DOI: 10.2478/ahr-2025-0011
Acta hort regiotec, 28, 2025(2): 89–98

**Research Article**

# Prolonging Shelf Life and Preserving Quality: A Study on Orange Varieties Under Different Storage Conditions

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Article Details: Received: 2025-02-09 | Accepted: 2025-08-11 | Available online: 2025-11-30



Mandarin oranges are highly perishable fruits that often suffer significant postharvest losses due to improper storage and handling conditions. This study evaluated the effects of different storage treatments on the shelf life and quality retention of two orange varieties, Darjeeling mandarin and Chinese mandarin. The experiment was arranged in a completely randomized design with three replications, and six postharvest treatments were applied: control (ambient storage), polypropylene (PP) bags with and without perforation, hot water treatment at 50 ±1 °C for 5 min, and cold storage at 6 °C with or without PP bags. Fruits were evaluated periodically for weight loss, total soluble solids, vitamin C content, disease incidence, and shelf life. Results showed that the longest shelf life (47 days) was observed in Chinese mandarins stored at 6 °C in sealed PP bags, while the shortest (12 days) occurred in Darjeeling mandarins stored in non-perforated PP bags at ambient temperature. This cold storage condition also retained the highest vitamin C content (16.80 mg.100 $g^{-1}$), the lowest weight loss (2.65%), and no disease incidence. In contrast, the greatest vitamin C degradation (80.17%) and highest disease incidence (94.44%) were found in hot water-treated fruits and those stored in perforated bags at room temperature. These findings suggest that storing mandarins in sealed PP bags at low temperatures is an effective approach to extend shelf life and preserve fruit quality.

**Keywords:** Mandarin orange, cold storage, shelf life, postharvest treatment, fruit quality

## 1 Introduction

The orange, commonly known as the sweet orange to distinguish it from the bitter orange (*Citrus aurantium*), is a member of the Rutaceae family. Botanically, it is a hybrid (*Citrus* × *sinensis*) derived from the pomelo (*Citrus maxima*) and mandarin (*Citrus reticulata*). In Bangladesh, during the 2022–2023 period, orange cultivation covered 987.21 ha, producing 3,616.43 metric tons (Howlader et al., 2024b). Originating in a region encompassing Southern China, Northeast India, and Myanmar, the earliest mention of the sweet orange was found in Chinese literature in 314 BCE (Adetunji et al., 2018). Today, oranges are widely grown in tropical and subtropical regions for their sweet and nutritious fruit, consumed fresh or processed into juice and other products. In 2022, global production reached 76 million tons, with Brazil accounting for 22%, followed by India and China (Dhiman et al., 2022).

Orange trees are evergreen, flowering plants that typically grow to a height of 9 m to 10 m, with some older specimens reaching 15 m. Their oval leaves are alternately arranged, measuring 0.04–0.10 m in length, with crenulated edges (Gao et al., 2019; Hasan et al., 2025a). The unripe fruit is green, while the ripe fruit ranges from bright orange to yellow-orange, although green patches may persist in warm climates. These trees

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thrive in moderate temperatures between 15.5 °C and 29 °C, requiring abundant sunlight and water, making them ideal for cultivation in tropical and subtropical regions (Carvalho et al., 2023).

Oranges are highly nutritious, containing approximately 87% water, 12% carbohydrates, and 1% protein, with negligible fat content. A 100 g portion provides about 47 kcal and fulfills approximately 64% of the daily vitamin C requirement (Habibi et al., 2021). They also contain 0.93 g protein, 0.3 g fat, 11.02 g carbohydrates, 0.4 g minerals, 0.05 g calcium, 0.02 g phosphorus, and 0.1 g iron. One kilogram of oranges yields about 490 kcal. Oranges are widely used in the preparation of jam, jelly, juice, and squash, while the peel is valued in perfume production. A single tree can produce 300–400 fruits, with an average fruit weight of 190 g (Hasan et al., 2025c). Additionally, oranges are rich in phytochemicals, including carotenoids, flavonoids, and volatile compounds.

In Bangladesh, oranges are mainly grown in Sylhet, the Chittagong Hill Tracts, Rangpur, and Panchagarh. Despite their nutritional value and popularity, average daily fruit consumption per capita is only 35 g, far below the recommended 100 g, highlighting oranges' potential to address this gap (Ali et al., 2025). However, poor postharvest handling and storage cause significant losses. As non-climacteric fruits, oranges show minimal changes in respiration and ethylene production after harvest. Postharvest losses in Bangladesh range from 20% to 50%, compared to 5% to 25% in developed countries (Howlader et al., 2024c).

Inadequate postharvest management leads to substantial quality decline, economic setbacks, and nutritional losses in oranges. Their high moisture content makes them highly perishable, causing water loss, peel shrinkage, and wilting under improper storage conditions (Yesmin et al., 2023). Poor sanitation and handling further exacerbation issues, encouraging fungal infections like those from *Penicillium* species, resulting in decay and reduced marketable yield (Mia et al., 2025). Key nutrients, such as vitamin C, degrade rapidly in unfavorable conditions like high temperatures and low humidity, diminishing their nutritional value. Economic losses arise from the reduced appeal and marketability of damaged fruits, while increased spoilage adds to environmental waste. Failure to maintain optimal storage humidity (90–95%) shortens shelf life, limiting the fruit's availability for consumption or processing into products like juice (Mia et al., 2025). In developing nations, postharvest losses can reach 20–50%, underscoring the need for improved management to enhance food security, economic resilience, and sustainable orange production (Carmona et al., 2017).

Rising food demand due to population growth, coupled with declining production and postharvest losses, emphasizes the need for advanced postharvest technologies. This research focuses on developing storage methods to extend orange shelf life, analyzing postharvest changes, and recommending preservation techniques to improve orange quality, reduce losses, and ensure better availability in Bangladesh.

## 2 Materials and Methods

### *2.1 Experimental Site and Design*

The experiment to evaluate the effects of maturity stage and postharvest treatments on the shelf life and quality of mandarin oranges was carried out in December 2023 at the Postharvest Laboratories, Department of Horticulture, Bangladesh Agricultural University (BAU), Mymensingh. During the study period, daily temperature and relative humidity were recorded using a digital thermohygrometer (THERMO, TFA, Germany). The temperature ranged from 25.1 °C to 26.1 °C, while the relative humidity fluctuated between 79% and 84%. Freshly harvested mandarin oranges, uniform in size and shape and free from visible defects, were collected from "Mrs. Ma-Babar Doya" Fruit Garden in Sherpur. The fruits were transported to the laboratory in corrugated fiber cartons with careful handling to prevent mechanical damage.

The experiment followed a two-factor completely randomized design (CRD) with three replications. Each replication included three fruits, of which two were used for nondestructive quality analysis and one for destructive testing. Factor A consisted of two varieties: Darjeeling mandarin orange ($V_1$) and Chinese mandarin orange ($V_2$). Factor B included six postharvest treatments: $T_1$, untreated fruits stored under ambient conditions (control); $T_2$, fruits sealed in non-perforated polypropylene (PP) bags (50 µm) and stored at ambient conditions; $T_3$, fruits sealed in PP bags (50 µm) with punch-hole perforations and stored at ambient conditions; $T_4$, fruits treated with hot water at 50 ±1 °C for 5 min and stored at ambient conditions; $T_5$, fruits sealed in PP bags (50 µm) and stored at 6 °C; and $T_6$, fruits stored at 6 °C without PP bags. This experimental design allowed for the evaluation of treatment and variety effects on both qualitative and quantitative postharvest attributes of the fruits.

### *2.2 Application of Treatments*

The experiment comprised six postharvest treatment methods, each applied to three randomly selected fruits per replication. In the first treatment, fruits were placed on a laboratory table under ambient conditions without any treatment, serving as the control. In the second treatment, fruits were individually sealed in non-perforated plastic bags with a thickness of 50 µm and stored at ambient temperature. The third treatment involved sealing fruits in perforated plastic bags (50 µm) and storing them similarly under ambient conditions. In the fourth treatment, fruits were immersed in hot water at 50 ±1 °C for 5 min using a Hot Water Bath (Model No. GFL), and then stored under ambient conditions. In the fifth treatment, fruits were sealed in non-perforated polypropylene (PP) bags (50 µm) and stored in a refrigerator maintained at 6 °C. For the sixth and final treatment, fruits were stored at 6 °C without being sealed in PP bags, allowing for the observation of storage effects in the absence of packaging. These treatments were selected to compare the impact of temperature, packaging, and sanitation on the postharvest behavior of mandarin oranges.

### 2.3 Data Collection

Throughout the storage period, the oranges used in the experiment were monitored daily. Data were collected every alternate day to assess the effects of different postharvest treatments across the varieties. The observed parameters are detailed below (Howlader et al., 2025c).

Weight loss was calculated using the following formula 1 (Hasan et al., 2025a; Karim et al., 2024; Haque et al., 2025).

$$\textit{percent weight loss}\ (\%) = \frac{IW\ (\mathrm{g}) - FW\ (\mathrm{g})}{IW\ (\mathrm{g})} \qquad (1)$$

where: *IW* – initial weight; *FW* – fresh weight

Total soluble solids (TSS) content of orange pulp was estimated using Abbe's Refractometer. A drop of orange juice squeezed from the fruit pulp was placed on the prism of the refractometer, and TSS was recorded as % Brix from direct reading of the instrument. Temperature corrections were made using the Temperature Correction Chart. Vitamin C was determined using formula 2 (Howlader et al., 2024b).

$$\textit{ascorbic acid}\ (\mathrm{mg \cdot 100\ g^{-1}}) = \frac{\textit{titre}\ (\mathrm{ml}) \cdot \textit{dye factor} \cdot \textit{volume made up}\ (100\ \mathrm{ml}) \cdot 100}{\textit{aliquot used for estimation}\ (10\ \mathrm{ml}) \cdot \textit{sample weight}\ (10\ \mathrm{g})} \qquad (2)$$

Disease incidence means the percentage of fruits infected with the disease. This is measured by calculating the percentage of fruits infected. The diseased fruits were identified symptomatically. The disease incidence was calculated using formula 3 (Karim et al., 2024; Laboni et al., 2024; Hasan et al., 2025b).

$$\textit{percent disease incidence} = \frac{\textit{number of infected fruits in each replication}}{\textit{total number of fruits in each replication}} \cdot 100 \qquad (3)$$

Disease severity represents the percent diseased portion of the infected orange fruit. The infected fruits of each replication of each treatment were selected to determine the percent fruit area infected and were measured based on eye estimation (Rahman et al., 2024).

The shelf life of orange fruits as influenced by different postharvest treatments was calculated by counting the number of days required to ripen fully with retained optimum marketing and eating qualities.

### 2.4 Statistical Analysis

The data collected was analyzed using ANOVA with the MSTAT Statistical Package. Mean values were calculated, and differences were assessed using the LSD test at 1% and 5% probability levels, as described.

## 3 Results and Discussions

This chapter summarizes the results of orange storage experiments, highlighting changes in appearance, color, firmness, freshness, shrinkage, flavor, weight loss, disease severity, total soluble solids, and shelf life. Detailed analyses are provided in Tables and Figures.

### 3.1 Weight Loss

Significant variation in weight loss of mandarin oranges was observed during storage, influenced by both variety and postharvest treatments. After 26 days of storage, Darjeeling oranges exhibited a higher weight loss (35.30%) compared to Chinese mandarins (22.66%). Among the treatments, the lowest weight loss (2.88%) was recorded in fruits stored at 6 °C in polypropylene (PP) bags ($T_5$), while the highest weight loss (55.99%) occurred in the control group ($T_1$), where fruits were kept under ambient conditions without any treatment. The interaction effect between variety and treatment was also statistically significant. The best result was obtained from Darjeeling mandarins stored at 6 °C in PP bags ($V_1T_5$), which showed the lowest weight loss of 2.65%. In contrast, the highest weight loss (68.44%) was recorded in Darjeeling mandarins stored under control conditions ($V_1T_1$) after 26 days (Table 1). The minimal weight loss observed in treatment $T_5$ was likely due to reduced transpiration and better humidity retention within the PP packaging, contributing to slower moisture loss during cold storage (Nikson et al., 2024; Bashir et al., 2025).

**Table 1** Main effect of variety on percent weight loss at different days after storage of orange, the effect of postharvest treatment on percent weight loss at different days after storage of orange, and combined effects of variety and postharvest treatment on percent weight loss at different days after storage of orange

| **Variety** | **Initial wt. (g)** | **Percent of weight loss on different days after storage** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **4** | **7** | **10** | **13** | **16** | **19** | **22** | **26** | **32** | **39** | **47** |
| **$V_1$** | 91.28 | 6.01 | 9.20 | 12.32 | 14.48 | 17.11 | 22.15 | 26.24 | 35.30 | 56.51 | 63.76 | 72.74 |
| **$V_2$** | 37.70 | 5.37 | 8.93 | 12.15 | 14.23 | 16.30 | 18.34 | 20.50 | 22.66 | 35.43 | 59.14 | 72.54 |
| **$LSD_{0.05}$** | - | 0.61 | 0.54 | 0.63 | 0.61 | 0.76 | 0.79 | 0.83 | 2.45 | 18.66 | - | - |
| **$LSD_{0.01}$** | - | 0.82 | 0.73 | 0.85 | 0.83 | 1.03 | 1.07 | 1.12 | 3.32 | 25.28 | - | - |
| **Level of significance** | ND | * | NS | NS | NS | * | ** | ** | ** | ND | ND | ND |
| **Postharvest treatment** | **Initial wt. (g)** | **Percent weight loss on different days after storage** | | | | | | | | | | |
| | | **4** | **7** | **10** | **13** | **16** | **19** | **22** | **26** | **32** | **39** | **47** |
| **$T_1$** | 66.77 | 9.83 | 16.21 | 22.60 | 26.74 | 31.58 | 37.66 | 41.00 | 55.99 | 79.48 | - | - |
| **$T_2$** | 65.15 | 1.99 | 2.83 | 4.03 | 5.02 | 5.92 | 11.27 | 20.92 | 34.74 | 71.07 | - | - |
| **$T_3$** | 70.38 | 1.62 | 2.46 | 3.30 | 4.21 | 4.79 | 10.30 | 11.20 | 12.28 | 33.91 | 36.49 | - |
| **$T_4$** | 63.53 | 10.98 | 17.20 | 23.15 | 27.22 | 31.77 | 35.37 | 39.17 | 41.53 | 60.84 | - | - |
| **$T_5$** | 55.58 | 0.69 | 1.65 | 1.84 | 2.00 | 2.50 | 2.67 | 2.81 | 2.88 | 3.15 | 4.22 | 6.24 |
| **$T_6$** | 65.53 | 9.03 | 14.04 | 18.48 | 20.92 | 23.67 | 24.20 | 25.10 | 26.44 | 27.34 | 27.99 | 29.59 |
| **$LSD_{0.05}$** | - | 1.05 | 0.94 | 1.09 | 1.07 | 1.32 | 1.36 | 1.43 | 4.24 | 32.32 | - | - |
| **$LSD_{0.01}$** | - | 1.42 | 1.27 | 1.48 | 1.44 | 1.78 | 1.85 | 1.94 | 5.74 | 43.79 | - | - |
| **Level of significance** | ND | ** | ** | ** | ** | ** | ** | ** | ** | ND | ND | ND |
| **Treatment combination** | **Initial wt. (g)** | **Percent weight loss on different days after storage** | | | | | | | | | | |
| | | **4** | **7** | **10** | **13** | **16** | **19** | **22** | **26** | **32** | **39** | **47** |
| **$V_1T_1$** | 97.21 | 9.80 | 16.17 | 22.32 | 26.33 | 30.92 | 39.03 | 41.82 | 68.44 | - | - | - |
| **$V_1T_2$** | 91.84 | 2.00 | 3.12 | 5.04 | 6.64 | 7.78 | 16.44 | 33.01 | 55.73 | - | - | - |
| **$V_1T_3$** | 95.08 | 1.67 | 2.09 | 3.55 | 4.26 | 4.81 | 14.58 | 15.23 | 17.03 | 48.28 | 48.47 | - |
| **$V_1T_4$** | 90.92 | 11.29 | 17.26 | 23.09 | 26.90 | 31.11 | 34.41 | 37.49 | 39.28 | 58.32 | - | - |
| **$V_1T_5$** | 76.36 | 0.61 | 1.39 | 1.63 | 1.57 | 2.26 | 2.42 | 2.54 | 2.65 | 2.85 | 3.57 | 4.45 |
| **$V_1T_6$** | 96.27 | 10.66 | 15.14 | 18.28 | 21.16 | 25.75 | 25.99 | 27.36 | 28.65 | 29.59 | 30.51 | 32.00 |
| **$V_2T_1$** | 36.33 | 9.86 | 16.24 | 22.87 | 27.16 | 32.24 | 36.29 | 40.18 | 43.55 | 58.96 | - | - |
| **$V_2T_2$** | 38.47 | 1.97 | 2.54 | 3.02 | 3.39 | 4.05 | 6.09 | 8.84 | 13.76 | 42.15 | - | - |
| **$V_2T_3$** | 45.68 | 1.57 | 2.82 | 3.06 | 4.17 | 4.77 | 6.01 | 7.18 | 7.53 | 19.55 | 24.52 | - |
| **$V_2T_4$** | 36.15 | 10.66 | 17.13 | 23.20 | 27.53 | 32.42 | 36.34 | 40.85 | 43.77 | 63.36 | - | - |
| **$V_2T_5$** | 34.80 | 0.77 | 1.90 | 2.06 | 2.43 | 2.73 | 2.92 | 3.08 | 3.11 | 3.46 | 4.86 | 8.03 |
| **$V_2T_6$** | 34.78 | 7.39 | 12.93 | 18.67 | 20.69 | 21.59 | 22.41 | 22.85 | 24.23 | 25.09 | 25.47 | 27.19 |
| **$LSD_{0.05}$** | - | 1.48 | 1.33 | 1.54 | 1.51 | 1.86 | 1.93 | 2.03 | 5.99 | 45.70 | - | - |
| **$LSD_{0.01}$** | - | 2.01 | 1.80 | 2.09 | 2.04 | 2.52 | 2.61 | 2.75 | 8.12 | 61.93 | - | - |
| **Level of significance** | ND | ** | ** | ** | ** | ** | ** | ** | ** | ND | ND | ND |

values marked with double asterisks (**) are significant at the 1% level of probability, while those marked with a single asterisk (*) are significant at the 5% level; "ND" indicates that statistical analysis was not performed. $V_1$ and $V_2$ represent the Darjeeling and Chinese mandarin varieties, respectively; $T_1$ refers to the control treatment where fruits were stored under ambient conditions without packaging; $T_2$ indicates fruits sealed in polypropylene (PP) bags with a thickness of 50 µm, without punch-hole perforation, and stored at ambient conditions; $T_3$ refers to fruits sealed in 50 µm PP bags with punch-hole perforations and stored at ambient conditions; $T_4$ represents fruits treated with hot water at 50 ±1 °C for 5 min and stored at ambient conditions; $T_5$ refers to fruits stored at 6 °C in PP bags (50 µm), and $T_6$ represents fruits stored at 6 °C without PP bags

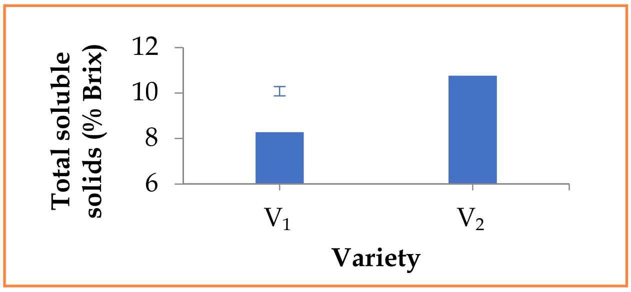


**Figure 1** Main effect of variety on total soluble solids (TSS) of orange
the vertical bar indicates LSD at 1% level of probability; $V_1$ – Darjeeling orange, $V_2$ – Chinese orange

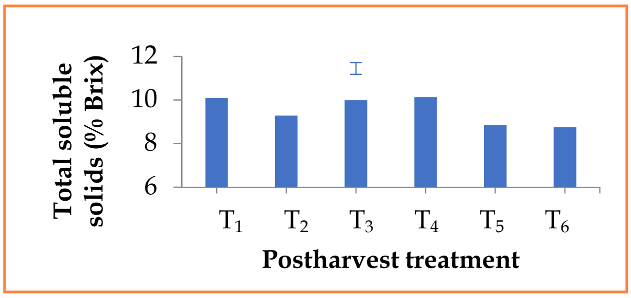


**Figure 2** Main effect of postharvest treatment on total soluble solids (TSS) of orange
the vertical bar indicates LSD at 1% level of probability; $T_1$ – control, $T_2$ – orange sealed in PP bag (50 µm) without punch-hole perforation and held at ambient condition, $T_3$ – orange sealed in PP bag (50 µm with punch-hole perforation and held at ambient condition, $T_4$ – orange treated with hot water at 50 ±1 °C for 5 min and held at ambient condition, $T_5$ – orange held at 6 °C temperature with PP bag (50 µm), $T_6$ – orange held at 6 °C temperature without PP bag (50 µm)

### 3.2 *Total Soluble Sugar (TSS)*

The combined effects of variety and postharvest treatments significantly influenced the total soluble solids (TSS) content of mandarin oranges. The highest TSS (11.66% Brix) was recorded in Chinese mandarins ($V_2$) stored in non-perforated polypropylene (PP) bags (50 µm) at ambient conditions ($T_2$), whereas the lowest TSS (6.90% Brix) was observed in Darjeeling mandarins ($V_1$) under the same treatment (Fig. 1). On the 36$^{th}$ day of storage, the TSS values of Darjeeling and Chinese mandarins were 8.28% and 10.76% Brix, respectively, highlighting varietal differences in sugar accumulation. Postharvest treatments also had a significant effect on TSS development. The lowest TSS (8.75% Brix) was found in fruits stored at 6 °C without PP bags ($T_6$), indicating slower ripening due to cold exposure. In contrast, the highest TSS among treatments (10.13% Brix) was recorded in oranges treated with hot water at 50 ±1 °C for 5 min and stored at ambient temperature ($T_4$) (Fig. 2). The increased TSS in $T_4$ may be attributed to heat-induced enzymatic activity accelerating polysaccharide hydrolysis. Similarly, the elevated TSS in Chinese mandarins under treatment $T_2$ ($V_2T_2$) was likely due to enhanced sugar accumulation and faster metabolic activity during storage. In contrast, the significantly lower TSS in $V_1T_2$ (6.90% Brix) may be explained by varietal limitations in sugar synthesis. These trends align with the findings of El-Beltagi et al. (2023), who reported that temperature and packaging conditions influence sugar concentration in citrus fruits (Fig. 3).

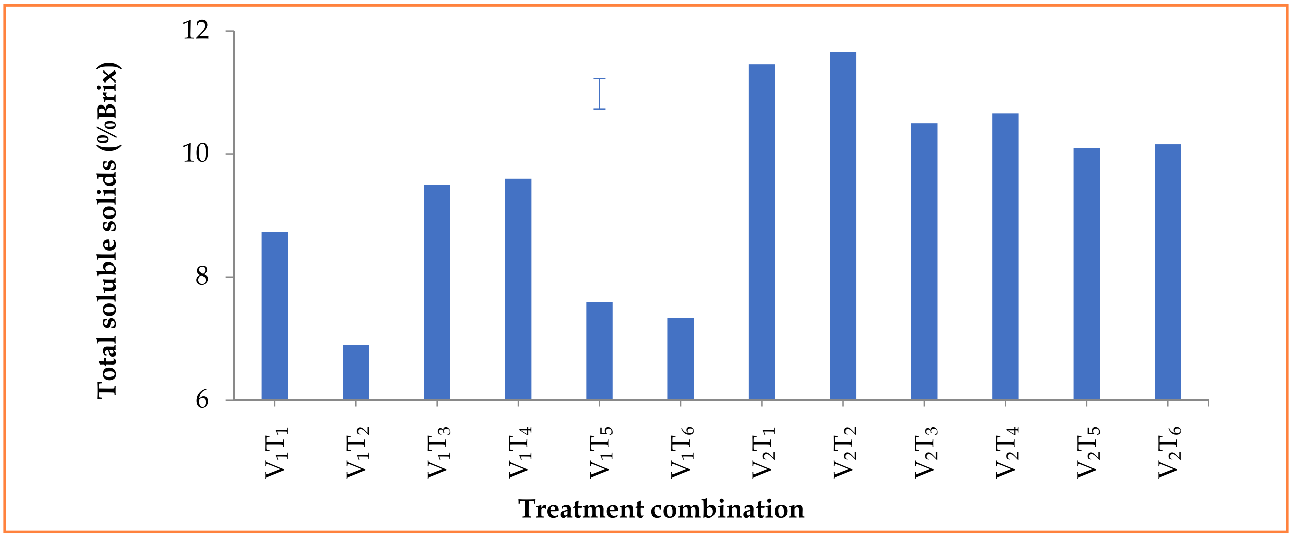


**Figure 3** Combined effects of variety and postharvest treatments on total soluble solids (TSS) of orange
the vertical bar indicates LSD at 1% level of probability; $V_1$ – Darjeeling orange, $V_2$ – Chinese orange and $T_1$ – control, $T_2$ – orange sealed in PP bag (50 µm) without punch-hole perforation and held at ambient condition, $T_3$ – orange sealed in PP bag (50 µm with punch-hole perforation and held at ambient condition, $T_4$ – orange treated with hot water at 50 ±1 °C for 5 min and held at ambient condition, $T_5$ – orange held at 6 °C temperature with PP bag (50 µm), $T_6$ – orange held at 6 °C temperature without PP bag (50 µm)

**Table 2** Main effect of variety on vitamin C at different days after storage of orange, effect of postharvest treatment on vitamin C at different days after storage of orange and combined effects of variety and postharvest treatment on vitamin C at different days after storage of orange

| **Variety** | **Vitamin C (mg.100 g$^{-1}$) at different days after storage** | | **Percent of decrease** |
|---|---|---|---|
| | **initial (1st day)** | **36 days** | |
| **$V_1$** | 40.30 | 11.79 | 71.72 |
| **$V_2$** | 41.70 | 11.05 | 73.71 |
| **$LSD_{0.05}$** | - | 0.09 | 0.19 |
| **$LSD_{0.01}$** | - | 0.12 | 0.26 |
| **Level of significance** | ND | ** | ** |
| **Postharvest treatment** | **Vitamin C (mg.100 g$^{-1}$) at different days after storage** | | **Percent of decrease** |
| | **initial (1st day)** | **36 days** | |
| **$T_1$** | 41.00 | 10.07 | 75.42 |
| **$T_2$** | 41.00 | 10.58 | 77.26 |
| **$T_3$** | 41.00 | 11.04 | 73.07 |
| **$T_4$** | 41.00 | 8.755 | 78.61 |
| **$T_5$** | 41.00 | 15.29 | 62.62 |
| **$T_6$** | 41.00 | 12.81 | 69.29 |
| **$LSD_{0.05}$** | - | 0.16 | 0.33 |
| **$LSD_{0.01}$** | - | 0.21 | 0.46 |
| **Level of significance** | ND | ** | ** |
| **Treatment combination** | **Vitamin C (mg.100 g$^{-1}$) at different days after storage** | | **Percent of decrease** |
| | **initial (1st day)** | **36 days** | |
| **$T_1V_1$** | 40.30 | 10.20 | 74.68 |
| **$T_2V_1$** | 40.30 | 10.64 | 79.59 |
| **$T_3V_1$** | 40.30 | 10.61 | 73.67 |
| **$T_4V_1$** | 40.30 | 9.243 | 77.06 |
| **$T_5V_1$** | 40.30 | 16.80 | 58.31 |
| **$T_6V_1$** | 40.30 | 13.30 | 66.99 |
| **$T_1V_2$** | 41.70 | 9.940 | 76.16 |
| **$T_2V_2$** | 41.70 | 10.53 | 74.74 |
| **$T_3V_2$** | 41.70 | 11.48 | 72.47 |
| **$T_4V_2$** | 41.70 | 8.267 | 80.17 |
| **$T_5V_2$** | 41.70 | 13.79 | 66.93 |
| **$T_6V_2$** | 41.70 | 12.33 | 71.53 |
| **$LSD_{0.05}$** | - | 0.22 | 0.46 |
| **$LSD_{0.01}$** | - | 0.30 | 0.63 |
| **Level of significance** | ND | ** | ** |

** – significant at 1% level of probability, * – significant at 1% level of probability, ND – statistical analysis not done; $V_1$ – Darjeeling, $V_2$ – Chinese and $T_1$ – control, $T_2$ – orange sealed in PP bag (50 µm) without punch-hole perforation and held at ambient condition, $T_3$ – orange sealed in PP bag (50 µm) with punch-hole perforation and held at ambient condition, $T_4$ – orange treated with hot water at 50 ±1 °C for 5 min and held at ambient condition, $T_5$ – orange held at 6 °C temperature with PP bag (50 µm), $T_6$ – orange held at 6 °C temperature without PP bag (50 µm)

### 3.3 *Vitamin C*

Oranges are a rich source of vitamin C, with significant variation observed among varieties by the 36th day of storage. Darjeeling oranges had 11.79 mg.100 g$^{-1}$ of vitamin C, while Chinese oranges had 11.05 mg.100 g$^{-1}$, the latter showing the highest decrease (73.71%) during storage. Postharvest treatments significantly affected vitamin C content. The lowest vitamin C concentration (8.75 mg.100 g$^{-1}$) was found in oranges treated with hot water at 50 ±1 °C for 5 min and stored under ambient conditions ($T_4$). The highest content (15.29 mg.100 g$^{-1}$) was noted in oranges wrapped in PP bags and stored at 6 °C. The most considerable percentage decrease (78.61%) occurred under $T_4$ treatment. The combined effects of variety and treatment were highly significant. Darjeeling oranges ($V_1$) stored in PP bags at 6 °C ($T_5$) exhibited the highest vitamin C content (16.80 mg.100 g$^{-1}$). Conversely, Chinese oranges ($V_2$) treated with hot water at 50 ±1 °C for 5 min and stored under ambient conditions ($T_4$) recorded the lowest vitamin C level (8.267 mg.100 g$^{-1}$) (Table 2). Darjeeling oranges stored in PP bags at 6 °C ($V_1T_5$) retained the highest vitamin C content (16.80 mg.100 g$^{-1}$), as cold storage slows down oxidation and enzymatic degradation. The greatest loss (78.61%) occurred in hot water-treated oranges at ambient temperature ($T_4$) due to oxidative damage (Pradhan & Srijaya., 2023; Howlader et al., 2024b).

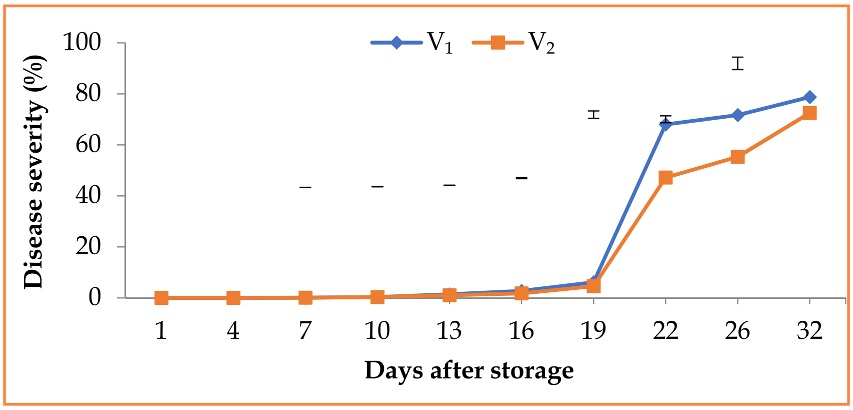


**Figure 4** Main effect of variety on percent disease severity at different days after storage of orange
the vertical bars indicate LSD at 1% level of probability; $V_1$ – Darjeeling orange, $V_2$ – Chinese orange

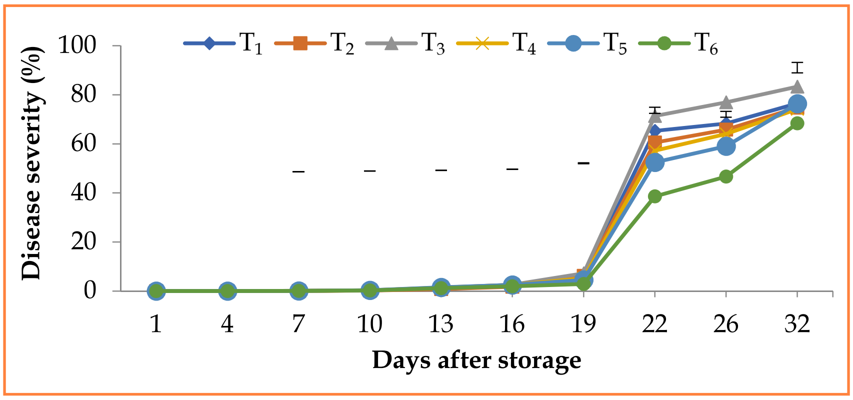


**Figure 5** Main effect of postharvest treatment on percent disease severity at different days after storage of orange
the vertical bars indicate LSD at 1% level of probability; T1 – control, $T_2$ – orange sealed in PP bag (50 µm) without punch-hole perforation and held at ambient condition, $T_3$ – orange sealed in PP bag (50 µm) with punch-hole perforation and held at ambient condition, $T_4$ – orange treated with hot water at 50 ±1 °C for 5 min and held at ambient condition, $T_5$ – orange held at 6 °C temperature with PP bag (50 µm), $T_6$ – orange held at 6 °C temperature without PP bag (50 µm)

### 3.4 *Disease Incident*

Disease incidence in orange fruit is significantly influenced by temperature and humidity during storage. By the 32nd day, disease incidence reached 49.87% and 56.48% in Chinese oranges. Postharvest treatments significantly impacted disease incidence. At 32 days, the highest incidence (90.67%) occurred in oranges sealed in PP bags with punch-hole perforation and stored under ambient conditions ($T_3$), while no disease (0%) was observed in oranges wrapped in PP bags and stored at 6 °C (Fig. 4). The combined effects of varieties and treatments were also significant. The highest disease incidence (94.44%) was recorded for Chinese oranges ($V_2$) sealed in PP bags with punch-hole perforation and stored under ambient conditions ($T_3$). In contrast, no disease (0%) was found in both Darjeeling ($V_1$) and Chinese ($V_2$) oranges stored at 6 °C without PP bags ($T_6$) (Fig. 5). Fruits stored at 6 °C ($T_5$ and $T_6$) exhibited no disease incidence (0%), as refrigeration inhibits fungal and microbial activity (Budiarto et al., 2024; Mia et al., 2025). The highest incidence (94.44%) was in Chinese oranges ($V_2T_3$) at ambient temperature, highlighting the importance of cold storage.

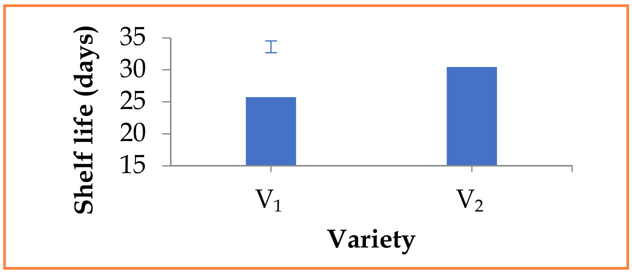


**Figure 6** Main effect of variety on shelf life (days) of orange
the vertical bar indicates LSD at 1% level of probability; $V_1$ – Darjeeling orange, $V_2$ – Chinese orange

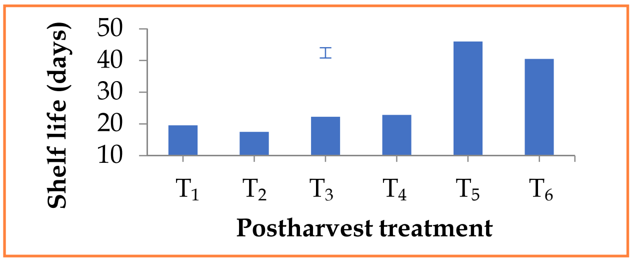


**Figure 7** Main effect of postharvest treatment on shelf life (days) of orange
the vertical bar indicates LSD at 1% level of probability; $T_1$ – control, $T_2$ – orange sealed in PP bag (50 µm) without punch-hole perforation and held at ambient condition, $T_3$ – orange sealed in PP bag (50 µm with punch-hole perforation and held at ambient condition, $T_4$ – orange treated with hot water at 50 ±1 °C for 5 min and held at ambient condition, $T_5$ – orange held at 6 °C temperature with PP bag (50 µm), $T_6$ – orange held at 6 °C temperature without PP bag (50 µm)

### *3.5 Shelf Life*

The shelf life of oranges varied significantly by variety. Darjeeling oranges had a shelf life of 25.75 days, while Chinese oranges lasted 30.46 days (Fig. 6). Postharvest treatments had a highly significant effect on shelf life. The shortest shelf life (17.50 days) was observed in oranges sealed in PP bags without punch-hole perforation and stored under ambient conditions ($T_2$). The longest shelf life (46.00 days) occurred in oranges wrapped in PP bags and stored at 6 °C (Fig. 7). The combined effects of varieties and postharvest treatments were also highly significant. Darjeeling oranges ($V_1$) sealed in PP bags without punch-hole perforation and stored under ambient conditions had the shortest shelf life (12.00 days). The longest shelf life (47.00 days) was noted in Chinese oranges ($V_2$) wrapped in PP bags and stored at 6 °C ($V_2T_5$) (Fig. 8). Chinese oranges stored at 6 °C in PP bags ($V_2T_5$) achieved the longest shelf life (47 days) due to reduced respiration and microbial growth (Howlader et al., 2024c), while Darjeeling oranges in non-perforated bags ($V_1T_2$) spoiled the fastest (12 days) due to limited gas exchange (Gupta et al., 2022; Yesmin et al., 2023).

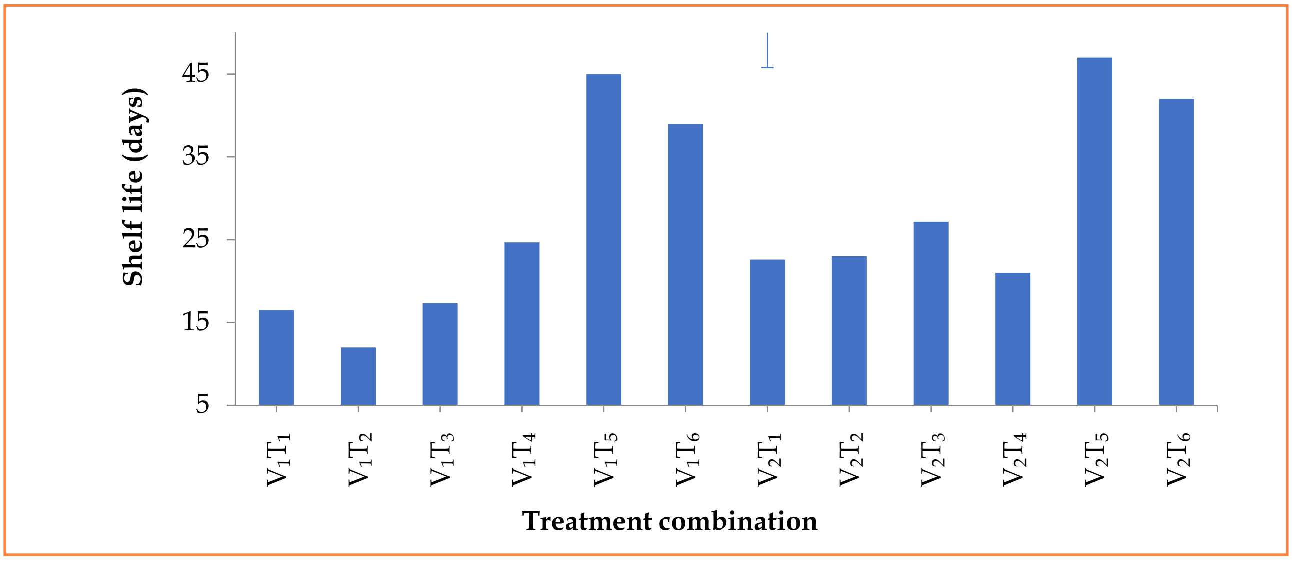


**Figure 8** Combined effects of variety and postharvest treatment on shelf life of orange
the vertical bar indicates LSD at 1% level of probability; $V_1$ – Darjeeling orange, $V_2$ – Chinese orange, $T_1$ – control, $T_2$ – orange sealed in PP bag (50 µm) without punch-hole perforation and held at ambient condition, $T_3$ – orange sealed in PP bag (50 µm) with punch-hole perforation and held at ambient condition, $T_4$ – orange treated with hot water at 50 ±1 °C for 5 min and held at ambient condition, $T_5$ – orange held at 6 °C temperature with PP bag (50 µm), $T_6$ – orange held at 6 °C temperature without PP bag (50 µm)

## 4 Conclusion

Oranges are highly nutritious, but postharvest losses are a major issue, particularly in developing countries, where around 25% of production is lost annually due to improper handling and overripening. Modern postharvest technologies, such as modified atmospheric packaging, controlled atmosphere storage, and cold storage, can help reduce losses by preventing disease and weight loss while improving fruit quality. This experiment identified effective methods to extend shelf life, with oranges stored at 6 °C in a 50 µm PP bag showing significant improvements. Darjeeling oranges at ambient temperature had a shelf life of 12 days, while Chinese oranges in the same PP bag at 6 °C lasted up to 47 days. The lowest weight loss (2.65%), Vitamin C decrease (58.31%), and disease incidence (0%) were observed in oranges stored in PP bags at 6 °C. Further research is recommended to explore the impact of postharvest treatments on fruit quality and shelf life.

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