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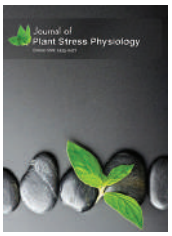
Research Article



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Assessment of different storage methods on postharvest quality and shelf life of Darjeeling and Chinese mandarins (*Citrus reticulata* L.)

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ABSTRACT

Oranges are highly susceptible to postharvest losses due to improper handling and unsuitable storage practices. To address this problem, an experiment was conducted in December 2023 at the Postgraduate Laboratory, Department of Horticulture, Bangladesh Agricultural University, Mymensingh, with the objective of identifying effective methods to extend shelf life and reduce postharvest losses. The study followed a completely randomized design (CRD) with three replications, using two orange varieties: Darjeeling mandarin (V1) and Chinese mandarin (V2). Six treatments were applied: T1 (control), T2 (sealed in 50 μ PP bag without perforation), T3 (sealed in 50 μ PP bag with perforation), T4 (hot water treatment at 50 ± 1 °C for 5 minutes), T5 (sealed in 50 μ PP bag and stored at 6 °C), and T6 (stored at 6 °C without PP bag). The shortest shelf life (12 days) was recorded in Darjeeling mandarins stored in non-perforated PP bags under ambient conditions, while the longest shelf life (47 days) was observed in Chinese mandarins stored in PP bags at 6 °C. This treatment also ensured superior fruit quality in terms of color, firmness, flavor, texture, appearance, minimal shrinkage, and disease-free condition up to 32 days. Furthermore, the lowest weight loss (2.88% at 26 days) and minimal Vitamin C degradation (58.31% at 36 days) were also obtained under this treatment. In contrast, the highest weight loss (68.44%) occurred in fruits stored at 6 °C without PP bags, while the greatest Vitamin C loss (80.17%) was found in hot water–treated fruits stored at ambient conditions. The maximum TSS content (11.66%) was recorded in fruits stored at 6 °C without PP bags, whereas the lowest (6.90%) was observed in fruits sealed in non-perforated PP bags at ambient conditions. In conclusion, packaging mandarins in 50 μ PP bags and storing them at 6 °C proved to be the most effective method for prolonging shelf life and maintaining postharvest quality.

KEYWORDS: Postharvest losses, Orange shelf life, Storage conditions, Physio-chemical changes, PP bag packaging

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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 hectares, producing 3,616.43 metric tons. 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 (Shehata *et al.*, 2020; Dhiman *et al.*, 2022).

Orange trees are evergreen, flowering plants that typically grow to a height of 9-10 meters, with some older specimens reaching 15 meters. Their oval leaves are alternately arranged, measuring

4-10 cm long, with crenulated edges (Gao *et al.*, 2019; Jentzsch *et al.*, 2021). 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 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 (Khedr *et al.*, 2019).

Oranges are highly nutritious, consisting of 87% water, 12% carbohydrates, and 1% protein, with negligible fat. A 100-gram portion provides 47 calories and 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 calories. Widely used in making jam, jelly, juice, and squash, their peel is also valued in perfume production. A single tree produces 300-400 fruits, averaging 190 grams each (Rokaya *et al.*, 2016). 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 grams, far below the recommended 100 grams, highlighting oranges' potential to address this gap (Baltazari *et al.*, 2020). 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.

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 (Strano *et al.*, 2022; Zhang *et al.*, 2022). Poor sanitation and handling further exacerbate issues, encouraging fungal infections like those from Penicillium species, resulting in decay and reduced marketable yield (Matsuzaki *et al.*, 2022). 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 (Magalhães *et al.*, 2019). 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.

MATERIALS AND METHODOLOGY

Experimental Site and Design

The experiment on the effects of maturity stage and postharvest treatments on the shelf life and quality of mandarin oranges. The study was conducted in December 2023 at the Postharvest Laboratories, Department of Horticulture, Bangladesh Agricultural University (BAU), Mymensingh. Daily temperature and relative humidity were recorded using a digital thermos-hygrometer (THERMO, TFA, Germany). Temperatures ranged from 25.1 °C to 26.1 °C, and relative humidity varied between 79% and 84%. Freshly harvested oranges of uniform size and shape, free from visible defects, were collected from "Mrs. Ma-Babar Doya" Fruit Garden, Sherpur, and transported to the laboratory in corrugated fiber cartons with careful handling to avoid damage (Figure 1).

The experiment comprised two factors, with three fruits used per replication. Of these, two were allocated for nondestructive analysis, while one was designated for destructive testing. Factor A involved two varieties: Darjeeling Mandarin Orange (V1) and Chinese Mandarin Orange (V2). Factor B included six treatments: control (T1), oranges sealed in a polypropylene (PP) bag (50 µ) without perforation and stored at ambient conditions (T2), oranges sealed in a PP bag (50 µ) with punch-hole perforations and stored at ambient conditions (T3), oranges treated with hot water at 50±1 °C for 5 minutes and stored at ambient conditions (T4), oranges stored at 6 °C in a PP bag (50 µ) (T5), and oranges stored at 6 °C without a PP bag (50 µ) (T6). The two-factor experiment was conducted using a completely randomized design with three replications. Of the three fruits per replication, two were allocated for nondestructive analysis to evaluate fruit quality and shelf life, while the third fruit was used for destructive sampling.

Application of Treatments

The experiment involved six treatment methods, each using three randomly selected fruits from the experimental lot. Fruits were placed on a laboratory table at ambient conditions without any treatment. Fruits were individually sealed in unperforated plastic bags (50 µ) and stored on the laboratory table under ambient conditions. Fruits were individually sealed in perforated plastic bags (50 µ) and stored similarly under ambient conditions. Fruits were treated with hot water at 50 °C for 5 minutes using a Hot Water Bath (Model No. GFL) and then stored in ambient conditions. Fruits were sealed in unperforated polypropylene bags (50 µ) and stored at 6 °C in a refrigerator. Fruits were stored at 6 °C without being sealed in polypropylene bags for observation (Figure 2).

Collecting Data

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.

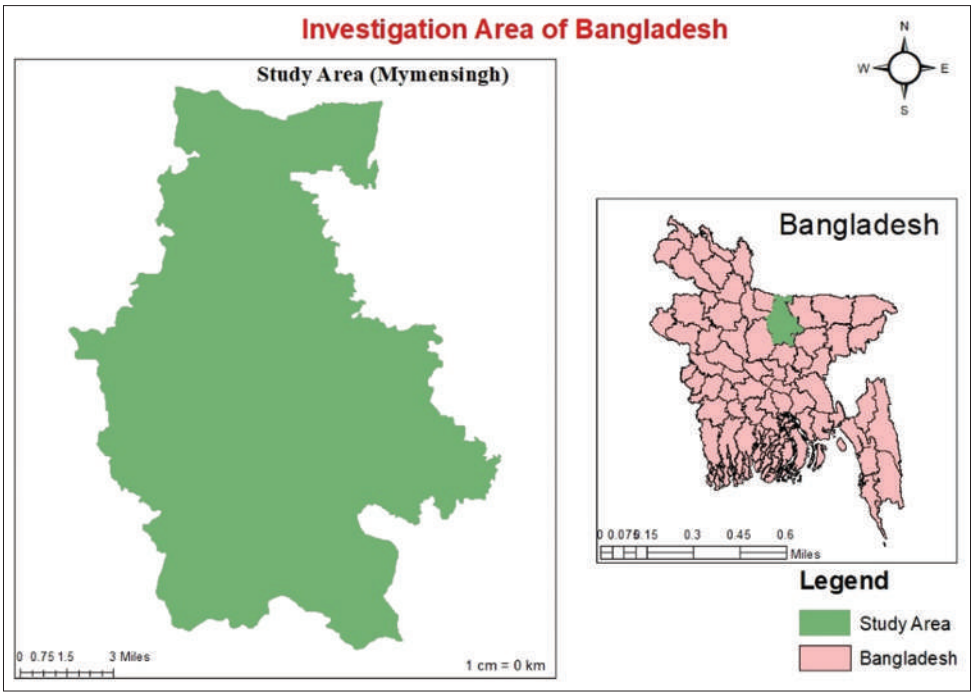

Figure 1: Study area where the investigation was conducted

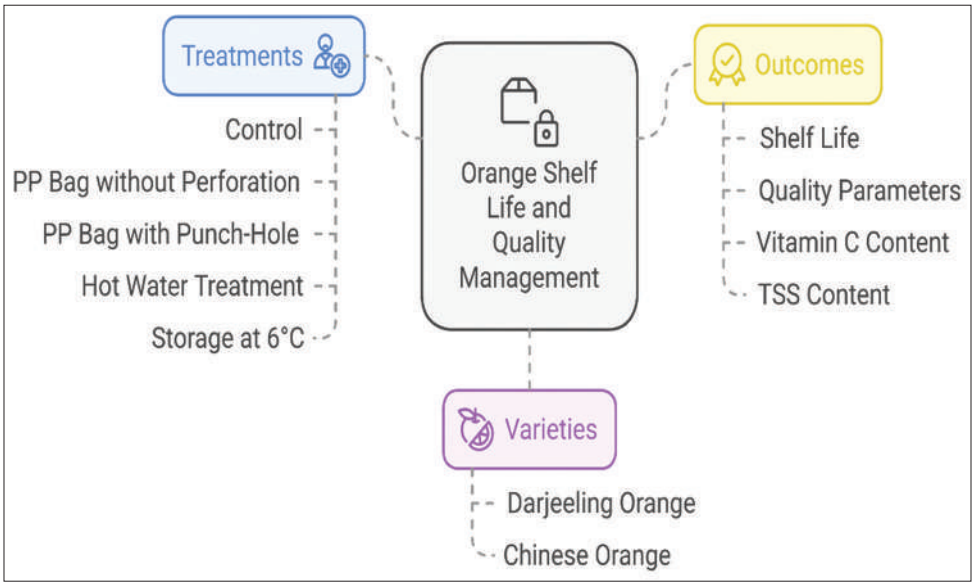

Figure 2: The experimental procedure followed in this research is outlined

The visual quality of fruits serves as an external indicator of their condition. The time required to reach various stages of visual quality during storage was assessed using an objective numerical rating scale ranging from 1 to 4 for oranges, where 1 indicates "Excellent," 2 signifies "Good," 3 represents "Fair," and 4 corresponds to "Poor" (Zhang *et al*., 2019). The color changes in oranges were evaluated using a numerical scale ranging from 1 to 6, where 1 corresponds to "Green," 2 to "Breaker," 3 to "<25% orange," 4 to "25% to <50% orange," 5 to "50% to <75% orange," and 6 to "75% to 100% orange." Firmness of orange was determined by hand feeling using a numerical rating scale of 1-4. Where, 1=Firm, 2=Sprung, 3=Soft, 4=Over ripe. Days required to reach different stages of freshness during storage were determined objectively using Likert scale of 1 to 4 for orange, where 1=Excellent, 2=Good, 3=Fair, 4=Poor Shrinkage was recorded at the different days (1-12) after treatments visual rating scale 1-4 (1=No shrinkage, 2=Slight shrinkage, 3=Moderate shrinkage, 4=Shrinkage). Days required to reach different stages of flavour during storage were determined objectively using a numerical rating scale of 1 to 4 for orange, where 1=Excellent, 2=Good, 3=Fair, 4=Poor. Three oranges of each replication of each treatment were weighed initially and held under different

postharvest treatments for data collection. Weight loss was calculated using the following formula (Fatima *et al.*, 2024; Hasan *et al.*, 2025).

$$\text{Percent weight loss (\%WL)} = \frac{IW - FW}{IW} \text{ x100}$$

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. The vitamin C was determined by following formula (Howlader *et al.*, 2023).

$$\text{Ascorbic Acid (mg/100 gm)} = \frac{\text{Titre(mL)} \times \text{dye factor} \times \text{volume made up(100 mL)} \times 100}{\text{Aliquot used for estimation(10 mL)} \times \text{sample weight(10 g)}}$$

Disease's incidence means percentage of fruits infected with disease. This is measured by calculating the percentage of fruits infected. The diseased fruits were identified symptomatically. The disease incidence was calculated as follows (Fatima *et al.*, 2024; Laboni *et al.*, 2024).

$$\text{Disease incidence (\%)} = \frac{\text{Number of infected fruits in each replication}}{\text{Total number of fruits in each replication}} \times 100$$

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 percent fruit area infected, and was measured based on eye estimation.

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.

Statistical Analysis

The data collected were 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.

RESULTS

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.

Appearance

Significant variations in orange appearance were observed based on variety and postharvest treatments. At 32 days of storage, Darjeeling and Chinese oranges scored 2.39 and 2.17, respectively (Table 1). Postharvest treatments significantly influenced appearance retention, with the best score (1.25) in oranges wrapped in PP bags and stored at 6 °C (T5), while the poorest (3.50) was in the control group (T1) (Table 2). Combined effects of variety and treatment were also significant, with the best appearance (score 1.50) in PP-wrapped oranges stored at 6 °C (V1T5 and V2T5), and poorer scores (3.00) for several other treatment combinations (Table 3).

Colour

Fruit color is a critical indicator of freshness. Significant variations in orange color were observed due to varietal differences. On the 32nd day of storage, the color scores for Darjeeling and Chinese oranges were 2.83 and 4.53, respectively (Table 4). Postharvest treatments significantly influenced color retention. The best color (score 2.76) was found in oranges stored at 6 °C without PP bags (T6), while the poorest color (score 4.90) occurred in the control condition (T1) on the 32nd day (Table 5). The interaction between varieties and treatments was also significant. Chinese oranges (V2) retained the best color, with the highest score (5.00) observed in those wrapped in PP bags and stored at 6 °C (V2T5), comparable to V2T2, V2T3, V2T4, and V2T1. Conversely, the poorest appearance was noted for Chinese oranges stored at 6 °C with PP bags by the 32nd day (Table 6).

Firmness

During the storage period, significant changes in firmness were observed among orange varieties. The main effect of variety

Table 1: Main effect of variety on appearance at different days after storage of orange

Variety	Appearance[a] at different days after storage (DAS)											
	1	4	7	10	13	16	19	22	26	32	39	47
V_1	1.00	1.00	1.72	1.75	1.81	1.83	1.97	2.06	2.28	2.39	2.42	3.00
V_2	1.00	1.00	1.33	1.33	1.33	1.56	1.64	2.08	2.09	2.17	2.30	3.00
$LSD_{0.05}$	-	-	0.06	0.13	0.13	0.16	0.17	0.08	0.21	0.22	-	-
$LSD_{0.01}$	-	-	0.08	0.17	0.17	0.22	0.23	0.11	0.29	0.30	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; V_1 = Darjeeling orange; V_2 = Chinese orange; [a] = Appearance scale: 1 = Excellent, 2 = Good, 3 = Fair, 4 = Poor

Table 2: Main effect of postharvest treatment on appearance at different days after storage of orange

Postharvest treatment	Appearance[a] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
T_1	1.00	1.00	2.00	2.08	2.17	2.25	2.50	3.00	3.00	3.50	-	-
T_2	1.00	1.00	1.50	1.50	1.50	2.00	2.50	2.50	2.75	3.00	-	-
T_3	1.00	1.00	1.50	1.50	1.58	1.83	1.88	1.95	2.00	2.38	2.83	-
T_4	1.00	1.00	2.00	2.00	2.00	2.17	2.37	2.50	3.00	3.10	-	-
T_5	1.00	1.00	1.00	1.00	1.00	1.08	1.12	1.17	1.25	1.25	2.00	3.00
T_6	1.00	1.00	1.17	1.17	1.67	2.00	2.00	2.00	2.00	2.00	2.50	3.00
$LSD_{0.05}$	-	-	0.10	0.22	0.22	0.28	0.30	0.14	0.37	0.38	-	-
$LSD_{0.01}$	-	-	0.13	0.30	0.30	0.38	0.40	0.19	0.50	0.52	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; T_1 = Control, T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ); [a] = Appearance scale: 1 = Excellent, 2 = Good, 3 = Fair, 4 = Poor

Table 3: Combined effects of variety and postharvest treatment on appearance at different days after storage of orange

Treatment combination	Appearance[a] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	32	47
V_1T_1	1.00	1.00	2.00	2.17	2.33	2.50	3.00	3.00	3.00	3.00	-	-
V_1T_2	1.00	1.00	2.00	2.00	2.00	2.00	2.50	3.00	3.00	3.00	-	-
V_1T_3	1.00	1.00	2.00	2.00	2.17	2.50	1.00	1.33	2.67	1.67	1.67	-
V_1T_4	1.00	1.00	2.00	2.00	2.00	2.50	2.50	2.60	3.00	3.00	-	-
V_1T_5	1.00	1.00	1.00	1.00	1.00	1.00	1.27	1.30	1.43	1.50	2.00	3.00
V_1T_6	1.00	1.00	1.33	1.33	1.33	2.00	2.10	2.30	2.30	2.50	3.00	3.00
V_2T_1	1.00	1.00	2.00	2.00	2.00	2.00	2.00	3.00	3.00	3.00	-	-
V_2T_2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	2.50	3.00	-	-
V_2T_3	1.00	1.00	1.00	1.00	0.00	1.17	1.17	1.17	1.33	1.50	2.00	-
V_2T_4	1.00	1.00	2.00	2.00	2.00	2.00	2.33	3.00	3.00	3.00	-	-
V_2T_5	1.00	1.00	1.00	1.00	1.00	1.17	1.33	1.33	1.50	1.50	2.00	3.00
V_2T_6	1.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	3.00
$LSD_{0.05}$	-	-	0.14	0.31	0.31	0.40	0.42	0.20	0.53	0.54	-	-
$LSD_{0.01}$	-	-	0.19	0.43	0.43	0.54	0.57	0.27	0.71	0.74	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	**	ND	ND

**=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 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ); [a] = Appearance scale: 1 = Excellent, 2 = Good, 3 = Fair, 4 = Poor

significantly influenced firmness, with Darjeeling and Chinese varieties recording firmness scores of 2.63 and 1.91, respectively, on the 32nd day of storage (Table 7). Postharvest treatments also significantly impacted firmness. The lowest firmness score (1.39) was observed in oranges wrapped in polypropylene (PP) bags and stored at 6 °C (T5), while the highest score (3.00) was found in oranges treated with hot water at 50±1 °C for 5 minutes and stored at ambient conditions (T4) on the 32nd day (Table 8).

The interaction between variety and postharvest treatments was significant. The best firmness result (1.00) was achieved with Chinese oranges wrapped in PP bags and stored at 6 °C (V1T5), comparable to treatments V2T5 and V2T6. In contrast, the lowest firmness (3.00) was recorded under control conditions (V1T1) on the 32nd day (Table 9).

Freshness

Significant differences in orange freshness were observed during storage, influenced by the varieties used. At 32 days of storage, the Darjeeling variety had a freshness score of 2.53, while the Chinese variety scored 2.06 (Table 10). Postharvest treatments also significantly impacted freshness. The lowest freshness score (1.56) was recorded in oranges stored at 6 °C in PP bags (T5), while the highest score (3.00) was observed in oranges treated with hot water (50±1 °C for 5 minutes) and stored at ambient conditions (T4) (Table 11). Combined effects of variety and postharvest treatments were also significant. The best freshness (score 1.50) was seen in Chinese oranges stored in PP bags at 6 °C (V2T5), while the highest freshness scores (3.00) were recorded for Darjeeling oranges under control or hot water treatments (V1T1, V1T2, V1T4, V2T4) at 32 days (Table 12).

Flavour

Significant variation in orange flavor was observed during storage, influenced by variety. At 32 days, the flavor scores were 1.52 for Darjeeling oranges and 2.06 for Chinese oranges (Table 13). Postharvest treatments also had a significant effect on flavor changes. The lowest flavor change score (1.00) was

Table 4: Main effect of variety on color at different days after storage of orange

Variety	Color[b] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
V_1	1.00	2.39	2.48	2.52	2.52	2.59	2.65	2.68	2.75	2.83	2.97	3.00
V_2	3.00	3.33	3.33	3.69	4.00	4.14	4.26	4.36	4.39	4.53	4.83	5.00
$LSD_{0.05}$	-	0.28	0.24	0.41	0.39	0.43	0.35	0.30	0.31	0.14	-	-
$LSD_{0.01}$	-	0.38	0.33	0.56	0.53	0.58	0.48	0.41	0.42	0.19	-	-
Level of significance	ND	**	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; V_1 = Darjeeling orange; V_2 = Chinese orange; [b] = Colour scale: 1 = Green, 2 = Breaker, 3=<25% orange, 4 = 25 to < 50% orange, 5 = 50 to < 75% orange, and 6 = 75-100% orange

Table 5: Main effect of postharvest treatment on color at different days after storage of orange

Postharvest treatment	Color[b] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
T_1	2.00	3.58	3.58	4.25	4.25	4.42	4.67	4.76	4.81	4.90	-	-
T_2	2.00	2.50	2.58	3.25	3.58	3.58	4.00	4.00	4.00	4.67	-	-
T_3	2.00	2.92	3.00	3.22	3.34	3.43	3.52	3.58	3.67	3.67	3.67	-
T_4	2.00	3.17	3.33	3.33	3.92	4.08	4.33	4.42	4.67	4.76	-	-
T_5	2.00	2.50	2.50	2.50	2.83	2.83	3.00	3.10	3.42	4.00	4.00	4.00
T_6	2.00	2.50	2.50	2.50	2.50	2.50	2.25	2.35	2.35	2.76	2.76	2.76
$LSD_{0.05}$	-	0.49	0.42	0.72	0.67	0.74	0.61	0.53	0.53	0.24	-	-
$LSD_{0.01}$	-	0.66	0.57	0.97	0.91	1.00	0.83	0.71	0.72	0.33	-	-
Level of significance	ND	**	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; T_1 = control; T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ). [b] = Colour scale: =Green, 2 = Breaker, 3=<25% orange, 4 = 25 to < 50% orange, 5 = 50 to < 75% orange, and 6 = 75-100% orange

Table 6: Combined effects of variety and postharvest treatment on color at different days after storage of orange

Treatment combination	Color[b] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
V_1T_1	1.00	3.17	3.17	3.50	3.50	3.83	4.00	4.17	4.17	4.67	-	-
V_1T_2	1.00	2.00	2.17	2.87	3.00	3.16	3.29	3.30	3.43	3.90	-	-
V_1T_3	1.00	2.83	3.00	3.13	3.24	2.36	3.53	3.53	3.65	3.83	3.83	-
V_1T_4	1.00	2.33	2.67	2.67	3.00	3.33	3.67	3.83	4.33	4.40	-	-
V_1T_5	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.33	2.83	3.00	3.00	3.00
V_1T_6	1.00	2.00	2.00	2.00	2.00	2.00	2.33	2.33	2.67	3.00	3.00	3.00
V_2T_1	3.00	4.00	4.00	4.25	4.25	4.50	4.50	5.00	5.00	5.00	-	-
V_2T_2	3.00	3.00	3.00	3.17	3.50	4.33	4.50	5.00	5.00	5.00	-	-
V_2T_3	3.00	3.00	3.00	4.00	4.00	4.00	4.00	4.17	4.33	5.00	5.00	-
V_2T_4	3.00	4.00	4.00	4.00	4.83	4.83	5.00	5.00	5.00	5.00	-	-
V_2T_5	3.00	3.00	3.00	3.00	3.67	3.67	4.00	4.00	4.00	5.00	5.00	5.00
V_2T_6	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
$LSD_{0.05}$	-	0.69	0.60	1.01	0.95	1.04	0.86	0.74	0.75	0.34	-	-
$LSD_{0.01}$	-	0.93	0.81	1.37	1.29	1.41	1.17	1.01	1.02	0.47	-	-
Level of significance	ND	**	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; V_1 = Darjeeling orange; V_2 = Chinese orange and T_1 = control; T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ); [b] = Colour scale: 1 = Green, 2 = Breaker, 3=<25% orange, 4 = 25 to < 50% orange, 5 = 50 to < 75% orange, and 6 = 75-100% orange

recorded in oranges stored at 6 °C in PP bags (T5), while the highest score (2.50) was observed under control conditions (T1) (Table 14). The combined effects of variety and treatments were significant. The best results, with the lowest flavor change score (1.00), were seen in both Darjeeling and Chinese oranges stored in PP bags at 6 °C (V1T5, V2T5). In contrast, the highest flavor change score (3.00) was recorded in V2T6, V1T1, and V2T1 at 32 days (Table 15).

Weight loss

Significant variation in orange weight loss was observed during storage, influenced by variety. At 26 days, Darjeeling oranges showed a weight loss of 35.30%, while Chinese oranges had 22.66% (Table 16). Postharvest treatments significantly affected weight loss. The lowest weight loss (2.88%) was recorded in oranges stored at 6 °C in PP bags (T5), while the

Table 7: Main effect of variety on firmness at different days after storage of orange

Variety	Firmness[c] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
V_1	1.00	1.00	1.58	1.72	1.81	2.00	2.23	2.25	2.28	2.63	2.83	3.00
V_2	1.00	1.00	1.33	1.33	1.36	1.44	1.58	1.75	1.81	1.91	1.97	2.50
$LSD_{0.05}$	-	-	0.09	0.11	0.11	0.21	0.16	0.18	0.18	0.18	-	-
$LSD_{0.01}$	-	-	0.14	0.16	0.16	0.28	0.22	0.25	0.25	0.25	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; V_1 = Darjeeling, V_2 = Chinese; [c] = Firmness scale: 1 = Firm, 2 = Sprung, 3 = Soft, 4 = Over ripe

Table 8: Main effect of postharvest treatment on firmness at different days after storage of orange

Postharvest treatment	Firmness[c] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
T_1	1.00	1.00	2.00	2.00	2.08	2.33	2.53	2.58	2.67	2.69	-	-
T_2	1.00	1.00	1.50	1.67	1.67	1.83	1.92	1.95	2.25	2.27	-	-
T_3	1.00	1.00	1.00	1.25	1.42	1.67	1.69	1.73	1.75	1.77	1.83	-
T_4	1.00	1.00	2.00	2.00	2.00	2.17	2.42	2.50	3.00	3.00	-	-
T_5	1.00	1.00	1.00	1.00	1.00	1.00	1.13	1.20	1.31	1.39	1.50	2.50
T_6	1.00	1.00	1.25	1.25	1.33	1.33	1.42	1.75	1.80	1.80	2.25	3.00
$LSD_{0.05}$	-	-	0.18	0.20	0.20	0.36	0.28	0.31	0.31	0.31	-	-
$LSD_{0.01}$	-	-	0.26	0.27	0.27	0.48	0.38	0.43	0.43	0.43	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistically not done; T_1 = Control; T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ); [c] = Firmness scale: 1 = Firm, 2 = Sprung, 3 = Soft, 4 = Over ripe

Table 9: Combined effects of variety and postharvest treatment on firmness at different days after storage of orange

Treatment combination	Firmness[c] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
V_1T_1	1.00	1.00	2.00	2.00	2.17	2.33	3.00	3.00	3.00	3.00	-	-
V_1T_2	1.00	1.00	2.00	2.33	2.33	2.67	0.83	2.00	3.00	3.00	-	-
V_1T_3	1.00	1.00	1.00	1.50	1.83	2.33	1.00	1.33	1.67	1.67	1.67	-
V_1T_4	1.00	1.00	2.00	2.00	2.00	2.17	2.50	2.67	3.00	2.00	-	-
V_1T_5	1.00	1.00	1.00	1.00	1.00	1.00	0.67	1.00	1.00	1.00	2.00	3.00
V_1T_6	1.00	1.00	1.50	1.50	1.50	1.50	1.33	2.00	2.00	2.00	3.00	3.00
V_2T_1	1.00	1.00	2.00	2.00	2.00	2.33	2.67	3.00	3.00	2.00	-	-
V_2T_2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.50	1.50	2.00	-	-
V_2T_3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.17	1.33	1.67	2.00	-
V_2T_4	1.00	1.00	2.00	2.00	2.00	2.17	2.33	2.33	3.00	2.00	-	-
V_2T_5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00
V_2T_6	1.00	1.00	1.00	1.00	1.17	1.17	1.50	1.50	1.00	1.00	2.00	3.00
$LSD_{0.05}$	-	-	0.25	0.28	0.28	0.51	0.40	0.44	0.44	0.44	-	-
$LSD_{0.01}$	-	-	0.35	0.38	0.38	0.69	0.54	0.60	0.60	0.60	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; V_1 = Darjeeling orange, V_2 = Chinese orange and T_1 = Control; T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ); [c] = Firmness scale: 1 = Firm, 2 = Sprung, 3 = Soft, 4 = Over ripe

Table 10: Main effect of variety on freshness at different days after storage of orange

Variety	Freshness[d] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
V_1	1.00	1.00	1.72	1.75	1.89	2.17	1.22	1.25	2.28	2.53	2.62	3.00
V_2	1.00	1.00	1.33	1.33	1.33	1.42	1.47	1.83	2.00	2.06	2.10	3.00
$LSD_{0.05}$	-	-	0.06	0.13	0.20	0.19	0.17	0.17	0.16	0.21	-	-
$LSD_{0.01}$	-	-	0.08	0.17	0.27	0.26	0.23	0.23	0.22	0.28	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; V_1 = Darjeeling orange, V_2 = Chinese orange; [d] = Freshness scale: 1 = Excellent, 2 = Good, 3 = Fair, 4 = Poor

Table 11: Main effect of postharvest treatment on freshness at different days after storage of orange

Postharvest treatment	Freshness[d] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
T_1	1.00	1.00	2.00	2.08	2.25	2.25	2.50	2.62	2.83	3.00	-	-
T_2	1.00	1.00	1.50	1.50	1.67	1.67	1.78	1.97	2.25	2.30	-	-
T_3	1.00	1.00	1.50	1.50	1.58	1.63	1.74	1.79	1.82	1.87	1.93	-
T_4	1.00	1.00	2.00	2.00	2.00	2.50	2.67	2.75	2.87	3.00	-	-
T_5	1.00	1.00	1.00	1.00	1.00	1.00	1.17	1.20	1.37	1.65	2.00	3.00
T_6	1.00	1.00	1.17	1.17	1.17	1.50	1.77	2.00	2.00	2.00	2.50	3.00
$LSD_{0.05}$	-	-	0.10	0.22	0.34	0.33	0.30	0.29	0.28	0.36	-	-
$LSD_{0.01}$	-	-	0.13	0.30	0.47	0.45	0.40	0.40	0.38	0.48	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; T_1 = Control; T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ); [d] = freshness scale: 1 = excellent, 2 = good, 3 = fair, 4 = poor

Table 12: Combined effects of variety and postharvest treatment on freshness at different days after storage of orange

Treatment combination	Freshness[d] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
V_1T_1	1.00	1.00	2.00	2.17	2.50	2.50	2.63	2.71	2.84	3.00	-	-
V_1T_2	1.00	1.00	2.00	2.00	2.33	2.47	2.59	2.82	3.00	3.00	-	-
V_1T_3	1.00	1.00	2.00	2.00	2.17	2.23	2.28	2.34	2.39	2.47	2.50	-
V_1T_4	1.00	1.00	2.00	2.00	2.00	2.00	3.00	3.00	3.00	3.00	-	-
V_1T_5	1.00	1.00	1.00	1.00	1.00	1.00	1.33	1.33	1.33	2.00	2.00	3.00
V_1T_6	1.00	1.00	1.33	1.33	1.33	2.00	2.00	2.00	2.00	2.00	3.00	3.00
V_2T_1	1.00	1.00	2.00	2.00	2.00	2.00	2.00	2.83	3.00	3.00	-	-
V_2T_2	1.00	1.00	1.00	1.00	1.00	1.33	1.33	1.50	1.50	2.00	-	-
V_2T_3	1.00	1.00	1.00	1.00	1.00	1.17	1.17	1.17	1.17	1.83	2.00	-
V_2T_4	1.00	1.00	2.00	2.00	2.00	2.00	2.33	2.50	3.00	3.00	-	-
V_2T_5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.33	1.50	2.00	3.00
V_2T_6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00	3.00
$LSD_{0.05}$	-	-	0.14	0.31	0.49	0.47	0.42	0.42	0.40	0.51	-	-
$LSD_{0.01}$	-	-	0.19	0.43	0.66	0.63	0.57	0.56	0.54	0.69	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistically not done; V_1 = Darjeeling orange; V_2 = Chinese orange and T_1 = Control, T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ); [d] = Freshness scale: 1 = Excellent, 2 = Good, 3 = Fair, 4 = Poor

Table 13: Main effect of variety on flavour at different days after storage of orange

Variety	Flavour[f] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
V_1	1.00	1.00	1.00	1.14	1.33	1.33	1.42	1.46	1.46	1.52	1.64	1.89
V_2	1.00	1.00	1.00	1.00	1.33	1.33	1.33	1.44	1.64	2.06	2.17	2.50
$LSD_{0.05}$	-	-	-	0.13	0.16	0.16	0.17	0.16	0.15	0.23	-	-
$LSD_{0.01}$	-	-	-	0.17	0.22	0.22	0.23	0.22	0.21	0.31	-	-
Level of significance	ND	ND	ND	*	NS	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; *=Significant at 5% level of probability; ND = Statistical analysis not done; NS = Not significance; V_1 = Darjeeling orange; V_2 = Chinese orange; [f] = Flavour scale: 1 = Excellent, 2 = Good, 3 = Fair, 4 = Poor

highest (55.99%) occurred under control conditions (T1) (Table 17). Combined effects of variety and treatments were also significant. The best result, with the lowest weight loss (2.65%), was observed in Darjeeling oranges stored in PP bags at 6 °C (V1T5). Conversely, the highest weight loss (68.44%) was recorded in Darjeeling oranges under control conditions (V1T1) at 26 days (Table 18).

Texture

Significant variation in orange texture was observed during storage, influenced by variety. At 32 days, Darjeeling oranges had a texture score of 2.30, while Chinese oranges scored 2.08 (Table 19). Postharvest treatments significantly impacted texture. The lowest texture score (1.00) was observed in

Table 14: Main effect of postharvest treatment on flavour at different days after storage of orange

Postharvest treatment	Flavour[f] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
T_1	1.00	1.00	1.00	1.08	1.67	2.08	2.25	2.25	2.50	2.50	-	-
T_2	1.00	1.00	1.00	1.33	1.33	1.33	1.43	1.75	1.75	1.75	-	-
T_3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.25	1.33	1.67	1.67	-
T_4	1.00	1.00	1.00	1.00	1.67	1.67	2.00	2.00	2.00	2.50	-	-
T_5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.50	2.00
T_6	1.00	1.00	1.00	1.00	1.00	1.00	1.17	1.50	2.00	2.00	2.00	3.00
$LSD_{0.05}$	-	-	-	0.22	0.28	0.28	0.30	0.28	0.26	0.40	-	-
$LSD_{0.01}$	-	-	-	0.30	0.38	0.38	0.40	0.38	0.36	0.54	-	-
Level of significance	ND	ND	ND	*	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; *=Significant at 5% level of probability; ND = Statistical analysis not done; T_1 = Control; T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ); [f] = Flavour scale: 1 = Excellent, 2 = Good, 3 = Fair, 4 = Poor

Table 15: Combined effects of variety and postharvest treatment on flavour at different days after storage of orange

Treatment combination	Flavour[f] at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
V_1T_1	1.00	1.00	1.00	1.17	1.33	2.17	2.50	3.00	3.00	3.00	-	-
V_1T_2	1.00	1.00	1.00	1.67	1.67	1.73	1.87	2.00	2.00	2.00	-	-
V_1T_3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.33	1.33	1.33	-	-
V_1T_4	1.00	1.00	1.00	1.00	1.33	2.00	2.00	2.00	2.00	2.00	-	-
V_1T_5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	2.00
V_1T_6	1.00	1.00	1.00	1.00	1.00	1.00	1.33	2.00	2.00	2.00	2.00	3.00
V_2T_1	1.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00	2.00	3.00	-	-
V_2T_2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.50	1.50	2.00	-	-
V_2T_3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.17	1.33	2.00	2.00	-
V_2T_4	1.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00	2.00	3.00	-	-
V_2T_5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00
V_2T_6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00	3.00
$LSD_{0.05}$	-	-	-	0.31	0.40	0.40	0.42	0.40	0.37	0.56	-	-
$LSD_{0.01}$	-	-	-	0.43	0.54	0.54	0.57	0.54	0.50	0.76	-	-
Level of significance	ND	ND	ND	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; V_1 = Darjeeling orange, V_2 = Chinese orange and T_1 = Control; T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ); [f] = Flavour scale: 1 = Excellent, 2 = Good, 3 = Fair, 4 = Poor

Table 16: Main effect of variety on percent weight loss at different days after storage of orange

Variety	Initial wt. (g)	Weight loss (%) at 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

**=Significant at 1% level of probability; *=Significant at 5% level of probability; ND = Statistical analysis not done; NS = Not significance; V_1 = Darjeeling orange, V_2 = Chinese orange

oranges stored at 6 °C in PP bags (T5), while the highest score (3.00) occurred under control conditions (T1) (Table 20). Combined effects of variety and treatments were also significant. The best texture (score 1.00) was recorded for Darjeeling and Chinese oranges stored in PP bags at 6 °C (V1T5, V2T5). In contrast, the highest texture score (3.00) was observed in V2T6, V1T2, V2T1, and V2T4 at 32 days (Table 21).

TSS

During fruit maturation and ripening, total soluble solids (TSS) increase with storage duration. In this study, significant variations in TSS were observed among orange varieties during storage. At 36 days, the TSS of Darjeeling and Chinese oranges were 8.28% and 10.76% brix, respectively (Figure 3). Postharvest treatments significantly influenced TSS changes. The lowest TSS (8.75%

Table 17: Main effect of postharvest treatment on percent weight loss at different days after storage of orange

Postharvest treatment	Initial wt. (g)	Weight loss (%) at 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

**=Significant at 1% level of probability; ND = Statistical analysis not done; T_1 = Control; T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ)

Table 18: Combined effects of variety and postharvest treatment on percent weight loss at different days after storage of orange

Treatment combination	Initial wt. (g)	Weight loss (%) at 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

**=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 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ)

Table 19: Main effect of variety on texture at different days after storage of orange

Variety	Texture at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
V_1	1.00	1.00	1.53	1.69	2.08	2.06	1.89	2.22	2.44	2.30	2.17	2.50
V_2	1.00	1.00	1.33	1.33	1.33	1.33	1.33	1.44	1.81	2.08	1.67	2.50
$LSD_{0.05}$	-	-	0.06	0.08	0.15	0.17	0.16	0.20	0.22	0.20	-	-
$LSD_{0.01}$	-	-	0.08	0.11	0.21	0.23	0.22	0.27	0.30	0.27	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	*	ND	ND

**=Significant at 1% level of probability; *=Significant at 5% level of probability; ND = Statistical analysis not done; V_1 = Darjeeling Orange; V_2 = Chinese Orange

brix) was found in oranges ripened without PP bags and stored at 6 °C (T6). In contrast, the highest TSS (10.13% brix) was observed in oranges treated with hot water at 50 °C for 5 minutes and stored at ambient conditions (T4) (Figure 4). The combined effects of varieties and treatments were also significant. The highest TSS (11.66% brix) was recorded in Chinese oranges (V2) stored in PP bags (50 µ, no perforation) at ambient conditions (T2), while the lowest TSS (6.90% brix) was found in Darjeeling oranges (V1) under the same treatment (Figure 5).

Vitamin C

Oranges are a rich source of vitamin C, with significant variation observed between varieties by the 36th day of storage. Darjeeling oranges had 11.79 mg/100 g of vitamin C, while Chinese oranges had 11.05 mg/100 g, with the latter showing the highest decrease (73.71%) during storage (Table 22). Postharvest treatments significantly impacted vitamin C content. The lowest vitamin C (8.75 mg/100 g) was found in oranges treated with hot water

Table 20: Main effect of postharvest treatment on texture at different days after storage of orange

Postharvest treatment	Texture at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
T_1	1.00	1.00	2.00	2.00	2.00	2.33	2.08	2.33	2.50	3.00	-	-
T_2	1.00	1.00	1.08	1.50	1.50	1.67	1.75	2.25	2.25	1.00	-	-
T_3	1.00	1.00	1.00	1.17	1.42	1.67	1.33	1.42	1.83	2.00	2.25	-
T_4	1.00	1.00	2.00	2.00	2.00	2.00	2.00	2.50	3.00	3.00	-	-
T_5	1.00	1.00	1.00	1.00	1.83	1.00	1.00	1.00	1.17	1.00	1.50	2.00
T_6	1.00	1.00	1.50	1.42	1.50	1.50	1.50	1.50	2.00	2.00	2.00	3.00
$LSD_{0.05}$	-	-	0.10	0.14	0.26	0.30	0.28	0.34	0.38	0.34	-	-
$LSD_{0.01}$	-	-	0.13	0.19	0.36	0.40	0.38	0.47	0.52	0.47	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; T_1 = Control; T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ); Texture scale: 1 = Fine, 2 = Mood, 3 = Medium rough, 4 = Rough

Table 21: Combined effects of variety and postharvest treatment on texture at different days after storage of orange

Treatment combination	Texture at different days after storage											
	1	4	7	10	13	16	19	22	26	32	39	47
V_1T_1	1.00	1.00	2.00	2.00	2.00	2.67	2.17	2.67	3.00	3.00	-	-
V_1T_2	1.00	1.00	1.17	2.00	2.00	2.33	2.50	3.00	3.00	3.00	-	-
V_1T_3	1.00	1.00	1.00	1.33	1.83	2.33	1.67	1.67	2.33	2.50	2.50	-
V_1T_4	1.00	1.00	2.00	2.00	2.00	2.00	2.00	3.00	3.00	3.00	-	-
V_1T_5	1.00	1.00	1.00	1.00	2.67	1.00	1.00	1.00	1.33	1.00	2.00	2.00
V_1T_6	1.00	1.00	2.00	1.83	2.00	2.00	2.00	2.00	2.00	2.00	2.00	3.00
V_2T_1	1.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	3.00	-	-
V_2T_2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.50	1.50	2.00	-	-
V_2T_3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.17	1.33	1.50	2.00	-
V_2T_4	1.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	3.00	3.00	-	-
V_2T_5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00
V_2T_6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00	3.00
$LSD_{0.05}$	-	-	0.14	0.20	0.37	0.42	0.40	0.49	0.54	0.49	-	-
$LSD_{0.01}$	-	-	0.19	0.27	0.50	0.57	0.54	0.66	0.74	0.66	-	-
Level of significance	ND	ND	**	**	**	**	**	**	**	**	ND	ND

**=Significant at 1% level of probability; ND = Statistical analysis not done; V_1 = Darjeeling orange; V_2 = Chinese orange and T_1 = Control, T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ); Texture scale: 1 = Fine, 2 = Mood, 3 = Medium rough, 4 = Rough

at 50±1 °C for 5 minutes and stored at ambient conditions (T4). The highest content (15.29 mg/100 g) was observed in oranges wrapped in PP bags and stored at 6 °C. The greatest percentage decrease (78.61%) occurred under T4 treatment (Table 23). The combined effects of variety and treatment were highly significant. Darjeeling oranges (V1) stored in PP bags at 6 °C (T5) had the highest vitamin C content (16.80 mg/100 g). Conversely, Chinese oranges (V2) treated with hot water at 50±1 °C for 5 minutes and stored at ambient conditions (T4) recorded the lowest vitamin C (8.267 mg/100 g) (Table 24).

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 (Figure 6). Postharvest treatments had a significant impact on disease incidence. At 32 days, the highest incidence (90.67%) occurred in oranges sealed in PP bags with punch-hole perforation and stored at ambient conditions (T3), while no disease (0%) was observed in oranges wrapped in PP bags and stored at 6 °C (Figure 7). The combined effects of varieties and treatments were also significant. The highest disease incidence (94.44%) was recorded for Chinese oranges (V2) sealed in PP bags with punch-hole perforation and stored at ambient conditions (T3). In contrast, no disease (0%) was found in both Darjeeling (V1) and Chinese (V2) oranges stored at 6 °C without PP bags (T6) (Table 24).

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 (Figure 8). Postharvest treatments had a highly significant effect on shelf life. The shortest shelf life (17.50 days) was found in oranges sealed in PP bags without punch-hole perforation and stored at ambient conditions (T2). The longest shelf life (46.00 days) occurred in oranges wrapped in PP bags and stored at 6 °C (Figure 9). The combined effects of varieties and postharvest treatments were also highly significant. Darjeeling oranges (V1) sealed in PP bags without punch-hole

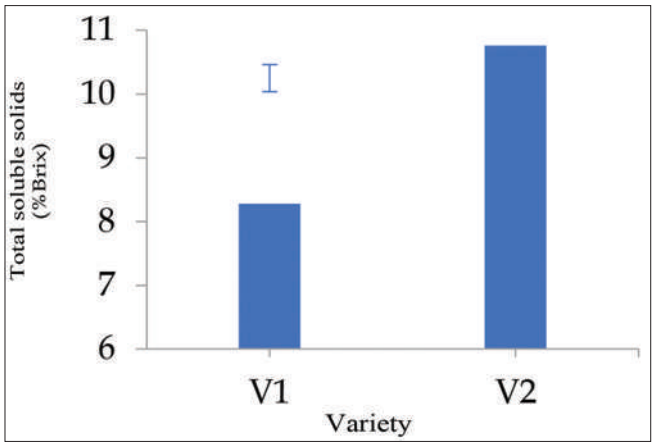

Figure 3: Main effect of variety on total soluble solids (TSS) of orange. The vertical bar indicates LSD at 1% level of probability. V_1=Darjeeling orange; V_2=Chinese orange

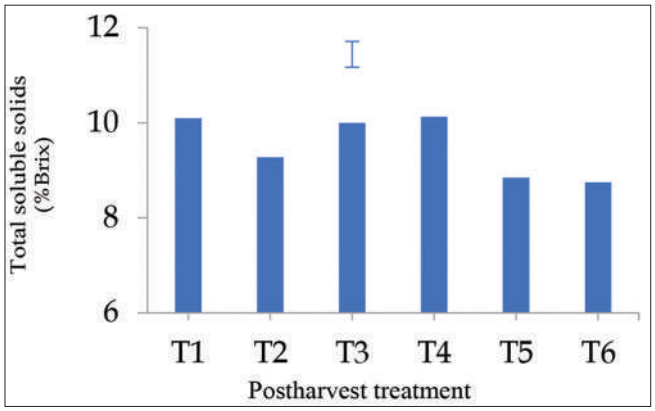

Figure 4: Main effect of postharvest treatment on total soluble solids (TSS) of orange. The vertical bars indicate LSD at 1% level of probability. T_1=Control; T_2=Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3=Orange sealed in PP bag (50 µ) with punch-hole 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 µ); T_6=Orange held at 6 °C temperature without PP bag (50 µ)

perforation and stored at ambient conditions had the shortest shelf life (12.00 days). The longest shelf life (47.00 days) was found in Chinese oranges (V2) wrapped in PP bags and stored at 6 °C (V2T5) (Figure 10).

DISCUSSION

This experiment aimed to evaluate the postharvest quality and shelf life of two different orange varieties, namely Darjeeling and Chinese, under varying storage conditions. The study spanned 32 days and focused on a range of quality attributes, such as visual appearance, peel color, texture, firmness, freshness, shrinkage, flavor, and vitamin C content. The experiment also considered the influence of temperature, storage method, and packaging type on these factors, offering a comprehensive analysis of the most effective postharvest treatments for preserving fruit quality.

The two orange varieties were subjected to different postharvest treatments, including storage at ambient temperature and at a controlled 6 °C, with varying packaging methods such as polypropylene (PP) bags, perforated PP bags, and plastic boxes (Zacarías-García *et al.*, 2023). The study found that temperature control had a significant impact on the overall quality of the fruit during the storage period. Oranges stored at the cooler

Table 22: Main effect of variety on vitamin C at different days after storage of orange

Variety	Vit C (mg/100 g) at different days after storage		% 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	**	**

**=Significant at 1% level of probability; ND = Statistical analysis not done; V_1 = Darjeeling Orange; V_2 = Chinese Orange

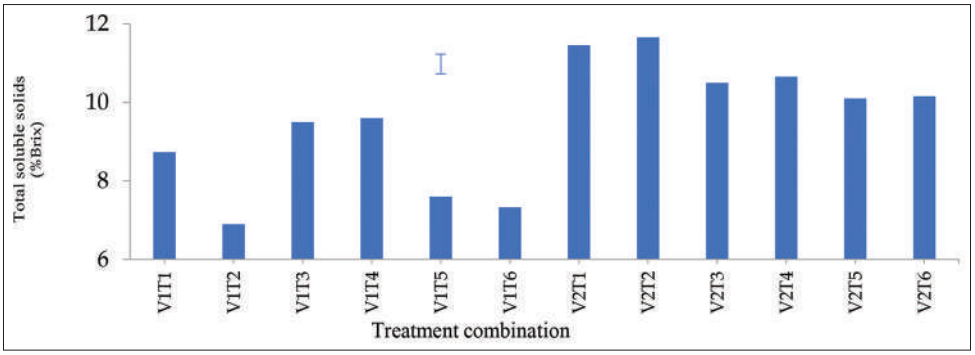

Figure 5: Combined effects of variety and postharvest treatments on total soluble solids (TSS) of orange. The vertical bar indicates LSD at 1% level of probability. V_1= Darjeeling orange; V_2=Chinese orange and T_1=Control; T_2=Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3=Orange sealed in PP bag (50 µ) 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 µ); T_6=Orange held at 6 °C temperature without PP bag (50 µ)

temperature of 6 °C in PP bags retained better appearance, color, and firmness, with a slower decline in freshness compared to those stored at ambient temperature. In contrast, oranges stored at room temperature experienced quicker deterioration, including higher rates of peel color changes, softening, and shrinkage (Chaudhry *et al.*, 2023).

One of the key findings was that oranges stored at 6 °C exhibited minimal weight loss and were better preserved in terms of texture and freshness (Gupta *et al.*, 2022; Martins *et al.*, 2023). This condition also helped delay the onset of fruit shriveling and the development of surface diseases. On the other hand, oranges stored at higher temperatures showed significant weight loss, loss of firmness, and visible texture changes over the storage period (Ambreen *et al.*, 2023). The study also measured the vitamin C content of the oranges, which was found to decline substantially in both varieties, especially for those stored at higher temperatures. This highlights the importance of temperature management in retaining the nutritional value of the fruit (Owoyemi *et al.*, 2023).

Regarding packaging, the study found that fruit stored in PP bags with punch-hole perforation showed a higher incidence of disease, including fungal infections. These fruits also displayed greater weight loss and quality deterioration when compared to those stored in PP bags without perforations. The presence of perforations likely facilitated the entry of pathogens and increased the exposure to environmental factors, exacerbating the fruit's decline. The best storage method for both orange varieties was found to be the use of PP bags without perforations, combined with storage at 6 °C (El-Beltagi *et al.*, 2023). This combination was most effective in maintaining fruit quality, preventing disease, and slowing down the natural degradation process.

The experiment also monitored other factors like flavor, which was found to degrade over time, especially for the oranges stored at ambient temperatures. However, those stored at 6 °C maintained their flavor profile much longer (Pradhan *et al.*, 2023). Additionally, the storage method had a significant influence on peel color. Oranges stored at 6 °C retained a more vibrant and consistent peel color, which is an important factor for marketability and consumer acceptance (Budiarto *et al.*, 2024).

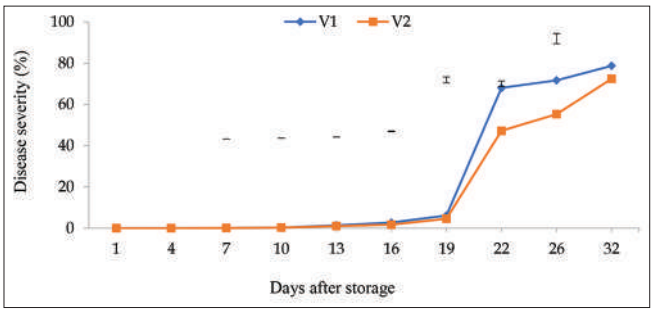

Figure 6: Main effect of variety on percent disease severity at different days after storage of orange. The vertical bars indicate LSD at 1% level of probability. V_1=Darjeeling Orange, V_2=Chinese Orange

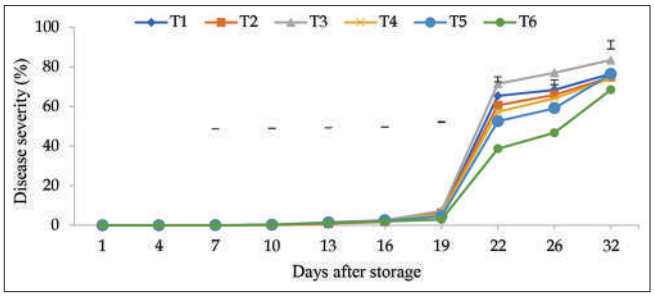

Figure 7: Main effect of postharvest treatment on percent disease severity at different days after storage of orange. The vertical bars indicate LSD at 1% level of probability. T_1 = Control, T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition, T_3 = Orange sealed in PP bag (50 µ) 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 µ), T_6 = Orange held at 6 °C temperature without PP bag (50 µ)

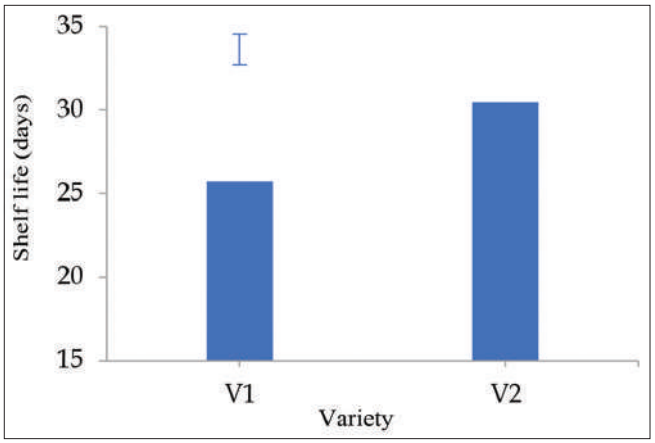

Figure 8: Main effect of variety on shelf life (days) of orange. The vertical bar indicates LSD at 1% level of probability. V_1=Darjeeling orange, V_2=Chinese orange

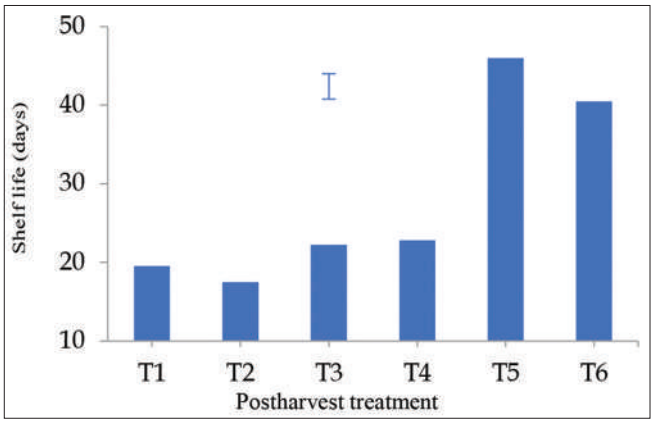

Figure 9: Main effect of postharvest treatment on shelf life (days) of orange. The vertical bar indicates LSD at 1% level of probability. T_1=Control, T_2=Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3=Orange sealed in PP bag (50 µ) with punch-hole perforation 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 µ); T_6=Orange held at 6 °C temperature without PP bag (50 µ)

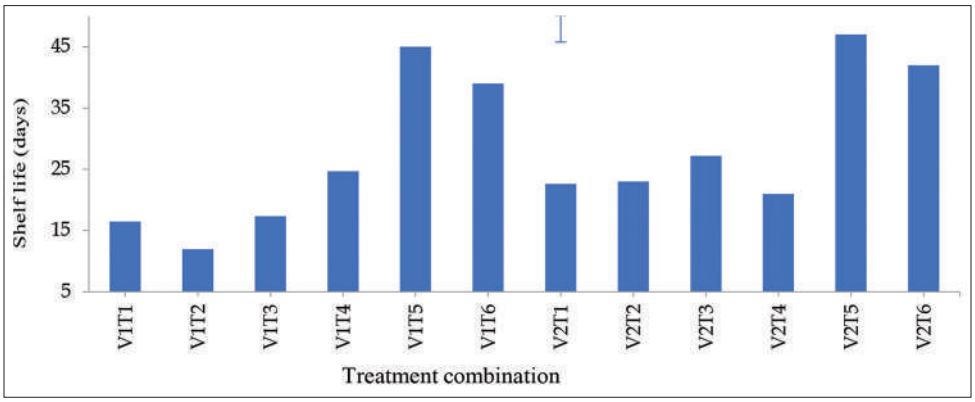

Figure 10: Combined effects of variety and postharvest treatment on shelf life of orange. The vertical bar indicates LSD at 1% level of probability. V_1=Darjeeling orange; V_2=Chinese orange and T_1=Control; T_2=Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3=Orange sealed in PP bag (50 µ) 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 µ); T_6=Orange held at 6 °C temperature without PP bag (50 µ)

Table 23: Main effect of postharvest treatment on vitamin C at different days after storage of orange

Postharvest treatment	Vit C (mg/100 g) at different days after storage		% 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	**	**

**=Significant at 1% level of probability; ND = Statistical analysis not done; V1 = Darjeeling orange; V_2 = Chinese orange and T_1 = Control; T_2 = Orange sealed in PP bag (50 µ) without perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) with 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ)

Table 24: Combined effects of variety and postharvest treatment on vitamin C at different days after storage of orange

Treatment combination		Vit C (mg/100 g) at different days after storage		% of Decrease
		Initial (1st day)	36(days)	
V_1	T_1	40.30	10.20	74.68
	T_2	40.30	10.64	79.59
	T_3	40.30	10.61	73.67
	T_4	40.30	9.243	77.06
	T_5	40.30	16.80	58.31
	T_6	40.30	13.30	66.99
V_2	T_1	41.70	9.940	76.16
	T_2	41.70	10.53	74.74
	T_3	41.70	11.48	72.47
	T_4	41.70	8.267	80.17
	T_5	41.70	13.79	66.93
	T_6	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; ND = Statistical analysis not done; V_1 = Darjeeling orange; V_2 = Chinese orange and T_1 = Control; T_2 = Orange sealed in PP bag (50 µ) without punch-hole perforation and held at ambient condition; T_3 = Orange sealed in PP bag (50 µ) 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 µ); T_6 = Orange held at 6 °C temperature without PP bag (50 µ)

In conclusion, the study provided valuable insights into the optimal conditions for preserving the quality of oranges after harvest. It emphasized the importance of temperature control and packaging in extending the shelf life and maintaining the nutritional and sensory qualities of the fruit. The results suggest that storing oranges at 6 °C in PP bags without perforations is the most effective postharvest treatment for maintaining quality, reducing disease incidence, and minimizing nutritional losses. These findings can be used to improve postharvest handling practices and contribute to more efficient storage strategies for citrus fruits in commercial settings.

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 µ 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.

AUTHORS' CONTRIBUTION

Md. Abdul Fahim - Methodology and Investigation; Md. Kamrul Hassan - Conceptualization, Validation, Supervision, Resource and Writing- review & editing; Nasrin Akhther - Supervision, Resource and Validation; Nayan Chandra Howlader - Formal analysis, Writing - original draft, Software and Visualizations; Shuvro Sarker and Md. Sazzad Hossain – Methodology; Subrina Akther and Arafath Hossain Rokon - Literature Review and Writing - review & editing.

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