19 ^a	21.10 ± 0.20 ^a	20.70 ± 0.18 ^a	18.60 ± 0.20 ^a	18.80 ± 0.16 ^c	19.30 ± 0.17 ^a	20.00 ± 0.17 ^a	20.60 ± 0.11 ^a	21.50 ± 0.22 ^e			
T_7	17.70 ± 0.17 ^{ef}	18.20 ± 0.19 ^f	18.60 ± 0.27 ^{cd}	19.20 ± 0.17 ^c	19.80 ± 0.17 ^d	19.30 ± 0.17 ^d	17.70 ± 0.19 ^g	17.80 ± 0.16 ^g	17.90 ± 0.16 ^g	18.20 ± 0.16 ^f	19.00 ± 0.19 ^f	19.60 ± 0.17 ^g			
T_8	17.50 ± 0.15 ^{fg}	17.90 ± 0.21 ^g	18.30 ± 0.22 ^d	18.80 ± 0.16 ^f	19.40 ± 0.17 ^e	18.90 ± 0.19 ^e	17.50 ± 0.16 ^h	17.70 ± 0.19 ^h	17.80 ± 0.16 ^h	18.00 ± 0.16 ^h	18.50 ± 0.16 ⁱ	19.40 ± 0.17 ^h			
T_9	17.80 ± 0.26 ^e	18.30 ± 0.17 ^{ef}	19.10 ± 0.21 ^b	19.80 ± 0.17 ^c	19.30 ± 0.18 ^f	18.90 ± 0.17 ^e	17.80 ± 0.18 ^f	17.90 ± 0.16 ^f	18.20 ± 0.16 ^f	18.40 ± 0.16 ^e	19.00 ± 0.19 ^f	19.80 ± 0.17 ^f			
T_{10}	18.10 ± 0.16 ^{cd}	18.70 ± 0.19 ^{cd}	19.60 ± 0.10 ^a	20.40 ± 0.18 ^a	20.00 ± 0.17 ^c	19.70 ± 0.17 ^c	18.10 ± 0.16 ^d	18.30 ± 0.16 ^d	18.80 ± 0.16 ^d	19.10 ± 0.17 ^c	19.50 ± 0.17 ^d	20.40 ± 0.18 ^c			
T_{11}	17.10 ± 0.15 ^h	17.80 ± 0.15 ^g	18.60 ± 0.22 ^c	18.10 ± 0.16 ^g	17.60 ± 0.16 ⁱ	17.00 ± 0.21 ^j	17.10 ± 0.21 ^j	17.30 ± 0.16 ⁱ	17.60 ± 0.16 ⁱ	18.00 ± 0.16 ^h	18.70 ± 0.16 ^g	18.40 ± 0.16 ^j			

Mean ± SD (n = 3); the superscript letters with in column are indicating the significant different at $p < 0.05$

respiration processes are high under ambient temperature storage conditions, which causes an increase in TSS due to loss of moisture and juice [26].

TSS increased due to the breakdown of polysaccharides (cellulose, starch, and pectic substances) into simple sugars and water loss [27, 28]. Chawla et al. [29] found a similar trend of increase in TSS up to the 9th day of storage in guava fruits and, after that, decreased from the 12th day onward after storage. The reduction of TSS on the 10th day after storage might be due to the loss of solids through respiration and transpiration. Present results regarding TSS are in accordance with the findings of Selvan and Bal [30] in guava and Mahajan and Dutt [31] in pear. Goutam et al. [32] also followed a similar trend of TSS; it increased up to the 10th day after storage in guava.

Titrateable acidity (%)

Titrateable acidity in ber fruits decreased with an increase in storage period in all the treatments under ambient and low-temperature storage conditions. Titrateable acidity after 10 days of storage was recorded as the lowest ($0.21 \pm 0.01\%$) in T_6 under ambient temperature storage conditions, whereas under low-temperature storage conditions, it was observed as the lowest ($0.28 \pm 0.01\%$) in T_7 . The highest titrateable acidity was observed in control under both the storage conditions, i.e., ambient temperature, and low-temperature storage conditions, i.e., 0.51 ± 0.01 and $0.51 \pm 0.01\%$ at zero days and 0.35 ± 0.01 and $0.39 \pm 0.01\%$ at 10 days after storage, respectively (Table 3). The decrease in respiratory activities under low-temperature storage was lesser than under ambient temperature storage conditions, which led to a decrease in the hydrolysis of organic acids [33]. Kanwal et al. [10] also observed the minimum acidity in ber fruits treated with 1 Mm salicylic acid. Minimum acidity in fruits may be ascribed to the higher accumulation of sugars, better translocation of sugars into fruit tissues, and conversion of organic acids into sugars [34]. The acidity decreased at a faster rate under ambient temperature storage, which may be due to faster metabolic activities at higher temperatures. The decline in titrateable acidity might be due to the utilization of organic acids during respiration and metabolic processes, which convert acids into sugars [35]. The acidity decreased during the storage may be due to chemical interaction with the organic constituents of fruit and the reversal glycolytic pathway [36]. These results are in close agreement with Jawanda et al. [37] in Ber and Parven et al. [38] in papaya.

TSS/acid ratio

These findings exhibited a significant increase in TSS/acid ratio with pre-harvest chemicals spray compared to control. TSS/acid ratio increased with the storage period in all the

Table 3 Changes in titrateable acidity (%) of ber fruits in response to pre-harvest application of chemicals during storage at different conditions

Treatments/ Storage period	Ambient temperature storage					Low temperature storage (10 °C)						
	0 day	2 days	4 days	6 days	8 days	10 days	0	2	4	6	8	10
T ₁	0.46±0.02 ^c	0.41±0.02 ^e	0.39±0.01 ^d	0.36±0.01 ^d	0.34±0.02 ^d	0.30±0.02 ^d	0.46±0.01 ^c	0.44±0.02 ^c	0.41±0.02 ^{cd}	0.38±0.02 ^f	0.36±0.01 ^e	0.33±0.01 ^d
T ₂	0.45±0.01 ^{cd}	0.40±0.01 ^e	0.38±0.01 ^e	0.35±0.01 ^e	0.33±0.01 ^e	0.23±0.01 ^f	0.45±0.03 ^{cd}	0.42±0.01 ^{de}	0.40±0.01 ^d	0.37±0.01 ^g	0.35±0.01 ^f	0.32±0.01 ^e
T ₃	0.39±0.02 ^e	0.34±0.02 ^g	0.32±0.01 ^g	0.29±0.01 ^g	0.27±0.01 ^h	0.26±0.01 ^e	0.39±0.01 ^e	0.37±0.02 ^f	0.36±0.03 ^e	0.34±0.01 ^h	0.32±0.01 ^g	0.29±0.01 ^g
T ₄	0.51±0.03 ^a	0.45±0.01 ^b	0.42±0.01 ^b	0.39±0.01 ^b	0.37±0.02 ^b	0.35±0.01 ^{ab}	0.51±0.01 ^a	0.47±0.01 ^b	0.45±0.01 ^a	0.43±0.01 ^b	0.41±0.01 ^b	0.38±0.01 ^b
T ₅	0.49±0.01 ^b	0.44±0.01 ^c	0.42±0.03 ^{bc}	0.39±0.01 ^b	0.37±0.01 ^b	0.33±0.02 ^{bc}	0.49±0.03 ^b	0.46±0.01 ^b	0.45±0.02 ^a	0.42±0.01 ^c	0.40±0.01 ^c	0.35±0.01 ^c
T ₆	0.37±0.01 ^{fg}	0.32±0.01 ⁱ	0.30±0.02 ^h	0.25±0.01 ⁱ	0.22±0.01 ^j	0.21±0.01 ^g	0.37±0.01 ^{fg}	0.44±0.01 ^c	0.43±0.01 ^b	0.40±0.02 ^d	0.37±0.01 ^d	0.32±0.01 ^e
T ₇	0.36±0.02 ^g	0.33±0.01 ^h	0.31±0.01 ^h	0.28±0.01 ^h	0.26±0.01 ⁱ	0.22±0.02 ^{fg}	0.36±0.02 ^g	0.36±0.01 ^f	0.35±0.01 ^e	0.32±0.01 ⁱ	0.30±0.01 ^h	0.28±0.01 ^h
T ₈	0.38±0.01 ^{ef}	0.34±0.02 ^g	0.31±0.01 ^h	0.29±0.01 ^g	0.28±0.01 ^g	0.27±0.01 ^e	0.38±0.01 ^{ef}	0.41±0.02 ^e	0.40±0.01 ^d	0.37±0.01 ^g	0.34±0.02 ^f	0.29±0.01 ^g
T ₉	0.48±0.01 ^b	0.43±0.01 ^d	0.41±0.01 ^c	0.38±0.02 ^c	0.36±0.02 ^c	0.32±0.02 ^c	0.48±0.02 ^b	0.46±0.03 ^b	0.43±0.01 ^b	0.40±0.02 ^d	0.37±0.01 ^d	0.33±0.01 ^d
T ₁₀	0.44±0.02 ^d	0.39±0.01 ^f	0.35±0.01 ^f	0.33±0.01 ^f	0.32±0.01 ^f	0.30±0.01 ^d	0.44±0.02 ^d	0.43±0.02 ^{cd}	0.42±0.01 ^{bc}	0.39±0.01 ^e	0.36±0.02 ^e	0.31±0.01 ^f
T ₁₁	0.51±0.01 ^a	0.46±0.01 ^a	0.44±0.01 ^a	0.41±0.02 ^a	0.39±0.01 ^a	0.35±0.01 ^a	0.51±0.01 ^a	0.49±0.01 ^a	0.46±0.01 ^a	0.44±0.01 ^a	0.42±0.01 ^a	0.39±0.01 ^a

Mean $\pm$ SD ($n = 3$); the superscript letters with in column are indicating the significant different at $p < 0.05$

Table 4 Changes in TSS: acid of ber fruits in response to pre-harvest application of chemicals during storage at different conditions

Treatments/ Storage period	Ambient temperature storage					Low temperature storage (10 °C)						
	0 day	2 days	4 days	6 days	8 days	10 days	0	2	4	6	8	10
T ₁	37.8 ± 1.0 ^g	43.2 ± 1.1 ^e	46.9 ± 1.1 ^e	52.5 ± 1.1 ^f	53.8 ± 1.0 ^f	59.3 ± 1.3 ^e	37.8 ± 1.1 ^d	39.8 ± 0.9 ^c	43.4 ± 0.9 ^e	47.6 ± 1.0 ^f	51.7 ± 1.0 ^f	58.5 ± 1.5 ^e
T ₂	39.8 ± 1.0 ^f	46.3 ± 1.0 ^d	50.3 ± 1.1 ^d	56.6 ± 1.0 ^e	58.5 ± 1.0 ^e	65.2 ± 1.1 ^d	39.8 ± 1.2 ^c	43.1 ± 1.1 ^b	46.3 ± 1.0 ^d	51.6 ± 1.0 ^e	55.7 ± 1.3 ^e	63.4 ± 1.0 ^d
T ₃	47.2 ± 1.0 ^c	55.9 ± 1.1 ^b	61.3 ± 1.2 ^b	69.7 ± 1.0 ^b	77.0 ± 0.9 ^b	88.7 ± 1.1 ^b	47.2 ± 1.2 ^b	50.3 ± 1.1 ^a	52.8 ± 1.0 ^b	57.7 ± 1.2 ^b	63.1 ± 1.0 ^b	72.1 ± 1.0 ^b
T ₄	34.7 ± 1.0 ^h	40.4 ± 1.2 ^{fg}	44.8 ± 1.1 ^e	50.0 ± 1.2 ^f	51.4 ± 1.2 ^f	53.1 ± 1.3 ^f	34.7 ± 1.1 ^e	37.9 ± 1.0 ^d	40.4 ± 1.0 ^e	43.0 ± 0.2 ^f	47.1 ± 1.1 ^f	52.6 ± 1.1 ^f
T ₅	37.1 ± 1.0 ^g	42.7 ± 1.2 ^{ef}	46.7 ± 1.0 ^e	52.3 ± 1.0 ^f	54.1 ± 1.1 ^f	59.7 ± 1.1 ^e	37.1 ± 0.9 ^d	40.0 ± 0.9 ^c	42.0 ± 1.1 ^e	46.7 ± 1.0 ^f	50.3 ± 1.1 ^f	59.7 ± 0.9 ^e
T ₆	50.3 ± 1.0 ^a	60.3 ± 1.0 ^a	66.0 ± 1.2 ^a	82.0 ± 1.1 ^a	95.9 ± 1.3 ^a	98.6 ± 1.0 ^a	50.3 ± 1.0 ^a	42.7 ± 1.1 ^b	44.9 ± 1.1 ^a	50.0 ± 1.1 ^a	55.7 ± 1.0 ^a	67.2 ± 1.0 ^a
T ₇	49.2 ± 1.0 ^b	55.2 ± 1.0 ^{bc}	60.0 ± 1.1 ^b	68.6 ± 1.0 ^{bc}	76.2 ± 1.3 ^b	87.7 ± 1.3 ^b	49.2 ± 1.0 ^a	49.4 ± 1.3 ^a	51.1 ± 0.9 ^b	56.9 ± 1.0 ^{bc}	63.3 ± 1.0 ^b	70.0 ± 1.1 ^b
T ₈	46.1 ± 1.0 ^d	52.7 ± 1.2 ^c	59.0 ± 1.2 ^b	64.9 ± 1.0 ^{cd}	69.3 ± 1.4 ^c	70.0 ± 1.1 ^c	46.1 ± 1.1 ^b	43.2 ± 1.0 ^b	44.5 ± 1.1 ^b	48.7 ± 1.0 ^{cd}	54.4 ± 1.3 ^c	66.9 ± 1.1 ^c
T ₉	37.1 ± 1.0 ^g	42.6 ± 1.2 ^{ef}	46.6 ± 1.2 ^e	52.1 ± 1.1 ^f	53.6 ± 1.1 ^f	59.1 ± 1.1 ^e	37.1 ± 1.0 ^d	38.9 ± 1.0 ^{cd}	42.3 ± 1.0 ^e	46.0 ± 1.2 ^f	51.4 ± 1.0 ^f	60.0 ± 1.0 ^e
T ₁₀	41.1 ± 1.0 ^e	48.0 ± 1.3 ^d	56.0 ± 1.2 ^c	61.8 ± 0.9 ^d	62.5 ± 1.3 ^d	65.7 ± 1.2 ^d	41.1 ± 0.9 ^c	42.6 ± 1.0 ^b	44.8 ± 1.1 ^c	49.0 ± 1.0 ^d	54.2 ± 1.0 ^d	65.8 ± 1.1 ^d
T ₁₁	33.5 ± 1.0 ⁱ	38.7 ± 1.0 ^g	42.3 ± 1.1 ^f	44.2 ± 0.1 ^g	45.1 ± 1.1 ^g	48.6 ± 1.2 ^g	33.5 ± 1.2 ^e	35.3 ± 1.0 ^e	38.3 ± 1.1 ^f	40.9 ± 1.1 ^g	44.5 ± 1.0 ^g	47.2 ± 1.0 ^g

Mean ± SD (n = 3); the superscript letters with in column are indicating the significant different at p < 0.05

treatments; the highest TSS/acid ratio was recorded in T₆ at 50.3 ± 1.0 and 50.3 ± 1.0 at zero days and 98.6 ± 1.0, while T₃ had 72.1 ± 1.0 at 10 days after storage under ambient and low-temperature storage conditions, respectively (Table 4). The application of calcium slows down respiration and metabolic activities, which delays the degradation of TSS [9]. Over time, the degradation of acids into soluble solids as the structural formula of acid is similar to glucose; therefore, a decrease in acid is correlated with an increase in TSS/acid ratio [39]. Similar results were also observed by Mandal et al. [40] in guava, Sarrwy et al. [41] in date palm, and Sidhu et al. [42] in strawberry. The titratable acidity decreased with the storage period in the current study, as described in Table 3. Therefore, a decrease in the denominator increases the ratio.

Total sugars (%)

Total sugars increased significantly with a spray of different concentrations of pre-harvest chemicals compared to the control. Initially, total sugars increased in all the treatments during storage up to 6 days after storage, except control, where it was increased up to 4 days after storage (11.98 ± 0.24%). However, in T₃ (12.83 ± 0.27%), T₆ (12.88 ± 0.25%), T₇ (12.62 ± 0.28%), and T₈ (12.31 ± 0.27%), it increased up to 8 days after storage; after that, it started declining under ambient temperature storage conditions (Table 5). Maximum total sugars were recorded as 10.16 ± 0.27% and 10.16 ± 0.27% at zero days and 12.47 ± 0.24 and 12.51 ± 0.27% at 10 days after storage in T₆ under both the storage conditions, i.e., ambient and low-temperature storage, respectively. The polymeric sugars, viz., starch and pectin, serve as substrates for respiratory metabolism or converting into monosaccharides [43]. The increase in total sugars with the advancement of the storage period may be due to the breakdown of complex organic metabolites into simpler molecules. At the later stages of storage, a decline in sugar content may be attributed to the utilization of sugars along with other organic acids as substrates in the respiration process [44]. The major role of calcium is to strengthen the cell wall as calcium pectate; it ultimately delays the respiration process or degradation or consumption of sugar.

Ascorbic acid (mg /100 g pulp)

The ascorbic acid content was retained more with an increase in the storage period in all the treatments during storage at ambient and low-temperature storage conditions compared to control. The retention of maximum ascorbic acid content (59.5 ± 1.5 mg /100 g pulp and 73.2 ± 1.4 mg /100 g pulp) was recorded in T₇ treatment 10 days after

Table 5 Changes in total sugars (%) of ber fruits in response to pre-harvest application of chemicals during storage at different conditions

Treatments/ Storage period	Ambient temperature storage					Low temperature storage (10 °C)						
	0 day	2 days	4 days	6 days	8 days	10 days	0 day	2 days	4 days	6 days	8 days	10 days
T ₁	9.75 ± 0.26 ^f	10.56 ± 0.32 ^f	11.22 ± 0.30 ^g	12.19 ± 0.32 ^f	11.65 ± 0.22 ^e	10.74 ± 0.23 ⁱ	9.75 ± 0.20 ^g	10.18 ± 0.27 ^h	10.59 ± 0.28 ^g	11.54 ± 0.31 ^{fg}	11.84 ± 0.25 ^f	12.10 ± 0.27 ^{ef}
T ₂	9.91 ± 0.26 ^d	10.72 ± 0.28 ^d	11.38 ± 0.25 ^{de}	12.35 ± 0.22 ^{bcd}	11.81 ± 0.22 ^{de}	10.90 ± 0.26 ^{fg}	9.91 ± 0.27 ^{de}	10.34 ± 0.27 ^e	10.75 ± 0.31 ^d	11.70 ± 0.19 ^{cd}	12.00 ± 0.18 ^{cde}	12.26 ± 0.23 ^{bde}
T ₃	10.07 ± 0.29 ^b	10.88 ± 0.24 ^b	11.44 ± 0.30 ^{cd}	12.38 ± 0.33 ^{abc}	12.83 ± 0.27 ^a	12.30 ± 0.26 ^b	10.07 ± 0.24 ^b	10.50 ± 0.27 ^b	10.91 ± 0.29 ^b	11.86 ± 0.23 ^{ab}	12.16 ± 0.23 ^{ab}	12.42 ± 0.20 ^{ab}
T ₄	9.81 ± 0.26 ^{ef}	10.62 ± 0.28 ^{ef}	11.28 ± 0.30 ^{fg}	12.25 ± 0.22 ^{def}	11.71 ± 0.25 ^e	10.80 ± 0.29 ^{hi}	9.81 ± 0.28 ^{fg}	10.24 ± 0.27 ^g	10.65 ± 0.31 ^f	11.60 ± 0.31 ^{def}	11.90 ± 0.27 ^{ef}	12.16 ± 0.26 ^{de}
T ₅	10.02 ± 0.31 ^{bc}	10.83 ± 0.29 ^{bc}	11.49 ± 0.30 ^{bc}	12.46 ± 0.33 ^a	11.92 ± 0.20 ^d	11.01 ± 0.29 ^e	10.02 ± 0.28 ^{bc}	10.45 ± 0.28 ^c	10.86 ± 0.23 ^c	11.81 ± 0.28 ^b	12.11 ± 0.33 ^{bc}	12.37 ± 0.24 ^{abc}
T ₆	10.16 ± 0.27 ^a	10.97 ± 0.29 ^a	11.53 ± 0.38 ^b	12.43 ± 0.20 ^{ab}	12.88 ± 0.25 ^a	12.47 ± 0.24 ^a	10.16 ± 0.32 ^a	10.59 ± 0.25 ^a	11.00 ± 0.29 ^a	11.95 ± 0.32 ^a	12.25 ± 0.32 ^a	12.51 ± 0.27 ^a
T ₇	9.83 ± 0.26 ^e	10.64 ± 0.30 ^e	11.30 ± 0.30 ^{ef}	12.27 ± 0.24 ^{def}	12.62 ± 0.28 ^b	11.92 ± 0.19 ^e	9.83 ± 0.29 ^{ef}	10.26 ± 0.32 ^{fg}	10.67 ± 0.28 ^{ef}	11.62 ± 0.22 ^{def}	11.92 ± 0.33 ^{ef}	12.18 ± 0.23 ^{de}
T ₈	9.80 ± 0.26 ^{ef}	10.61 ± 0.28 ^{ef}	11.27 ± 0.33 ^{fg}	12.24 ± 0.21 ^{ef}	12.31 ± 0.27 ^c	11.79 ± 0.31 ^d	9.80 ± 0.26 ^{fg}	10.23 ± 0.27 ^g	10.64 ± 0.30 ^f	11.59 ± 0.25 ^{ef}	11.89 ± 0.25 ^{ef}	12.15 ± 0.34 ^{de}
T ₉	9.86 ± 0.26 ^{de}	10.67 ± 0.23 ^{de}	11.33 ± 0.20 ^{ef}	12.30 ± 0.26 ^{cde}	11.76 ± 0.31 ^{de}	10.85 ± 0.29 ^{ab}	9.86 ± 0.23 ^{ef}	10.29 ± 0.27 ^f	10.70 ± 0.28 ^e	11.65 ± 0.26 ^{de}	11.95 ± 0.34 ^{def}	12.21 ± 0.23 ^{cde}
T ₁₀	9.98 ± 0.26 ^c	10.79 ± 0.29 ^c	11.45 ± 0.30 ^{bcd}	12.42 ± 0.19 ^{ab}	11.88 ± 0.31 ^d	10.97 ± 0.33 ^{ef}	9.98 ± 0.26 ^{cd}	10.41 ± 0.28 ^d	10.82 ± 0.29 ^c	11.77 ± 0.24 ^{bc}	12.07 ± 0.22 ^{bcd}	12.33 ± 0.24 ^{abcd}
T ₁₁	9.65 ± 0.26 ^g	10.46 ± 0.32 ^g	11.98 ± 0.24 ^a	11.55 ± 0.22 ^g	10.92 ± 0.29 ^f	10.64 ± 0.28 ^f	9.65 ± 0.22 ^h	10.08 ± 0.25 ⁱ	10.49 ± 0.28 ^h	11.44 ± 0.30 ^g	12.00 ± 0.23 ^{cde}	11.93 ± 0.23 ^f

Mean ± SD (n = 3); the superscript letters with in column are indicating the significant different at p < 0.05

Table 6 Changes in ascorbic acid content (mg/100 g pulp) of ber fruits in response to pre-harvest application of chemicals during storage at different conditions

Treatments/ Storage period	Ambient temperature storage					Low temperature storage (10 °C)						
	0 day	2 days	4 days	6 days	8 days	10 days	0 day	2 days	4 days	6 days	8 days	10 days
T ₁	82.6 ± 1.2 ^f	77.9 ± 1.1 ^f	70.0 ± 1.5 ^f	62.1 ± 1.4 ^f	53.1 ± 1.4 ^f	48.9 ± 1.3 ^f	82.6 ± 1.2 ^{ef}	79.9 ± 1.6 ^{ef}	76.1 ± 1.1 ^{ef}	71.7 ± 1.6 ^f	65.8 ± 1.5 ^f	61.6 ± 1.4 ^f
T ₂	85.4 ± 1.2 ^e	80.5 ± 1.1 ^e	72.6 ± 1.6 ^e	64.7 ± 1.1 ^e	55.7 ± 1.1 ^e	51.5 ± 1.2 ^e	85.4 ± 1.3 ^{de}	82.9 ± 1.6 ^{de}	79.3 ± 1.6 ^{de}	75.3 ± 1.2 ^{de}	69.4 ± 1.5 ^{de}	65.2 ± 1.1 ^{de}
T ₃	89.7 ± 1.3 ^c	84.8 ± 1.2 ^c	76.9 ± 1.0 ^c	69.0 ± 1.4 ^c	60.0 ± 1.6 ^c	55.8 ± 1.2 ^c	89.7 ± 1.1 ^{bc}	87.2 ± 1.7 ^{bc}	83.6 ± 1.6 ^{bc}	79.6 ± 1.5 ^{bc}	73.7 ± 1.2 ^{bc}	69.5 ± 0.9 ^{bc}
T ₄	83.2 ± 1.3 ^f	78.3 ± 1.4 ^f	70.4 ± 1.7 ^f	62.5 ± 1.2 ^f	53.5 ± 1.6 ^f	49.3 ± 1.3 ^f	83.2 ± 1.2 ^{ef}	80.7 ± 1.2 ^{ef}	77.1 ± 1.4 ^{ef}	73.1 ± 1.5 ^{ef}	67.2 ± 1.5 ^{ef}	63.0 ± 1.4 ^{ef}
T ₅	87.3 ± 1.3 ^d	82.4 ± 1.3 ^d	74.5 ± 1.4 ^d	66.6 ± 1.2 ^d	57.6 ± 1.7 ^d	53.5 ± 1.3 ^d	87.3 ± 1.2 ^{cd}	84.8 ± 1.6 ^{cd}	81.2 ± 1.1 ^{cd}	77.2 ± 1.5 ^{cd}	71.3 ± 1.2 ^{cd}	67.1 ± 1.5 ^{cd}
T ₆	91.2 ± 1.3 ^b	86.3 ± 1.3 ^b	78.4 ± 1.1 ^b	70.5 ± 1.2 ^b	61.5 ± 1.1 ^b	57.4 ± 1.4 ^b	91.2 ± 1.2 ^{ab}	88.7 ± 1.1 ^{ab}	85.2 ± 1.6 ^{ab}	81.1 ± 1.2 ^{ab}	75.2 ± 1.4 ^{ab}	71.0 ± 1.2 ^{ab}
T ₇	93.7 ± 1.2 ^a	88.5 ± 1.3 ^a	80.6 ± 1.1 ^a	72.7 ± 1.3 ^a	63.7 ± 1.7 ^a	59.5 ± 1.5 ^a	93.7 ± 1.3 ^a	91.1 ± 1.1 ^a	87.5 ± 1.4 ^a	83.3 ± 1.4 ^a	77.4 ± 1.4 ^a	73.2 ± 1.4 ^a
T ₈	90.2 ± 1.3 ^c	85.3 ± 1.2 ^c	77.4 ± 1.2 ^c	69.5 ± 1.3 ^{bc}	60.5 ± 1.0 ^{bc}	56.4 ± 1.1 ^{bc}	90.2 ± 1.4 ^{ab}	87.7 ± 1.4 ^{abc}	84.1 ± 1.3 ^{abc}	80.1 ± 1.2 ^{bc}	74.2 ± 1.5 ^{abc}	70.0 ± 1.1 ^{abc}
T ₉	82.4 ± 1.2 ^f	77.7 ± 1.1 ^f	69.8 ± 1.9 ^f	61.9 ± 1.6 ^f	52.9 ± 1.4 ^f	48.7 ± 1.8 ^f	82.4 ± 1.1 ^{ef}	79.9 ± 1.1 ^{ef}	76.4 ± 1.2 ^{ef}	72.5 ± 1.0 ^{ef}	66.6 ± 0.7 ^{ef}	62.4 ± 1.3 ^{ef}
T ₁₀	80.2 ± 1.4 ^g	75.6 ± 1.0 ^g	67.7 ± 1.7 ^g	59.8 ± 1.6 ^g	50.8 ± 1.8 ^g	46.6 ± 1.7 ^g	80.2 ± 1.0 ^{fg}	77.8 ± 1.2 ^{fg}	74.3 ± 1.4 ^{fg}	70.4 ± 1.3 ^{fg}	64.5 ± 1.2 ^{fg}	60.3 ± 1.3 ^{fg}
T ₁₁	77.5 ± 1.1 ^h	72.9 ± 1.2 ^h	65.0 ± 1.5 ^h	57.1 ± 1.5 ^h	48.1 ± 1.8 ^h	44.0 ± 1.6 ^h	77.5 ± 1.1 ^g	75.1 ± 1.2 ^g	71.6 ± 1.5 ^g	67.7 ± 1.3 ^g	61.8 ± 1.4 ^g	57.6 ± 1.4 ^g

Mean ± SD (n = 3); the superscript letters with in column are indicating the significant different at p < 0.05

storage under ambient and low-temperature storage conditions, respectively (Table 6).

Pre-harvest application of calcium inhibits the decline in ascorbic acid content in Nanfeng tangerines [45]. Kanwal et al. [10] reported the highest ascorbic acid (57.66 mg/100 g pulp) in ber fruits treated with 1.0 Mm salicylic acid. The catalytic effect of salicylic acid on the manufacturing of ascorbic acid from sugars or suppression of the activity of oxidative enzymes, or even both, may be responsible for an increase or retention in ascorbic acid [46]. Ascorbic acid content was reduced during the storage of fruits in both storage conditions; the decrease in ascorbic acid was observed more under ambient temperature than under low-temperature storage conditions. Low temperature suppresses the activities of oxidative enzymes and also reduces the losses through metabolic activities. Ascorbic acid decreased during storage may be due to oxidation of enzymes such as ascorbic acid oxidase, catalase, peroxidase and, polyphenol oxidase, etc. [20, 47]. The decrease in ascorbic acid during storage is caused by the reduction of antioxidant potential in fruits [48]. Results obtained regarding ascorbic acid are in confirmation with Ngullie [49] in mango, Davarynejad et al. [50] in plum, Gill and Bal [51] in ber, and Habibi et al. [52] in orange.

Total phenol content (TPC) (mg GAE/100 g pulp)

The phenol content decreased with an increase in the storage period from zero to 10 days after storage under ambient and low-temperature storage conditions in all the treatments. The decrease in phenol content is more significant under ambient temperature storage conditions than under low-temperature storage conditions. All the treatments were found effective in the retention of phenol content compared to the control up to 10 days after storage under both storage conditions. Among different pre-harvest treatments, the highest phenol content was observed in T₇ treatment, i.e., 239.4 ± 6.3 mg GAE/100 g pulp under ambient temperature and 275.4 ± 7.3 mg GAE/100 g pulp 10 days after storage under low-temperature storage conditions (Table 7).

The increase in total phenolic content with the application of salicylic acid (SA) indicates the delay in the ripening process. The ripening of grapes was delayed with the application of salicylic acid [53]. Kanwal et al. [10] observed similar results that the ber fruits treated with 1.0 mM salicylic acid recorded maximum TPC (263.93 mg GAE/100 g pulp). As per previous studies in Kinnow, SA treatments declined ethylene production during storage. SA also helps in the accumulation of phenolic substances along with increasing antioxidant activity and prevents cell membrane degradation by destroying free radicals [54]. Fruit weight, titratable acidity, TSS/acid ratio, and total sugars decreased at a slower rate with pre-harvest application of 1.5 percent

Table 7 Changes in phenol content (mg GAE/100 g) of ber fruits in response to pre-harvest application of chemicals during storage at different conditions

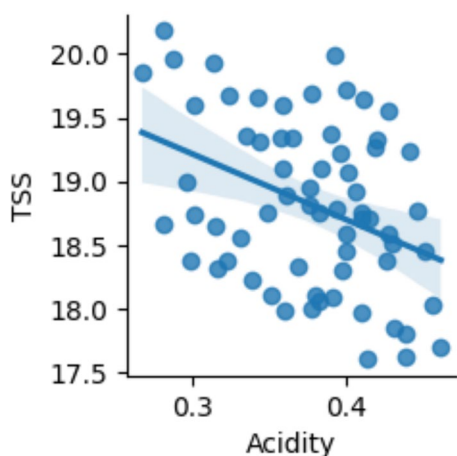
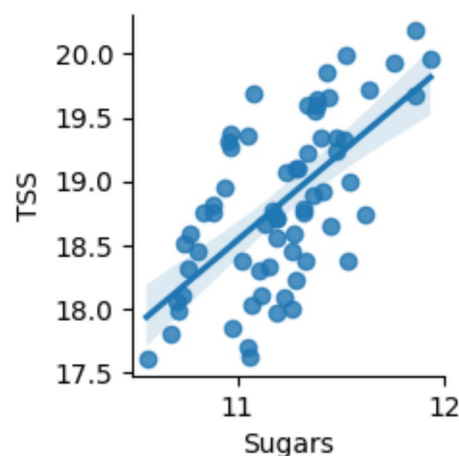
Treatments/ Storage period	Ambient temperature storage					Low temperature storage (10 °C)						
	0 day	2 days	4 days	6 days	8 days	10 days	0 day	2 days	4 days	6 days	8 days	10 days
T ₁	189.2 ± 5.0 ^{fg}	184.1 ± 4.9 ^{ef}	180.5 ± 4.8 ^{ef}	174.3 ± 4.6 ^{gh}	168.0 ± 4.4 ^{ef}	162.1 ± 4.3 ^e	189.2 ± 5.0 ^h	188.0 ± 5.0 ^h	186.8 ± 4.9 ^h	184.5 ± 4.9 ^h	182.4 ± 4.8 ^h	180.6 ± 4.8 ^h
T ₂	221.7 ± 5.9 ^e	216.6 ± 5.7 ^d	211.0 ± 5.6 ^d	208.3 ± 5.5 ^d	204.2 ± 5.4 ^b	200.4 ± 5.3 ^b	221.7 ± 5.9 ^f	220.5 ± 5.8 ^f	219.3 ± 5.8 ^f	217.0 ± 5.7 ^f	214.9 ± 5.7 ^f	211.1 ± 5.6 ^f
T ₃	244.9 ± 6.5 ^c	241.3 ± 6.4 ^c	236.4 ± 6.3 ^c	222.6 ± 5.9 ^c	212.4 ± 5.6 ^b	207.5 ± 5.5 ^b	244.9 ± 6.5 ^d	243.7 ± 6.4 ^d	242.5 ± 6.4 ^d	240.2 ± 6.4 ^d	238.1 ± 6.3 ^d	235.3 ± 6.2 ^d
T ₄	196.7 ± 5.2 ^f	191.2 ± 5.1 ^e	186.2 ± 4.9 ^e	183.8 ± 4.9 ^f	181.2 ± 4.8 ^{cd}	177.1 ± 4.7 ^d	196.7 ± 5.2 ^g	195.6 ± 5.2 ^g	194.4 ± 5.1 ^g	192.1 ± 5.1 ^g	190.0 ± 5.0 ^g	185.2 ± 4.9 ^g
T ₅	233.3 ± 6.2 ^d	221.1 ± 5.9 ^d	209.7 ± 5.5 ^d	200.0 ± 5.3 ^e	191.7 ± 5.1 ^c	186.1 ± 4.9 ^c	233.3 ± 6.2 ^e	232.1 ± 6.1 ^e	230.9 ± 6.1 ^e	228.6 ± 6.0 ^e	226.6 ± 6.0 ^e	221.8 ± 5.9 ^e
T ₆	268.2 ± 7.1 ^b	258.6 ± 6.8 ^b	253.5 ± 6.7 ^b	248.5 ± 6.6 ^{ab}	244.4 ± 6.5 ^a	236.5 ± 6.3 ^a	268.2 ± 7.1 ^b	267.0 ± 7.1 ^b	265.8 ± 7.0 ^b	263.5 ± 7.0 ^b	261.4 ± 6.9 ^b	257.6 ± 6.8 ^b
T ₇	284.6 ± 7.5 ^a	272.2 ± 7.2 ^a	266.3 ± 7.0 ^a	249.3 ± 6.4 ^a	246.0 ± 6.5 ^a	239.4 ± 6.3 ^a	284.6 ± 7.5 ^a	283.4 ± 7.5 ^a	282.2 ± 7.5 ^a	279.9 ± 7.4 ^a	277.8 ± 7.3 ^a	275.4 ± 7.3 ^a
T ₈	260.1 ± 6.9 ^b	249.2 ± 6.6 ^c	247.3 ± 6.5 ^b	241.4 ± 4.8 ^b	234.8 ± 6.2 ^a	232.5 ± 6.2 ^a	260.1 ± 6.9 ^c	258.9 ± 6.8 ^c	257.7 ± 6.8 ^c	255.4 ± 6.8 ^c	253.3 ± 6.7 ^c	248.5 ± 6.6 ^c
T ₉	187.2 ± 4.9 ^{fg}	185.2 ± 4.9 ^{ef}	183.9 ± 4.9 ^e	181.4 ± 4.5 ^{fg}	177.1 ± 4.7 ^{de}	174.2 ± 4.6 ^d	187.2 ± 5.0 ^h	186.1 ± 4.9 ^{hi}	184.8 ± 4.9 ^{hi}	182.6 ± 4.8 ^{hi}	180.5 ± 4.8 ^{hi}	176.7 ± 4.7 ⁱ
T ₁₀	190.1 ± 5.0 ^{fg}	181.3 ± 4.8 ^f	173.1 ± 4.6 ^{fg}	169.2 ± 4.3 ^{hi}	166.8 ± 4.4 ^{ef}	162.4 ± 4.3 ^e	190.1 ± 5.0 ^h	188.8 ± 5.0 ^h	187.6 ± 5.0 ^h	185.3 ± 4.9 ^h	183.2 ± 4.8 ^h	178.4 ± 4.7 ^{hi}
T ₁₁	183.0 ± 4.8 ^g	176.9 ± 4.7 ^f	169.7 ± 4.5 ^g	163.3 ± 4.4 ⁱ	158.1 ± 4.2 ^f	153.1 ± 4.1 ^f	183.1 ± 4.8 ⁱ	182.2 ± 4.8 ⁱ	181.5 ± 4.8 ⁱ	178.4 ± 4.7 ⁱ	176.3 ± 4.7 ⁱ	171.5 ± 4.5 ^j

Mean ± SD (n = 3); the superscript letters with in column are indicating the significant different at p < 0.05

Table 8 Correlation Matrix (Pearson) among different parameters

Parameters	TSS	Titrateable acidity	TSS: acid	Ascorbic acid	Sugars	Phenol
TSS	1.000**	-0.384**	0.573**	0.266*	0.638**	0.352**
Titrateable Acidity	-0.384**	1.000**	-0.931**	-0.270*	-0.348**	-0.589**
TSS: Acid	0.573**	-0.931**	1.000**	0.294*	0.616**	0.618**
Ascorbic Acid	0.266*	-0.270*	0.294*	1.000**	0.311*	0.832**
Sugars	0.638**	-0.348**	0.616**	0.311*	1.000**	0.477**
Phenol	0.352**	-0.589**	0.618**	0.832**	0.477**	1.000**

* significant at 5%, ** significant at 1% and NS non-significant

**Fig. 1** Correlation of TSS with acidity**Fig. 2** Correlation of TSS with total sugars

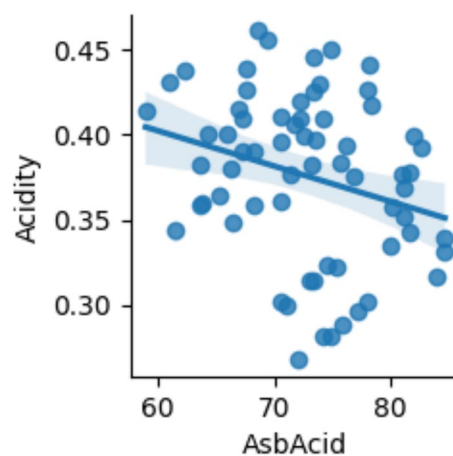
$\text{Ca}(\text{NO}_3)_2$ (T_6) during storage; however, ascorbic acid and TPC with 1mMsalicylic acid (T_7). The preharvest application of salicylic acid enhances the activities of the enzyme phenylalanine ammonia-lyase (PAL), which is involved in the initiation of the biosynthesis of phenolic compounds [55].

Correlation effect

All the parameters have significant correlations (positive or negative) with each other at the level of 1% except ascorbic acid, which correlated significantly at 5%. All the parameters have a positive correlation with TSS except titrateable acidity, which correlated negatively (Table 8). TSS had a negative correlation with titrateable acidity (Fig. 1), whereas sugars had a positive correlation (Fig. 2). Titrateable acidity with ascorbic acid and phenol had a negative correlation (Fig. 3, 4 and 5).

Conclusion

The ber fruits are consumed fresh and have less shelf life; during peak harvesting season, there is a glut in the market, causing post-harvest losses, and the orchardist gets less

**Fig. 3** Correlation of acidity with ascorbic acid

price, or the crop becomes uneconomic. To maintain the quality of fruits for a longer period, the preharvest application of chemicals and storage of fruits under ambient and low-temperature conditions was studied. The performance of quality parameters under low-temperature storage was found to be the best as compared to ambient temperature storage conditions. Fruit weight, TSS, acidity, total sugars, ascorbic acid, and phenol content were found to be higher under low

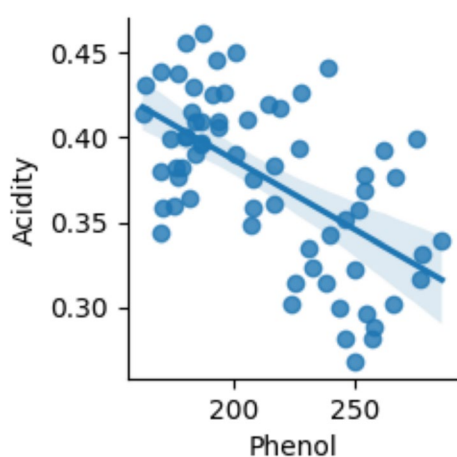
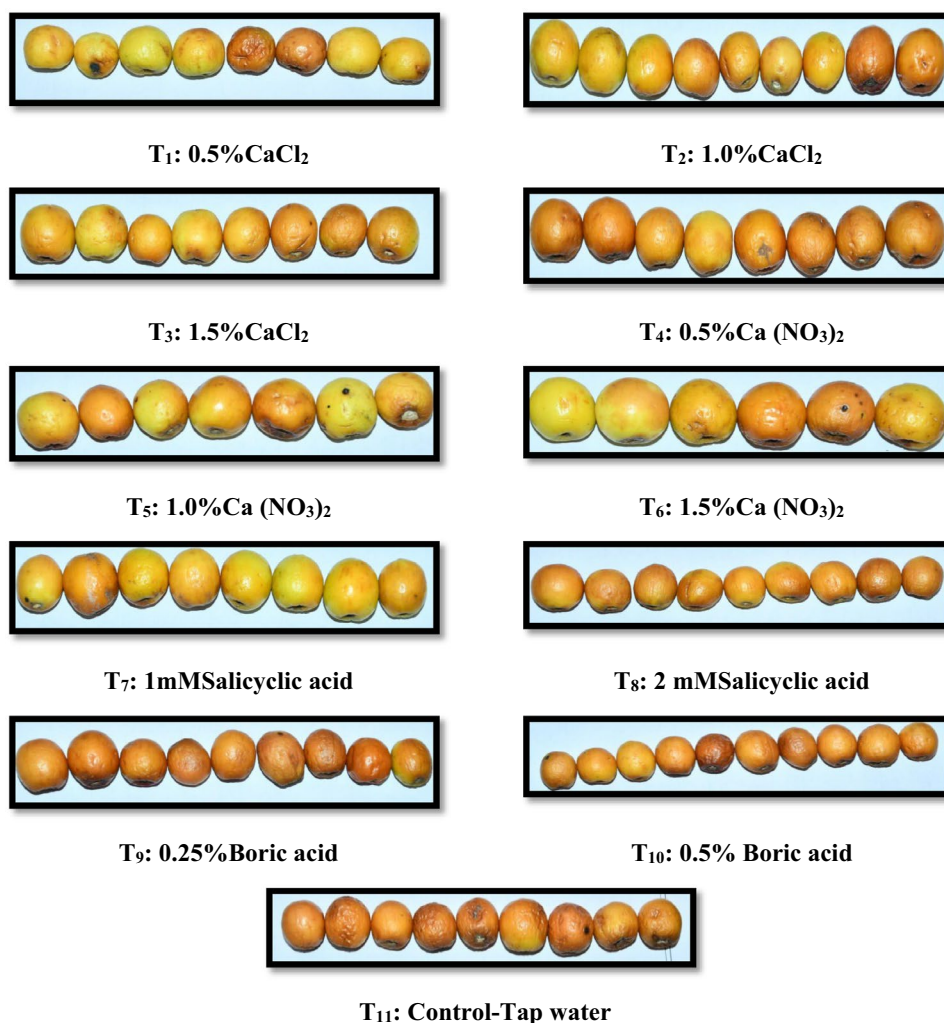


Fig. 4 Correlation of acidity with phenol

ascorbic acid, and phenol content decreased, whereas TSS, TSS: acid, and total sugars increased initially with an increase in storage period thereafter decreased. On an overall basis, pre-harvest application of T_6 (1.5 percent $\text{Ca}(\text{NO}_3)_2$) was found effective in maintaining the quality of fruits in terms of average fruit weight (13.24 ± 0.19 and 14.26 ± 0.20 g), TSS (20.70 ± 0.18 and $21.50 \pm 0.22^\circ\text{B}$), total sugars (12.47 ± 0.24 and $12.51 \pm 0.27\%$) while titratable acidity $0.21 \pm 0.01\%$ (T_6), 0.28 ± 0.01 (T_7), TSS/acid ratio 98.6 ± 1.0 (T_6) 72.1 ± 1.0 (T_3) in ambient and low-temperature storage conditions, respectively. However, 1 mM salicylic acid was found to be better in terms of ascorbic acid (59.5 ± 1.5 and 73.2 ± 1.4 mg/100 g pulp) and phenol content (239.4 ± 6.3 and 275.4 ± 7.3 mg GAE/ 100 g pulp). The preharvest-treated fruits stored under ambient temperature

temperatures, whereas TSS: acid was found to be higher under ambient temperature storage conditions. The physico-chemical parameters such as fruit weight, titratable acidity,

Fig. 5 Effect of different pre-harvest treatments on ber fruits under ambient temperature storage conditions at 10 days after storage



conditions are suitable for up to 8 days, while low-temperature stored fruits are suitable for consumption up to 10 days.

Funding Open access funding provided by the Carolinas Consortium.

Data availability Not applicable.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Anonymous. Area and production of horticultural crops. Ministry of Agriculture and Farmers Welfare (<https://www.indiastat.com/>), 2024, GOI, New Delhi.
- L. Bohane, R. Tiwari, K.K. Gautam, Integrated nutrient management in ber (*Zizyphus mauritiana* Lamk.) cv. Gola under Malwa Plateau conditions of Madhya Pradesh. *Indian J. Hortic.* **73**(1), 128–132 (2016)
- W.T. Yang, J.W. Kang, Y.X. Liu, M.R. Guo, G.G. Chen, Effect of salicylic acid treatment on antioxidant capacity and endogenous hormones in winter jujube during shelf life. *Food Chem.* **397**, 133788 (2022)
- M. Abdel-Sattar, K.F. Almutairi, A.M. Al-Saif, K.A. Ahmed, Fruit properties during the harvest period of eleven Indian jujube (*Zizyphus mauritiana* Lamk.) cultivars. *Saudi J. Biol. Sci.* **28**(6), 3424–3432 (2021)
- S. Pareek, L. Kitinoja, R.A. Kaushik, R. Paliwal, Postharvest physiology and storage of ber. *Stewart Post. Review.* **5**(5), 1–10 (2009)
- X. Ji, Q. Peng, H. Li, F. Liu, M. Wang, Chemical characterization and anti-inflammatory activity of polysaccharides from *Zizyphus jujube* cv. Muzao. *Int. J. Food Eng.* **13**, 20160382 (2017)
- H.H. Zhi, Q.Q. Liu, Y. Dong, M.P. Liu, W. Zong, Effect of calcium dissolved in slightly acidic electrolyzed water on antioxidant system, calcium distribution, and cell wall metabolism of peach in relation to fruit browning. *J. Hortic. Sci. Biotech.* **92**(6), 621–629 (2017)
- Y. Wu, X. Yang, X. Wang, L. Yan, X. Hu, M. Lian, Effect of foliar calcium fertilization on fruit quality, cell wall enzyme activity and expression of key genes in Chinese cherry. *Int. J. Fruit Sci.* **23**(1), 200–216 (2023)
- M.J. Guerrero, J.G.A. Herreral, G. Fischer, Effect of calcium on fruit quality: A review. *Agron Colomb* **42**(1), 1–14 (2024)
- M.A.J. Kanwal, S. Ahmad, M. Nasir, M.J. Jaskani, M. Aziz, Pre-harvest spray of salicylic acid to improve the quality and shelf life of ber fruit (*Zizyphus mauritiana*). *J. Post harvest Technol.* **9**(1), 64–71 (2021)
- A. Meena, B.L. Nagar, M.C. Jain, R.S. Naroliya, M. Kumar, Response of pre-harvest spray of GA3 and boron on storability and quality of Ber (*Zizyphus mauritiana* Lamk.) cv. Banarasi Karaka. *Pharm. Innov. J.* **10**(11), 475–478 (2021)
- S.K. Singh, R.S. Singh, O.P. Awasthi, Influence of pre-and post-harvest treatments on shelf-life and quality attributes of ber fruits. *Indian J Hortic.* **70**(04), 610–613 (2013)
- Y.Y. Sang, W.T. Yang, Y.X. Liu, W.D. Zhang, T.T. Guo, P. Shen, Y.S. Tang, M.R. Guo, G.G. Chen, Influences of low temperature on the postharvest quality and antioxidant capacity of winter jujube (*Zizyphus jujuba* Mill. cv. Dongzao). *LWT–Food Sci. Technol.* **154**, 112876 (2022)
- H. Huang, G. Jing, L. Guo, D. Zhang, B. Yang, X. Duan, Y. Jiang, Effect of oxalic acid on ripening attributes of banana fruit during storage. *Postharvest Bio. Technol.* **84**, 22–27 (2013)
- A.O.A.C. Official Methods of Analysis. 15th Edn. Association of official analytical chemist, Washington, D.C. 1990.
- A.C. Hulme, R. Narain, The ferricyanide method for determination of reducing sugars. A modification of Hagedorn Jesen–Hanes techniques. *Biochem. J.* **25**, 1051–1061 (1931)
- V. Singleton, J. Rossi, Colorimetry of total phenolic compounds with phosphomolybdic-phosphotungstic acid reagents. *Am. J. Enol. Vitic.* **16**, 144–158 (1965)
- Gopinath, P. P, Parsad, R, Joseph, B, Adarsh, V. S. GRAPES: General Rshiny Based Analysis Platform Empowered by Statistics. <https://www.kaugrapes.com/home>. Version 1.0.0. 10.5281/zenodo.4923220 (2020).
- M.Y. Bhat, A. Hafiza, F.A. Banday, M.A. Dar, F.A. Khan, Effect of calcium chloride and storage period at ambient temperature on physico-chemical characteristics of pear cv. Bartlett. *Indian J. Hortic.* **68**, 444–447 (2011)
- L.R. Ribeiro, S. Leonel, J.M.A. Souza, E.L. Garcia, M. Leonel, L.N.H. Monteiro, R.B. Ferreira, Improving the nutritional value and extending shelf life of red guava by adding calcium chloride. *LWT- Food Sci. Technol.* **130**, 109–655 (2020)
- M. Kumar, M. Kumar, A. Bishnoi, Effect of pre-harvest spray of calcium chloride and calcium nitrate on shelf life of aonla (*Phyllanthus emblica* L.) cv NA 7. *India J. Arid Hortic.* **3**(1&2), 37–40 (2021)
- P.K. Vishwakarma, M.M. Masu, S. Singh, Effect of various pre-harvest treatments on shelf life and morphological characteristics of fruits of mango (*Mangifera indica* L.) var. ‘Amrapali’. *J. Hortic. Sci.* **17**(1), 147–156 (2022)
- J.M.A. Souza, S. Leonel, M. Leonel, E.L. Garcia, L.R. Ribeiro, R.B. Ferreira, A.S. Duarte, Calcium nutrition in fig orchards enhance fruit quality at harvest and storage. *Horticulturae* **9**(1), 123 (2023)
- D.S. Mandloi, R.N. Kanpure, B.K. Kachouli, S.R. Anjanawe, Effect of pre-harvest spray of chemicals on the quality of pomegranate fruits. *Ann. Plant Sci. Soil Res.* **15**(1), 75–76 (2013)
- A. Kumar, V.K. Tripathi, V. Dubey, N.K. Katiyar, P. Tiwari, Influence of foliar application of calcium, zinc and boron on fruit drop, yield and quality attributes of aonla (*Emblia officinalis*) cv. NA-7. *Res. on Crops.* **18**(1), 91–97 (2017)
- F. Hameed, A. Kumar, N. Hamid, Effect of thermal treatment and storage on the quality of apple juice. *J. Pharmacogn. Phytochem.* **8**(1), 1976–1979 (2019)
- M. Kumar, D. Singh, R.K. Godara, S. Singh, J.K. Sandooja, C.P. Mehla, Studies on the suitability of dried ber fruits for preparation of RTS beverage. *Haryana J. Horti. Sci.* **38**(3&4), 216–219 (2009)
- R. Mor, M. Kumar, S. Kumar, S. Kumari, J.B. Soni, Assessment of phalsa (*Grewia subinaequalis* DC.) germplasm for distinction in yield, quality and shelf life under semi-arid conditions of Haryana. *Progressive Hortic.* **45**(1), 40–45 (2022)
- S. Chawla, R. Devi, V. Jain, Changes in physico-chemical characteristics of guava fruits due to chitosan and calcium chloride treatments during storage. *J. Pharmacog. Phytochem.* **7**(3), 1035–1044 (2018)

30. M.T. Selvan, J.S. Bal, Effect of different treatments on the shelf life of 'Sardar' guava during cold storage. *J. Res.* **42**, 28–33 (2005)
31. B.V.C. Mahajan, A.S. Dhath, Studies of postharvest calcium chloride application on storage behaviour and quality of Asian pear during cold storage. *J. Food Agric. Environ.* **2**(3–4), 157–159 (2004)
32. M. Goutam, H.S. Dhaliwal, B. Mahajan, Effect of pre-harvest calcium sprays on post-harvest life of winter guava (*Psidium guajava* L.). *J. Food Sci. Technol.* **47**, 501–506 (2010)
33. S. Ranjbar, A. Ramezani, M. Rahemi, Nano-calcium and its potential to improve 'Red Delicious' apple fruit characteristics. *Hortic. Environ. and Biotech.* **61**, 23–30 (2020)
34. M.M. Ali, R. Anwar, R.N.U. Rehman, S. Ejaz, S. Ali, A.F. Yousef, F. Chen, Sugar and acid profile of loquat (*Eriobotrya japonica* Lindl.), enzymes assay and expression profiling of their metabolism-related genes as influenced by exogenously applied boron. *Front. Plant Sci.* **13**, 1039360 (2022)
35. A. Mani, V.S.S.V. Prasanna, S. Halder, J. Praveena, Efficacy of edible coatings blended with Aloe vera in retaining post-harvest quality and improving storage attributes in Ber (*Ziziphus mauritiana* Lamk.). *Int. J. Chem. Stud.* **6**(6), 1727–1733 (2018)
36. M. Kumar, A. Nibhoria, Pooja, M. Buswal, Standardization of juice concentration for preparation of phalsa nectar and changes during storage. *J. Arid Hortic.* **3**, 25–28 (2021)
37. S.K. Jawandha, J.S. Randhawa, P.P.S. Gill, J. Singh, Effect of post-harvest treatment on storage quality in "Umran" ber Fruit. *J. Hortic. Sci.* **3**(1), 48–52 (2008)
38. A. Parven, M.R. Sarker, M. Megharaj, I.M. Meftaul, Prolonging the shelf life of Papaya (*Carica papaya* L.) using Aloe vera gel at ambient temperature. *Sci. Hortic.* **265**, 109–228 (2020)
39. T.K. Hazarika, T. Marak, Salicylic acid and oxalic acid in enhancing the quality and extending the shelf life of grape cv. Thompson Seedless. *Food Sci. Technol. Int.* **28**(6), 463–475 (2022)
40. G. Mandal, H.S. Dhaliwal, B.V.C. Mahajan, Effect of pre-harvest application of NAA and potassium nitrate on storage quality of winter guava (*Psidium guajava* L.). *Indian J. Agric. Res.* **82**(11), 985–989 (2012)
41. S.M.A. Sarwry, E.G. Gadalla, E.A.M. Mostafa, Effect of calcium nitrate and boric acid sprays on fruit set, yield and fruit quality of cv. Amhat date palm. *World J. Agric. Res.* **8**(5), 506–515 (2012)
42. R.S. Sidhu, N.P. Singh, S. Singh, R. Sharda, Foliar nutrition with calcium nitrate in strawberries (*Fragaria × ananassa* Duch.): effect on fruit quality and yield. *Indian J. Ecol.* **47**(1), 87–91 (2020)
43. L. Goldenberg, Y. Yaniv, T. Kaplunov, A. Doron-Faigenboim, R. Porat, N. Carmi, Genetic diversity among mandarins in fruit-quality traits. *J. Agric. Food Chem.* **62**, 4938–4946 (2014)
44. A. Bhatt, N.K. Mishra, D.S. Mishra, C.P. Singh, Foliar application of potassium, calcium, zinc and boron enhanced yield, quality and shelf life of mango cv. Dashehari. *HortFlora Res. Spectrum.* **1**(4), 300–305 (2012)
45. Z. Chen, Q. Ma, S. Zheng, X. Liu, D. Wu, Q. Gu, Q. Wei, Effect of pre-harvest calcium treatment on post-harvest fruit quality of nanfeng tangerine. *Horticulturae* **10**, 381 (2024)
46. X. Zheng, M. Gong, Q. Zhang, H. Tan, L. Li, Y. Tang, W. Deng, Metabolism and regulation of ascorbic acid in fruits. *Plants* **11**(12), 1602 (2022)
47. B.P. Singh, G. Panday, D.K. Sarolia, M.K. Panday, R.K. Pathak, Shelf-life evaluation of aonla cultivars. *Indian J. Hortic.* **62**(2), 137–140 (2005)
48. A. Baltazari, H.D. Mtui, M.W. Mwatawala, L.M. Chove, T. Mso-goya, J. Samwel, J. Subramanian, Effects of storage conditions, storage duration and post-harvest treatments on nutritional and sensory quality of orange (*Citrus sinensis* (L) Osbeck) fruits. *Int. J. Fruit Sci.* **20**(4), 737–749 (2020)
49. Ngullie, Chonpenthung R. Effect of acid and humic acid on flowering, fruiting, yield and quality of mango (*Mangifera indica* L) cv. Kesar. Thesis submitted to the Navsari Agricultural University Navsari, Gujarat, (2014)
50. G.H. Davarynejad, M. Zarei, M.E. Nasrabadi, E. Ardakani, Effects of salicylic acid and putrescine on storability, quality attributes and antioxidant activity of plum cv. 'Santa Rosa.' *J. Food Sci. Technol.* **52**, 2053–2062 (2015)
51. P.P.S. Gill, J.S. Bal, Effect of growth regulator and nutrients spray on control of fruit drop, fruit size and quality of ber under submontane zone of Punja. *J. Hortic. Sci.* **4**(2), 161–163 (2016)
52. F. Habibi, A. Ramezani, F. Guillén, M. Serrano, D. Valero, Blood oranges maintain bioactive compounds and nutritional quality by postharvest treatments with γ -aminobutyric acid, methyl jasmonate or methyl salicylate during cold storage. *Food Chem.* **306**, 125634 (2020)
53. G.P. Blanch, M.C. Gómez-Jiménez, M.L.R. Del Castillo, Exogenous salicylic acid improves phenolic content and antioxidant activity in table grapes. *Plant Foods Hum. Nutr.* **75**, 177–183 (2020)
54. S.A. Haider, S. Ahmad, A.S. Khan, M.A. Anjum, M. Nasir, S. Naz, Effects of salicylic acid on postharvest fruit quality of "Kinnow" mandarin under cold storage. *Sci. Hortic.* **259**, 108843 (2020)
55. A. Estaji, F. Niknam, Foliar salicylic acid spraying effect' on growth, seed oil content, and physiology of drought-stressed *Silybum marianum* L. plant. *Agric. Water Manag.* **234**, 106116 (2020)

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.