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# Effect of Growing Altitude and Post-Harvest Treatments with Gibberellic Acid on Quality and Shelf Life of Sweet Orange (*Citrus sinensis* Osbeck.)

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## ABSTRACT

The experiment was conducted from November 2021 to January 2022 at the Horticulture Laboratory of Agriculture and Forestry University, Rampur, Chitwan, Nepal. It followed a factorial arrangement in a Completely Randomized Design (CRD) with 12 treatments (comprising three altitude levels and four post-harvest treatments) and three replications. Fruits were harvested from elevations of 970, 1100, and 1230 m above sea level. The post-harvest treatments included gibberellic acid ($GA_3$) at concentrations of 150 ppm, 100 ppm, and 50 ppm, alongside a control treatment (distilled water). Notably, at 30 d after storage (DAS), fruits from the 970 masl elevation exhibited remarkable results, including the lowest post-harvest weight loss (PLW) of 9.33%, high juice content (42.71%), and elevated ascorbic acid levels (31.12 mg 100 $g^{-1}$). Conversely, fruits from 1230 masl demonstrated superior firmness (4.95 kg $cm^{-2}$), titratable acidity (1.16%), and an extended shelf life (29.75 d), though they had lower total soluble solids (TSS; 10.58 °Brix) and a reduced TSS/TA ratio. Among the $GA_3$ treatments, GA3 at 150 ppm proved most effective, reducing PLW (9.37%), TSS (10.20 °Brix), and juice pH (3.38) while enhancing juice content, ascorbic acid levels (32.07 mg 100 $g^{-1}$), fruit firmness (5.19 kg $cm^{-2}$), and shelf life (34 d). Based on these findings, the study recommends applying $GA_3$ at 150 ppm to sweet oranges harvested from higher altitudes to optimize post-harvest quality.

**Abbreviations:** Percentage (%), Degree Brix (°Brix), Degree Celsius (°C), Microgram (µg), Active ingredient (a.i.), Agriculture and Forestry University (AFU), Centimeter (cm), Square Centimeter (cm2), Completely Randomized Design (CRD), Cultivar (cv), Coefficient of Variance (CV), Days after storage (DAS), Degree of freedom (Df), Duncan's Multiple Range Test (DMRT), East (E), et alia/ and others (et al.), etcetera (etc.), Food and Agriculture Organization (FAO), Gram (g), Gibberellic acid (GA3), Hectare (ha), That is (i.e.), Kilogram (kg), Least Significant Difference (LSD), Square Meter ($m^2$), Meter Above Sea Level (masl), Milligram (mg), Millilitre (mL), Ministry of Agriculture and Livestock Development (MoALD), Microsoft (MS), Metric Tons (mt), North (N), Non-significant (NS), Probability value (P value), Potential of Hydrogen (pH), Physiological Loss in Weight (PLW), Parts per million (ppm), Relative Humidity (RH), Standard Error of Mean (SE), Species (spp), Titratable Acidity (TA), Total Soluble Solids (TSS), World Citrus Organization (WCO), Weight (wt.).

## Introduction

Citrus is among the most important fruit crops globally, playing a significant role in human diets due to its widespread availability and popularity. Most citrus cultivation occurs in tropical and subtropical regions situated between latitudes 35°N and 35°S, with the majority concentrated in the Northern Hemisphere (Liu et al., 2012). China is the leading global producer, contributing 28% of the total citrus output, amounting to 44.6 m tons (WCO, 2022).

In Nepal, citrus production spans a total area of 49,306 ha, with an annual production of 306,149 tons and a productivity rate of 9.47 t $ha^{-1}$ (MoALD, 2023). Among citrus fruits, sweet orange ranks as the second-most cultivated crop after mandarin oranges in terms of production. The total area devoted to sweet orange cultivation is 6,595 ha, of which 4,487 ha are productive, yielding 51,644 tons annually (MoALD, 2023). Sweet orange is grown across 49 districts in Nepal, with Sindhuli and Ramechhap being the leading producers. Sindhuli alone accounts for a productive area of 936 ha and an annual production of 14,075 tons (MoALD, 2023). Sweet orange (*Citrus sinensis* Osbeck.), a member of the Rutaceae family, originates from southern China and has been cultivated for thousands of years. In Nepal, it is commercially grown in the subtropical regions, often in remote highland areas with limited access to roads, markets, processing, or storage facilities. The absence of cold storage facilities necessitates storage and transportation at ambient temperatures, leading to inadequate post-harvest preservation. Consequently, post-harvest losses are significant; Kaini (2013) reported that 29% of citrus fruits, including sweet oranges, are lost after harvest. Factors such as improper harvesting timing and techniques, as well as inadequate transportation, storage, and packaging methods, exacerbate these losses (Arun and Ghimire, 2019).

Despite the mid-hill regions of Nepal possessing immense potential for sweet orange cultivation and export, the country remains reliant on imports to meet domestic demand (Bhattarai, 2018). Altitude-related factors, including temperature, sunlight exposure, atmospheric pressure, and soil composition, significantly influence fruit characteristics during growth and development, subsequently affecting the post-harvest quality of sweet oranges. Higher altitudes, characterized by cooler temperatures and lower humidity, slow fruit ripening, enhance flavor development, increase shelf life, and reduce susceptibility to decay. However, intense sunlight at higher altitudes may cause sunburn and skin damage, while lower atmospheric pressure can alter respiration rates and ethylene production, necessitating careful post-harvest management to control ripening and prevent premature decay.

Phytochemical content in sweet orange is heavily influenced by the interaction between climatic conditions and the specific variety of the fruit (Zeng et al., 2020). Environmental factors, such as light intensity and temperature, directly impact citrus juice quality (Levy et al., 1978; Olabinjo et al., 2017). These insights underline the importance of optimizing cultivation and post-harvest practices to reduce losses and improve the quality of sweet oranges in Nepal.

Post-harvest losses in sweet oranges can be minimized by reducing and monitoring transpiration, respiration, and the growth of contaminating microorganisms (Dashora and Mohammed, 1988). Various chemical treatments, either alone or combined with different packaging materials, have been shown to enhance the post-harvest shelf life of sweet oranges during storage. Specific compounds, such as plant growth regulators (PGRs) and botanical extracts, are particularly effective in reducing ethylene production, lowering respiration rates, and inhibiting microbial growth, thereby extending the shelf life of the fruit.

PGRs or phytohormones are organic compounds that regulate plant biological processes without serving as nutrients (Ghosh et al., 2022). Post-harvest applications of PGRs can significantly preserve fruit quality and extend shelf life. Gibberellins, for example, are well-known for their ability to delay senescence and are commonly used in powdered form. Numerous studies have explored the impact of gibberellic acid ($GA_3$), a widely used PGR, on various fruits, including citrus. $GA_3$ treatments have demonstrated promising results in enhancing fruit development, delaying senescence, improving color development, and maintaining post-harvest attributes such as firmness, acidity, and sugar content.

Dipping fruits in $GA_3$ solutions before storage is a widely practiced post-harvest treatment that has shown excellent results in preserving fruit quality (Atia et al., 2018). By addressing the dual influence of growing altitude and gibberellic acid application, this study aims to develop effective methods for mitigating significant post-harvest losses. Such advancements would support the creation of robust storage technologies, increase the availability of sweet oranges into the late

season, and ultimately improve the economic well-being of sweet orange growers.

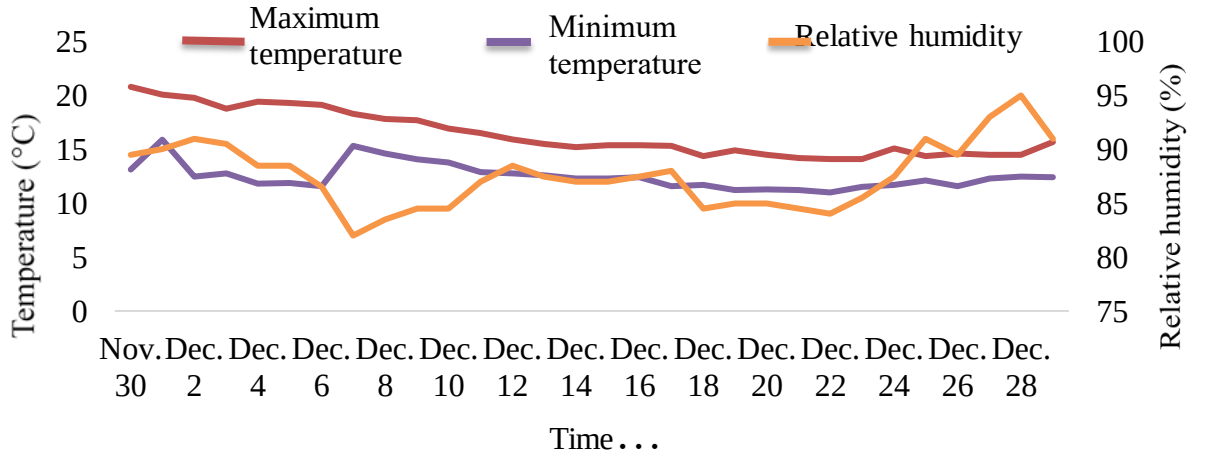
This study specifically investigates the effects of post-harvest treatments with $GA_3$ on extending shelf life and maintaining key quality attributes of sweet oranges, including ascorbic acid content, total soluble solids (TSS), titratable acidity (TA), juice content, weight loss, shrinkage, spoilage, and overall marketability under ambient room conditions.

## Material and methods

### *Harvesting and laboratory experimentation*

Uniformly ripe sweet orange fruits were handpicked from three altitudes in Golanjor-04, Sindhuli District, Nepal: Dunde (970 masl, 27° 13.217'N and 86° 04.550'E), Majhkuvinde (1100 masl, 27° 13.412'N and 86° 03.729'E), and Mathlo Aalegaun (1230 masl, 27° 13.670'N and 86° 03.507'E). The fruits were carefully collected in plastic crates to minimize damage and transported to the Horticulture Laboratory of Agriculture and Forestry University, Rampur, Chitwan (228 masl, 27° 39' 14"N and 84° 21' 6"E), for further experimentation.

The experiment was conducted from November 2021 to January 2022. During the study period (30 November 2021 to 29 December 2021), the temperature and relative humidity were recorded using a digital temperature and hygrometer (Model: HTC-1, India) (Fig. 1). These measurements ensured consistent monitoring of environmental conditions for accurate assessment of the post-harvest attributes of the fruits.




Average maximum temperature: 16.41 °C Average minimum temperature: 12.49 °C Average Relative Humidity: 87.58%

**Fig.1.** Temperature and relative humidity of storage room during storage period at Rampur, Chitwan, 2021.

### *Treatment details*

Fruits were treated with gibberellic acid ($GA_3$) solutions prepared using ethanol as a solubilizing agent, as $GA_3$ is insoluble in distilled water. To prepare the solution, one gram of $GA_3$ powder was dissolved in 5–10 mL of ethanol with gentle heating. Once fully dissolved, the solution was diluted with distilled water to prepare a 1000 mL stock solution at a concentration of 1000 ppm. The stock solution was further diluted to obtain working concentrations of 50 ppm, 100 ppm, and 150 ppm.

Prior to treatment, the fruits were washed with tap water and left to dry in the shade. Clean, dry sweet orange fruits were dipped in the respective $GA_3$ solutions for five min, following the method described by Shivani et al. (2021). For each replication, 18 fruits from each location were treated with four levels of $GA_3$: G0 (0 ppm, distilled water as control), G1 (50 ppm), G2 (100 ppm), and G3 (150 ppm). After treatment, the fruits were air-dried on newspaper in the shade, placed in plastic baskets, and stored at room temperature, where the average temperature was 14.45 °C and the average relative humidity was 87.57%.

### *Experimental design and layout*

The experiment followed a two-factor factorial Completely Randomized Design (CRD) with 12 treatments (three levels of altitude and four post-harvest treatments), each replicated three times. For each replication, 10 fruits were designated as destructive samples for qualitative data

collection, while 8 fruits were tagged as non-destructive samples for quantitative observations.

Physiological and quality parameters were recorded before treatment and monitored during storage until the end of the fruits' shelf life. Observations were made at five-d intervals. For chemical parameter analysis, one sweet orange fruit was randomly selected from the destructive sample. Physical parameters were assessed using the 8 tagged fruits from the non-destructive sample. The daily mean temperature and relative humidity of the storage room were also recorded throughout the experiment. Data were collected and analyzed for various physiological and quality parameters to evaluate the impact of altitude and post-harvest treatments on the sweet orange fruits.

### *Physiological loss in weight (PLW)*

Eight fruits from each replication of the treatments were randomly selected and labeled with numbers 1–8 using stickers for identification. The weight of these fruits was measured initially and at 5-d intervals throughout the storage period. Both cumulative weight loss (%) and interval-specific weight loss (%) were calculated and expressed as percentages using appropriate formulas.

This method allowed for accurate tracking of weight loss dynamics over time, providing critical data to assess the effects of altitude and post-harvest treatments on the post-harvest physiology of the sweet oranges.

$$\text{Physiological loss in weight (\%)} = \frac{\text{Initial weight (g)- Final weight (g)}}{\text{Initial weight (g)}} \times 100$$

### *Juice content*

The juice was extracted by squeezing manually. The average juice weight was calculated separately for each treatment and replication (expressed in percentages). The average juice percentage per fruit was obtained from the following formula:

$$\text{Juice (\%)} = \frac{\text{Juice weight per fruit (g)}}{\text{Individual fruit weight (g)}} \times 100$$

### *Firmness*

Fruit firmness was measured using a Penetrometer and a Universal Testing Machine (Model 5543 Single Column, Instron Corp, Canton MA, USA). Two readings were taken at opposite points around the equator of each fruit.

During measurement, the sample was placed on a stable surface, and the Penetrometer probe was pressed into the peel to create a hole by applying controlled pressure. A cylindrical probe was used to compress the sample, and the plunger's compression reading was recorded. The average firmness of each fruit was calculated from the two readings and expressed in kg $cm^{-2}$. This method ensured precise and consistent firmness assessment across samples.

### *Ascorbic acid content*

The ascorbic acid content of the fruits was measured using the volumetric method as described by Sadasivam and Manickam (1991). A 5 mL working standard solution was taken in a conical flask, and 10 mL of 4% oxalic acid solution was added. This mixture was titrated against a dye solution (2,6-dichloroindophenol) until the solution turned pink ($V_1$ mL). Afterward, 2 mL of the fruit sample and 10 mL of 4% oxalic acid solution were centrifuged. Five mL of the supernatant was pipetted out, to which 10 mL of 4% oxalic acid was added. This mixture was titrated against the dye ($V_2$ mL). The ascorbic acid content was calculated using the following formula and expressed as mg 100 $g^{-1}$:

$$\text{Amount of ascorbic acid (mg 100 g}^{-1}) = \frac{0.5 \text{ mg} \times V_2 \times 12 \times 100}{V_1 \times 5 \text{ mL} \times \text{weight of sample}}$$

### *Total soluble solids (TSS)*

Total soluble solids (°Brix) were determined using a hand-held refractometer (Model: ERMA, Japan). The prism was cleaned and dried with tissue paper before each use. A homogenized drop of juice from each fruit was placed on the prism, and the °Brix value was directly read from the refractometer. Observations were recorded at 5-d intervals, and the TSS was expressed in °Brix. This method provided a reliable measurement of the sugar content in the fruit juice.

### *Titratable acidity (TA)*

Titratable acidity was determined by titrating pulp juice against 0.1 N NaOH using phenolphthalein as an indicator. Titratable acidity was calculated using the following formula as mentioned by Saini et al. (2001) and expressed as percentages.

$$\text{Titratable acidity} = \frac{\text{Volume of NaOH} \times \text{Normality of NaOH} \times \text{mEq}}{\text{Volume of juice titrated}} \times 100$$

Where, mEq = Acid milliequivalent factor (mEq for citric acid is 0.064)

### *TSS/acid ratio*
The ratio was calculated by dividing the TSS content by the titratable acidity of each treatment and the average value was recorded.

### *Juice pH*
Juice from fruits was homogenized and filtered, followed by pH monitoring of the solutions using a pH meter (PHS – 3B, China) at 27 °C.

### *Shelf life*
The fruits were considered to have reached the end of their shelf life when 50% of the fruit sample exhibited visible signs of shrinkage or spoilage due to pathogens or rotting. The shelf life was evaluated by recording the number of d the fruits remained at an acceptable quality level, which was determined based on their appearance and extent of decay.

### *Data analysis*
Data collected during the experiment were entered into Microsoft Excel, and statistical analysis was performed using R Software (version 4.1.2). Duncan's Multiple Range Test (DMRT) was used for mean comparisons, following a method outlined by Gomez and Gomez (1984).

## Results
### *Physiological loss in weight*
The effect of increasing altitude on physiological loss in weight (PLW) differed significantly at $P < 0.05$ and showed a consistent increase over time during storage (Table 1). At five d after storage (DAS), PLW was significantly higher at 1230 masl (2.21%) compared to 970 masl, where it was lowest (1.78%). A similar pattern was observed at 10 DAS, with PLW being lowest at 970 masl (3.41%) and highest at 1230 masl (5.00%). This trend persisted at 15, 20, 25, and 30 DAS. By 30 DAS, the minimum PLW (9.33%) was recorded at 970 masl, followed by 1100 masl (11.61%), while the maximum PLW (12.28%) occurred at 1230 masl.

For $GA_3$ treatments, the control exhibited the highest PLW (2.45%) at 30 DAS, followed by 50 ppm $GA_3$ (2.15%), 100 ppm $GA_3$ (1.84%), and 150 ppm $GA_3$ (1.80%). Across different storage intervals, the control consistently recorded the maximum PLW: 4.58% at 10 DAS, 6.63% at 15 DAS, 8.80% at 20 DAS, 11.10% at 25 DAS, and 12.30% at 30 DAS. In contrast, the minimum PLW was consistently observed with 150 ppm $GA_3$: 3.61% at 10 DAS, 5.40% at 15 DAS, 6.72% at 20 DAS, 8.26% at 25 DAS, and 9.37% at 30 DAS. There was no significant interaction between altitude and $GA_3$ treatment on the physiological loss in weight of sweet oranges across the storage periods.

**Table 1.** Effect of growing altitude and post-harvest $GA_3$ treatment on physiological loss in weight of sweet orange at Rampur, Chitwan, 2021-22.

| Treatment | Physiological loss in weight (%) | | | | | |
|---|---|---|---|---|---|---|
| | 5 DAS | 10 DAS | 15 DAS | 20 DAS | 25 DAS | 30 DAS |
| **Growing Altitudes (Factor A)** | | | | | | |
| 970 masl | 1.78$^{b}$ | 3.41$^{b}$ | 4.81$^{b}$ | 6.56$^{b}$ | 8.00$^{b}$ | 9.33$^{b}$ |
| 1100 masl | 2.20$^{a}$ | 4.41$^{a}$ | 6.70$^{a}$ | 8.40$^{a}$ | 10.39$^{a}$ | 11.61$^{a}$ |
| 1230 masl | 2.21$^{a}$ | 5.00$^{a}$ | 7.31$^{a}$ | 9.10$^{a}$ | 11.00$^{a}$ | 12.28$^{a}$ |
| $LSD_{0.05}$ | 0.34 | 0.63 | 0.83 | 1.16 | 1.56 | 1.43 |
| SE (±) | 0.04 | 0.07 | 0.09 | 0.13 | 0.18 | 0.16 |
| F-test | * | *** | *** | *** | ** | *** |
| **$GA_3$ (Factor B)** | | | | | | |
| Control | 2.45$^{a}$ | 4.58$^{a}$ | 6.63$^{a}$ | 8.80$^{a}$ | 11.10$^{a}$ | 12.30$^{a}$ |
| 50 ppm $GA_3$ | 2.15$^{ab}$ | 4.58$^{a}$ | 6.57$^{a}$ | 8.21$^{a}$ | 10.01$^{ab}$ | 11.23$^{a}$ |
| 100 ppm $GA_3$ | 1.84$^{b}$ | 4.31$^{ab}$ | 6.50$^{a}$ | 8.34$^{a}$ | 9.81$^{ab}$ | 11.30$^{a}$ |
| 150 ppm $GA_3$ | 1.80$^{b}$ | 3.61$^{b}$ | 5.40$^{b}$ | 6.72$^{b}$ | 8.26$^{b}$ | 9.37$^{b}$ |
| $LSD_{0.05}$ | 0.40 | 0.72 | 0.95 | 1.34 | 1.80 | 1.65 |
| SE (±) | 0.03 | 0.06 | 0.08 | 0.12 | 0.15 | 0.14 |
| F-test | ** | * | * | * | * | * |
| CV,% | 19.7 | 17.4 | 15.6 | 17.2 | 18.8 | 15.3 |
| Altitude* $GA_3$ | NS | NS | NS | NS | NS | NS |
| Grand mean | 2.06 | 4.27 | 6.28 | 8.01 | 9.80 | 11.07 |

DAS: Days after storage, SE: Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of variation, NS, *, **, and *** indicate non-significant, significant at $P < 0.05$, significant at $P < 0.01$, and significant at $P < 0.001$ respectively. Means within the column followed by the same letter did not differ significantly at 5% level by DMRT.

## *Juice content*

The effect of altitude on the juice content of sweet orange fruits was non-significant at five DAS but became significant at subsequent observations ($P < 0.05$; Table 2). At 10 DAS, juice recovery was highest at 970 masl (46.35%), compared to 1230 masl (44.13%) and 1100 masl (43.93%). The maximum juice recovery was consistently observed at 970 masl across later storage intervals: 45.09% at 15 DAS, 43.83% at 20 DAS, 43.36% at 25 DAS, and 42.71% at 30 DAS. Conversely, the minimum juice recovery varied by altitude, with the lowest values recorded at 1100 masl on 15 DAS (43.42%), 1230 masl on 20 DAS (41.71%) and 25 DAS (41.39%), and 1100 masl on 30 DAS (41.22%).

**Table 2.** Effect of growing altitude and post-harvest $GA_3$ treatment on juice content of sweet orange at Rampur, Chitwan, 2021-22.

| Treatment | Juice content % | | | | | |
|---|---|---|---|---|---|---|
| | 5 DAS | 10 DAS | 15 DAS | 20 DAS | 25 DAS | 30 DAS |
| **Growing altitudes (Factor A)** | | | | | | |
| 970 masl | 47.10 | 46.35$^{a}$ | 45.09$^{a}$ | 43.83$^{a}$ | 43.36$^{a}$ | 42.71$^{a}$ |
| 1100 masl | 45.96 | 43.93$^{b}$ | 43.42$^{b}$ | 43.47$^{a}$ | 42.54$^{ab}$ | 41.22$^{b}$ |
| 1230 masl | 46.46 | 44.13$^{b}$ | 43.53$^{b}$ | 41.71$^{b}$ | 41.39$^{b}$ | 41.55$^{b}$ |
| $LSD_{0.05}$ | NS | 1.60 | 1.38 | 1.71 | 1.162 | 1.09 |
| SE (±) | | 0.18 | 0.16 | 0.20 | 0.13 | 0.12 |
| F-test | | ** | * | * | ** | * |
| **$GA_3$ (Factor B)** | | | | | | |
| Control | 45.01$^{b}$ | 43.85$^{b}$ | 42.56$^{c}$ | 41.52$^{b}$ | 41.43$^{b}$ | 40.64$^{c}$ |
| 50 ppm $GA_3$ | 46.60$^{a}$ | 43.73$^{b}$ | 43.43$^{bc}$ | 42.84$^{ab}$ | 42.14$^{ab}$ | 41.47$^{bc}$ |
| 100 ppm $GA_3$ | 46.73$^{a}$ | 45.24$^{ab}$ | 44.78$^{ab}$ | 43.05$^{ab}$ | 42.64$^{ab}$ | 42.12$^{ab}$ |
| 150 ppm $GA_3$ | 47.68$^{a}$ | 46.39$^{a}$ | 45.29$^{a}$ | 44.60$^{a}$ | 43.52$^{a}$ | 43.08$^{a}$ |
| $LSD_{0.05}$ | 1.53 | 1.85 | 1.593 | 1.98 | 1.34 | 1.26 |
| SE (±) | 0.13 | 0.16 | 0.14 | 0.17 | 0.12 | 0.11 |
| F-test | * | * | ** | * | * | ** |
| CV, % | 3.4 | 4.25 | 3.7 | 4.7 | 3.5 | 3.1 |
| Altitude*$GA_3$ | NS | NS | NS | NS | ** | NS |
| Grand mean | 46.50 | 44.80 | 44.01 | 43.00 | 42.43 | 41.82 |

DAS: Days after storage, SE: Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of variation, NS, *, **, and *** indicate non-significant, significant at $P < 0.05$, significant at $P < 0.01$, and significant at $P < 0.001$ respectively. Means within the column followed by the same letter did not differ significantly at 5% level by DMRT.

At five DAS, the 150 ppm $GA_3$ treatment recorded the highest juice recovery percentage (47.68%), followed by 100 ppm $GA_3$ (46.73%), 50 ppm $GA_3$ (46.60%), and the control, which had the lowest juice recovery percentage (45.01%). The maximum juice recovery percentage was consistently observed with 150 ppm $GA_3$ across the storage intervals: 46.39% at 10 DAS, 45.29% at 15 DAS, 44.60% at 20 DAS, 43.52% at 25 DAS, and 43.08% at 30 DAS. Conversely, the control consistently exhibited the lowest juice recovery percentages: 43.85% at 10 DAS, 42.56% at 15 DAS, 41.52% at 20 DAS, 41.43% at 25 DAS, and 40.64% at 30 DAS. A significant interaction effect between growing altitude and $GA_3$ treatment on juice content was observed only at 25 DAS.

## *Firmness*

The firmness of sweet orange fruits gradually decreased over storage time across all treatments (Table 3). The effect of altitude on fruit firmness was non-significant except at 30 DAS ($P < 0.05$). At 30 DAS, fruits treated with $GA_3$ exhibited higher firmness compared to the control, with fruits at 1230 masl showing significantly greater firmness (4.95 kg $cm^{-2}$). Among $GA_3$ treatments, the highest firmness was recorded with 150 ppm $GA_3$ (6.04 kg $cm^{-2}$), while the control, 50 ppm $GA_3$, and 100 ppm $GA_3$ treatments showed identical firmness values (5.96 kg $cm^{-2}$). The highest firmness values for 150 ppm $GA_3$ were observed consistently across storage intervals: 5.94 kg $cm^{-2}$ at 10 DAS, 5.79 kg $cm^{-2}$ at 15 DAS, 5.68 kg $cm^{-2}$ at 20 DAS, 5.47 kg $cm^{-2}$ at 25 DAS, and 5.19 kg $cm^{-2}$ at 30 DAS. No significant interaction effects were observed between altitude and $GA_3$ treatments on the firmness of sweet orange fruits at any storage interval.

**Table 3.** Effect of growing altitude and postharvest $GA_3$ treatment on firmness (kg $cm^{-2}$) of sweet orange at Rampur, Chitwan, 2021-22.

| Treatment | Firmness (kg $cm^{-2}$) | | | | | |
|---|---|---|---|---|---|---|
| | 5 DAS | 10 DAS | 15 DAS | 20 DAS | 25 DAS | 30 DAS |
| **Growing altitudes (Factor A)** | | | | | | |
| 970 masl | 5.98 | 5.79 | 5.62 | 5.43 | 5.1 | 4.69[b] |
| 1100 masl | 5.97 | 5.84 | 5.73 | 5.49 | 5.23 | 4.91[a] |
| 1230 masl | 5.98 | 5.83 | 5.66 | 5.45 | 5.26 | 4.95[a] |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | 0.20 |
| SE (±) | | | | | | 0.02 |
| F-test | | | | | | * |
| **$GA_3$ (Factor B)** | | | | | | |
| Control | 5.96[b] | 5.72[b] | 5.56[b] | 5.30[c] | 4.91[c] | 4.52[b] |
| 50 ppm $GA_3$ | 5.96[b] | 5.80[ab] | 5.68[ab] | 5.35[bc] | 5.11[bc] | 4.66[b] |
| 100 ppm $GA_3$ | 5.96[b] | 5.82[ab] | 5.65[ab] | 5.50[ab] | 5.28[ab] | 5.03[a] |
| 150 ppm $GA_3$ | 6.04[a] | 5.94[a] | 5.79[a] | 5.68[a] | 5.47[a] | 5.19[a] |
| $LSD_{0.05}$ | 0.06 | 0.14 | 0.14 | 0.19 | 0.23 | 0.24 |
| SE (±) | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 |
| F-test | ** | * | * | ** | *** | *** |
| CV, % | 1.0 | 2.5 | 2.6 | 3.5 | 4.5 | 5.0 |
| Altitude*$GA_3$ | NS | NS | NS | NS | NS | NS |
| Grand mean | 5.98 | 5.82 | 5.67 | 5.46 | 5.19 | 4.85 |

DAS: Days after storage, SE: Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of variation, NS, *, **, and *** indicate non-significant, significant at $P < 0.05$, significant at $P < 0.01$ and significant at $P < 0.001$ respectively. Means within the column followed by the same letter did not differ significantly at 5% level by DMRT.

### *Ascorbic acid content*

The initial ascorbic acid content of sweet orange fruits was 40.31 mg 100 $g^{-1}$ at 970 masl, 38.36 mg 100 $g^{-1}$ at 1100 masl, and 39.32 mg 100 $g^{-1}$ at 1230 masl. By 15 DAS, ascorbic acid content was significantly higher at 970 masl (33.71 mg 100 $g^{-1}$). At five DAS, the highest ascorbic acid content was observed in fruits treated with 150 ppm $GA_3$ (36.78 mg 100 $g^{-1}$), while the lowest was in those treated with 50 ppm $GA_3$ (35.33 mg 100 $g^{-1}$). The 150 ppm $GA_3$ treatment consistently resulted in the highest ascorbic acid content across storage intervals: 34.19 mg 100 $g^{-1}$ at 15 DAS, 33.01 mg 100 $g^{-1}$ at 20 DAS, 32.64 mg 100 $g^{-1}$ at 25 DAS, and 32.07 mg 100 $g^{-1}$ at 30 DAS. In all observations, fruits treated with 150 ppm $GA_3$ maintained higher ascorbic acid levels, while the control treatment consistently exhibited the lowest levels. The interaction effect between altitude and $GA_3$ treatment on ascorbic acid content was non-significant across all observation points (Table 4).

### *Total soluble solids*

The total soluble solid (TSS) content of sweet orange fruits on the first day of storage was 9.5 °Brix at 970 masl, 9.0 °Brix at 1100 masl, and 8.8 °Brix at 1230 masl. The effect of altitude on TSS content was non-significant ($P < 0.05$) across different d of storage.

At five DAS, the control treatment recorded the highest TSS value (10.47 °Brix), while the lowest value was observed in fruits treated with 150 ppm $GA_3$ (9.46 °Brix). The control consistently resulted in the maximum TSS values across subsequent storage intervals: 10.78 °Brix at 10 DAS, 10.82 °Brix at 15 DAS, 10.89 °Brix at 20 DAS, 11.00 °Brix at 25 DAS, and 11.16 °Brix at 30 DAS. Conversely, the lowest TSS values were consistently observed in fruits treated with 150 ppm $GA_3$: 9.84 °Brix at 10 DAS, 9.94 °Brix at 15 DAS, 10.13 °Brix at 20 DAS, 10.15 °Brix at 25 DAS, and 10.20 °Brix at 30 DAS. The interaction effect of altitude and $GA_3$ treatment on TSS content was non-significant across all d of storage (Table 5).

### *Titratable acidity*

At 30 DAS, the highest titratable acidity (TA) value (1.16%) was recorded at 1230 masl, while the lowest value (1.06%) was observed at 970 masl. At five DAS, the highest TA was observed with 150 ppm $GA_3$ (1.33%), and the lowest with the control (1.16%). Similarly, at 10 DAS, 150 ppm $GA_3$ recorded the highest TA (1.24%), while the control had the lowest (1.14%). This trend continued across storage intervals, with 150 ppm $GA_3$ consistently resulting in higher TA values: 1.23% at 15 DAS, 1.21% at 20 DAS, 1.18% at 25 DAS, and 1.17% at 30 DAS. In contrast, the control consistently exhibited the lowest TA values at all observations. A significant interaction effect between altitude and $GA_3$ treatment was observed only at 25 DAS ($P < 0.01$; Table 6).

**Table 4.** Effect of growing altitude and postharvest $GA_3$ treatment on ascorbic acid content (mg 100 $g^{-1}$) of sweet orange at Rampur, Chitwan, 2021-22.

| Treatment | Ascorbic acid (mg 100 $g^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | 5 DAS | 10 DAS | 15 DAS | 20 DAS | 25 DAS | 30 DAS |
| **Growing Altitudes (Factor A)** | | | | | | |
| 970 masl | 37.00$^{a}$ | 33.95 | 33.71$^{a}$ | 32.74 | 32.41 | 31.12 |
| 1100 masl | 35.17$^{b}$ | 33.62 | 32.66$^{b}$ | 32.02 | 31.89 | 31.20 |
| 1230 masl | 36.00$^{ab}$ | 33.30 | 32.66$^{b}$ | 32.09 | 31.72 | 30.60 |
| $LSD_{0.05}$ | 1.22 | NS | 0.921 | NS | NS | NS |
| SE (±) | 0.14 | | 0.11 | | | |
| F-test | * | | * | | | |
| **$GA_3$ (Factor B)** | | | | | | |
| Control | 36.11 | 33.55 | 32.37$^{b}$ | 31.61$^{b}$ | 31.49$^{b}$ | 29.66$^{c}$ |
| 50 ppm $GA_3$ | 35.33 | 33.33 | 32.79$^{b}$ | 32.37$^{ab}$ | 31.83$^{ab}$ | 30.81$^{b}$ |
| 100 ppm $GA_3$ | 36.00 | 33.12 | 32.69$^{b}$ | 32.15$^{ab}$ | 32.07$^{ab}$ | 31.38$^{ab}$ |
| 150 ppm $GA_3$ | 36.78 | 34.51 | 34.19$^{a}$ | 33.01$^{a}$ | 32.64$^{a}$ | 32.07$^{a}$ |
| $LSD_{0.05}$ | NS | NS | 1.06 | 0.95 | 0.79 | 0.99 |
| SE (±) | | | 0.09 | 0.08 | 0.07 | 0.08 |
| F-test | | | ** | * | * | *** |
| CV, % | | | 3.3 | 3.0 | 2.5 | 3.3 |
| Altitude*$GA_3$ | NS | NS | NS | NS | NS | NS |
| Grand mean | 36.06 | 33.62 | 33.01 | 32.28 | 32.01 | 30.97 |

DAS: Days after storage, SE: Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of variation, NS, *, **, and *** indicate non-significant, significant at $P < 0.05$, significant at $P < 0.01$ and significant at $P < 0.001$ respectively. Means within the column followed by same letter did not differ significantly at 5% level by DMRT.

**Table 5.** Effect of growing altitude and postharvest $GA_3$ treatment on total soluble solids (TSS) of sweet orange at Rampur, Chitwan, 2021-22.

| Treatment | TSS (°Brix) | | | | | |
|---|---|---|---|---|---|---|
| | 5 DAS | 10 DAS | 15 DAS | 20 DAS | 25 DAS | 30 DAS |
| **Growing Altitudes (Factor A)** | | | | | | |
| 970 masl | 10.06 | 10.58 | 10.60 | 10.62 | 10.67 | 10.73 |
| 1100 masl | 9.93 | 10.28 | 10.43 | 10.50 | 10.53 | 10.75 |
| 1230 masl | 9.75 | 10.08 | 10.11 | 10.37 | 10.50 | 10.58 |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | NS |
| **$GA_3$ (Factor B)** | | | | | | |
| Control | 10.47$^{a}$ | 10.78$^{a}$ | 10.82$^{a}$ | 10.89$^{a}$ | 11.00$^{a}$ | 11.16$^{a}$ |
| 50 ppm $GA_3$ | 9.93$^{ab}$ | 10.42$^{ab}$ | 10.47$^{ab}$ | 10.56$^{ab}$ | 10.64$^{ab}$ | 10.73$^{ab}$ |
| 100 ppm $GA_3$ | 9.80$^{ab}$ | 10.24$^{ab}$ | 10.27$^{bc}$ | 10.40$^{b}$ | 10.47$^{ab}$ | 10.67$^{b}$ |
| 150 ppm $GA_3$ | 9.46$^{b}$ | 9.84$^{b}$ | 9.94$^{c}$ | 10.13$^{b}$ | 10.15$^{b}$ | 10.20$^{c}$ |
| $LSD_{0.05}$ | 0.64 | 0.59 | 0.5 | 0.46 | 0.52 | 0.42 |
| SE (±) | 0.06 | 0.05 | 0.04 | 0.04 | 0.05 | 0.04 |
| F-test | * | * | * | * | * | * |
| CV, % | 6.6 | 5.8 | 4.9 | 4.5 | 5.2 | 4.1 |
| Altitude*$GA_3$ | NS | NS | NS | NS | NS | NS |
| Grand mean | 9.92 | 10.32 | 10.36 | 10.49 | 10.57 | 10.68 |

DAS: Days after storage, SE: Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of variation, NS, *, **, and *** indicate non-significant, significant at $P < 0.05$, significant at $P < 0.01$ and significant at $P < 0.001$ respectively. Means within the column followed by the same letter did not differ significantly at 5% level by DMRT.

**Table 6.** Effect of growing altitude and postharvest $GA_3$ treatment on titratable acidity of sweet orange at Rampur, Chitwan, 2021-22.

| Treatment | Titratable acidity (%) | | | | | |
|---|---|---|---|---|---|---|
| | 5 DAS | 10 DAS | 15 DAS | 20 DAS | 25 DAS | 30 DAS |
| **Growing Altitudes (Factor A)** | | | | | | |
| 970 masl | 1.20 | 1.14 | 1.15 | 1.11$^{b}$ | 1.08$^{b}$ | 1.06$^{b}$ |
| 1100 masl | 1.22 | 1.19 | 1.19 | 1.21$^{a}$ | 1.18$^{a}$ | 1.12$^{ab}$ |
| 1230 masl | 1.31 | 1.24 | 1.20 | 1.17$^{ab}$ | 1.16$^{a}$ | 1.16$^{a}$ |
| $LSD_{0.05}$ | NS | NS | NS | 0.07 | 0.05 | 0.08 |
| SE (±) | | | | 0.01 | 0.01 | 0.01 |
| F-test | | | | * | *** | * |
| **$GA_3$ (Factor B)** | | | | | | |
| Control | 1.16 | 1.14 | 1.10$^{b}$ | 1.08$^{b}$ | 1.07$^{b}$ | 1.03$^{b}$ |
| 50 ppm $GA_3$ | 1.21 | 1.18 | 1.16$^{ab}$ | 1.19$^{a}$ | 1.11$^{b}$ | 1.12$^{ab}$ |
| 100 ppm $GA_3$ | 1.27 | 1.21 | 1.22$^{a}$ | 1.19$^{a}$ | 1.18$^{a}$ | 1.16$^{a}$ |
| 150 ppm $GA_3$ | 1.33 | 1.24 | 1.23$^{a}$ | 1.21$^{a}$ | 1.18$^{a}$ | 1.17$^{a}$ |
| $LSD_{0.05}$ | NS | NS | 0.18 | 0.08 | 0.06 | 0.1 |
| SE (±) | | | 0.01 | 0.01 | 0.01 | 0.01 |
| F-test | | | * | * | ** | * |
| CV,% | | | 8.9 | 7.3 | 5.4 | 8.8 |
| Altitude*$GA_3$ | NS | NS | NS | NS | ** | NS |
| Grand mean | 1.24 | 1.19 | 1.17 | 1.17 | 1.14 | 1.12 |

DAS: Days after storage, SE: Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of variation, NS, *, **, and *** indicate non-significant, significant at $P < 0.05$, significant at $P < 0.01$ and significant at $P < 0.001$ respectively. Means within the column followed by the same letter did not differ significantly at 5% level by DMRT.

### *TSS: TA ratio*

At the start of the experiment, the TSS: TA ratio of sweet orange fruits was 6.75 at 970 masl, 7.21 at 1100 masl, and 5.75 at 1230 masl. By 20 DAS, the TSS: TA ratio was significantly higher at 970 masl (9.58) and lowest at 1100 masl (8.69). At 30 DAS, the highest ratio was again observed at 970 masl (10.25). Across storage intervals, the control consistently recorded the highest TSS: TA ratios: 9.07 at 5 DAS, 9.57 at 10 DAS, 9.99 at 15 DAS, 10.09 at 20 DAS, 10.22 at 25 DAS, and 10.93 at 30 DAS. Conversely, the lowest TSS: TA ratios were consistently observed in fruits treated with 150 ppm $GA_3$. The interaction between altitude and $GA_3$ concentration had no significant effect on the TSS: TA ratio of sweet orange fruits during the storage period (Table 7).

### *Juice pH*

The effect of altitude on the juice pH of sweet orange fruits was non-significant throughout the storage period ($P < 0.05$). Statistical analysis revealed that the application of $GA_3$ as a post-harvest treatment had no significant effect on juice pH at 5 DAS, 10 DAS, and 15 DAS. However, significant variations were observed at 20 DAS and 25 DAS, with highly significant differences recorded at 30 DAS.

At 20 DAS, the highest juice pH was recorded in the control treatment (3.39), followed by 50 ppm $GA_3$ (3.37), 100 ppm $GA_3$ (3.33), and 150 ppm $GA_3$ (3.33). The control treatment continued to exhibit the highest juice pH values at 25 DAS (3.42) and 30 DAS (3.46). In contrast, the lowest juice pH values were consistently observed with 150 ppm $GA_3$ at 25 DAS (3.35) and 30 DAS (3.38). The interaction between altitude and $GA_3$ concentration had no significant effect on the juice pH of sweet orange fruits during the storage period (Table 8).

### *Shelf life*

The storage room had an average temperature of 14.45 °C and a relative humidity of 87.57%. The fruits exhibited the shortest and longest shelf lives at 970 masl (25.58 d) and 1230 masl (29.75 d), respectively. Treatments with $GA_3$ significantly enhanced shelf life compared to the control group (Table 9). Among the $GA_3$ treatments, 150 ppm resulted in the longest shelf life (34.00 d), significantly outperforming 100 ppm (31.22 d), 50 ppm (27.00 d), and the control (18.78 d). No significant interaction was observed between altitude and $GA_3$ treatment in influencing the shelf life of sweet oranges during storage.

**Table 7.** Effect of growing altitude and postharvest $GA_3$ treatment on TSS: TA ratio of sweet orange at Rampur, Chitwan, 2021-22.

| Treatment | TSS:TA ratio | | | | | |
|---|---|---|---|---|---|---|
| | 5 DAS | 10 DAS | 15 DAS | 20 DAS | 25 DAS | 30 DAS |
| **Growing Altitudes (Factor A)** | | | | | | |
| 970 masl | 8.62 | 9.37 | 9.48 | 9.58$^{a}$ | 9.94$^{a}$ | 10.25$^{a}$ |
| 1100 masl | 8.24 | 8.82 | 8.83 | 8.69$^{b}$ | 8.98$^{b}$ | 9.66$^{ab}$ |
| 1230 masl | 7.68 | 8.27 | 8.59 | 8.94$^{ab}$ | 9.09$^{b}$ | 9.04$^{b}$ |
| $LSD_{0.05}$ | NS | NS | NS | 0.66 | 0.55 | 0.74 |
| SE (±) | | | | 0.08 | 0.06 | 0.08 |
| F-test | | | | * | ** | ** |
| **$GA_3$ (Factor B)** | | | | | | |
| Control | 9.07$^{a}$ | 9.57 | 9.99$^{a}$ | 10.09$^{a}$ | 10.22$^{a}$ | 10.93$^{a}$ |
| 50 ppm $GA_3$ | 8.40$^{ab}$ | 8.93 | 9.23$^{ab}$ | 8.95$^{b}$ | 9.65$^{a}$ | 9.64$^{b}$ |
| 100 ppm $GA_3$ | 7.88$^{ab}$ | 8.63 | 8.48$^{bc}$ | 8.80$^{b}$ | 8.84$^{b}$ | 9.27$^{b}$ |
| 150 ppm $GA_3$ | 7.37$^{b}$ | 8.15 | 8.15$^{c}$ | 8.44$^{b}$ | 8.63$^{b}$ | 8.77$^{b}$ |
| $LSD_{0.05}$ | 1.17 | NS | 0.86 | 0.76 | 0.64 | 0.85 |
| SE (±) | 0.10 | | 0.07 | 0.07 | 0.06 | 0.07 |
| F-test | * | | *** | *** | *** | *** |
| CV,% | 14.7 | | 9.9 | 8.6 | 7.0 | 9.1 |
| Altitude*$GA_3$ | NS | NS | NS | NS | NS | NS |
| Grand mean | 8.18 | 8.82 | 8.96 | 9.07 | 9.34 | 9.65 |

DAS: Days after storage, SE: Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of variation, NS, *, **, and *** indicate non-significant, significant at $P < 0.05$, significant at $P < 0.01$ and significant at $P < 0.001$ respectively. Means within the column followed by the same letter did not differ significantly at 5% level by DMRT.

**Table 8.** Effect of growing altitude and post-harvest $GA_3$ treatment on juice pH of sweet orange at Rampur, Chitwan, 2021-22.

| Treatment | Juice pH | | | | | |
|---|---|---|---|---|---|---|
| | 5 DAS | 10 DAS | 15 DAS | 20 DAS | 25 DAS | 30 DAS |
| **Growing Altitudes (Factor A)** | | | | | | |
| 970 masl | 3.31 | 3.33 | 3.34 | 3.36 | 3.39 | 3.42 |
| 1100 masl | 3.32 | 3.33 | 3.34 | 3.35 | 3.39 | 3.42 |
| 1230 masl | 3.30 | 3.34 | 3.35 | 3.35 | 3.37 | 3.41 |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | NS |
| **$GA_3$ (Factor B)** | | | | | | |
| Control | 3.34 | 3.37 | 3.38 | 3.39$^{a}$ | 3.42$^{a}$ | 3.46$^{a}$ |
| 50 ppm $GA_3$ | 3.28 | 3.34 | 3.35 | 3.37$^{ab}$ | 3.41$^{a}$ | 3.45$^{a}$ |
| 100 ppm $GA_3$ | 3.31 | 3.32 | 3.32 | 3.33$^{b}$ | 3.37$^{ab}$ | 3.39$^{b}$ |
| 150 ppm $GA_3$ | 3.29 | 3.33 | 3.32 | 3.33$^{b}$ | 3.35$^{b}$ | 3.38$^{b}$ |
| $LSD_{0.05}$ | NS | NS | NS | 0.05 | 0.05 | 0.04 |
| SE (±) | | | | 0.004 | 0.004 | 0.004 |
| F-test | | | | * | * | ** |
| CV,% | 1.5 | 1.6 | 1.7 | 1.4 | 1.6 | 1.3 |
| Altitude*$GA_3$ | NS | NS | NS | NS | NS | NS |
| Grand mean | 3.31 | 3.34 | 3.34 | 3.36 | 3.39 | 3.42 |

DAS: Days after storage, SE: Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of variation, NS, *, **, and *** indicate non-significant, significant at $P < 0.05$, significant at $P < 0.01$ and significant at $P < 0.001$ respectively. Means within the column followed by the same letter did not differ significantly at 5% level by DMRT.

**Table 9.** Effect of growing altitude and postharvest $GA_3$ treatment on shelf life of sweet orange at Rampur, Chitwan, 2021-22.

| Treatment | Shelf life (d) |
|---|---|
| **Growing altitudes (Factor A)** | |
| 970 masl | 25.58[b] |
| 1100 masl | 27.92[a] |
| 1230 masl | 29.75[a] |
| $LSD_{0.05}$ | 2.20 |
| SE (±) | 0.25 |
| F-test | ** |
| **GA3 (Factor B)** | |
| Control | 18.78[d] |
| 50 ppm $GA_3$ | 27.00[c] |
| 100 ppm $GA_3$ | 31.22[b] |
| 150 ppm $GA_3$ | 34.00[a] |
| $LSD_{0.05}$ | 2.54 |
| SE (±) | 0.22 |
| F-test | *** |
| CV,% | 9.4 |
| Altitude*$GA_3$ | NS |
| Grand mean | 27.75 |

DAS: Days after storage, SE: Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of variation, NS, *, **, and *** indicate non-significant, significant at $P < 0.05$, significant at $P < 0.01$ and significant at $P < 0.001$ respectively. Means within the column followed by the same letter did not differ significantly at 5% level by DMRT.

## Discussion

The higher physiological weight loss observed in sweet orange fruits grown at higher altitudes, compared to those from lower altitudes when stored at lower elevations, can be attributed to environmental differences. Fruits grown at higher altitudes experience lower temperatures and reduced atmospheric pressure, leading to increased respiration and water loss during storage at lower elevations. In terms of post-harvest treatments with $GA_3$, the highest physiological weight loss occurred in the control group, followed by fruits treated with 50 ppm $GA_3$, 100 ppm $GA_3$, and 150 ppm $GA_3$. These results align with the findings of Sahithya et al. (2015), who reported that $GA_3$ helps plants retain water by reducing both respiration and transpiration rates. Furthermore, $GA_3$ exhibits anti-senescent and anti-respirant properties that inhibit catabolic activities, thereby minimizing weight loss during storage (Brahmachari and Rani, 2005). $GA_3$ also increases polyamine levels and enhances the activity of enzymes involved in their synthesis, delaying senescence and reducing physiological processes that cause weight loss (Valero et al., 1998).

Fruits grown at an altitude of 970 masl had significantly higher juice content, consistent with Dhanaraj et al. (1986). This enhanced juice retention is likely due to metabolic variations in ripening rates influenced by elevation. Juice content increased with higher concentrations of $GA_3$ but decreased over time across all treatments, regardless of altitude or $GA_3$ concentration. The decline in juice percentage during storage likely results from moisture loss from the fruit surface, as noted by Kakade et al. (2021) and Hemalatha et al. (2015). Interestingly, $GA_3$-treated fruits retained more juice during storage compared to untreated fruits, as $GA_3$ acts as a barrier, reducing moisture loss.

Fruit firmness decreased over the storage period across all treatments and altitudes, a finding consistent with Gracia and Cantín (2022), who observed that apples from higher altitudes exhibited greater firmness due to cooler temperatures and thicker peels. Fruits treated with $GA_3$, particularly with 150 ppm, exhibited significantly higher firmness than those in the control group, corroborating the results of Chhetri and Ghimire (2023) in mangoes. Firmness declined with storage duration, a pattern previously reported by Sidhu et al. (2006) and Yadav et al. (2010). This decline is likely due to moisture loss and the loosening of cell walls, as pro-pectin, a cementing agent binding cellulose and hemicellulose, transforms into soluble pectin, weakening cell wall cohesion. $GA_3$ inhibits ethylene synthesis, a key hormone in fruit ripening and softening, further contributing to firmness retention during storage (Rana, 2006).

Ascorbic acid levels were higher in fruits from lower altitudes and lowest in those from higher altitudes during storage, a trend also observed by

Guevara-Terán et al. (2023) in strawberries. The elevated ascorbic acid content in fruits from lower altitudes can be attributed to the warmer climate, which accelerates ascorbic acid biosynthesis. Across all treatments, ascorbic acid content decreased as the storage period progressed, likely due to the activity of the ascorbate oxidase enzyme, which converts ascorbic acid to dehydroascorbic acid (Streif et al., 1997).

The study found that as the concentration of $GA_3$ increased, ascorbic acid content also increased. While earlier observations showed non-significant differences, $GA_3$-treated fruits exhibited significantly higher ascorbic acid levels compared to the control. This finding aligns with Devkota et al. (2019), who reported higher ascorbic acid content in $GA_3$-treated tomatoes and lower levels in untreated fruits throughout storage. The results suggest that $GA_3$ effectively slows the degradation of ascorbic acid in sweet orange fruits during storage. The highest ascorbic acid degradation occurred in control fruits, likely due to senescence, accompanied by rapid respiration, ethylene production, and decay.

TSS content increased with the storage period across all treatments, but fruits from different altitudes showed no significant variation in TSS throughout storage. The increase in TSS over time can be attributed to moisture loss, polysaccharide hydrolysis, and juice concentration caused by dehydration (Jadhao et al., 2008). TSS levels were significantly lower in $GA_3$-treated fruits compared to the control. The highest concentration of $GA_3$ (150 ppm) recorded the lowest TSS value, while the control treatment recorded the highest. The increased respiration rate, microbial spoilage, fruit degradation, and elevated ethylene production associated with ripening and senescence likely contributed to higher TSS levels in control fruits compared to $GA_3$-treated ones. These findings align with previous studies that reported a significant effect of $GA_3$ on TSS in various fruits, including sweet orange (Hemalatha et al., 2015), mandarin (Paudel et al., 2020), barhi dates (Atia et al., 2018), mango (Yadav et al., 2022), and banana (Ghimire et al., 2021; Tapas, 2016).

In all treatments, TA decreased during storage, with the rate of decrease varying based on altitude and GA3 concentration. This decline in TA over time is likely due to the utilization of organic acids in the tricarboxylic acid cycle during respiration (Rokaya et al., 2016). Fruits from higher altitudes consistently exhibited higher TA values compared to those from lower altitudes throughout the storage period. These results align with Ayer and Shrestha (2018), who suggested that cooler climates at higher altitudes promote greater accumulation of organic acids and slower ripening processes. Higher concentrations of GA3 were associated with higher TA values, consistent with findings by Chhetri and Ghimire (2023) in mango and Paudel et al. (2020) in mandarin, where post-harvest GA3 treatment preserved higher TA levels compared to untreated fruits. The TSS: TA ratio increased significantly in fruits from 970 masl due to a sharper rise in TSS and a more pronounced decline in TA during storage. This ratio rose in all treatments with storage time, driven by a decrease in TA and an increase in TSS content (Singh and Abidi, 1986). However, as GA3 concentration increased, the TSS: TA ratio decreased across all treatments. The control group exhibited the highest TSS: TA ratio due to organic acid metabolism and dehydration-induced increases in TSS. Similar results have been reported in mandarin (Paudel et al., 2020), mango (Chhetri and Ghimire, 2023), and banana (Ghimire et al., 2021).

The pH of the fruit juice declined over the storage period in all treatments, consistent with studies on papaya (Mahmud et al., 2008), sweet orange (Bhandari et al., 2020), and sweet pepper (Aryal, 2022). The reduction in acidity, attributed to the conversion of organic acids into sugars and their utilization as substrates for respiration (Marpudi et al., 2013; Batista-Silva et al., 2018), led to an increase in juice pH. However, altitude had no significant effect on juice pH throughout the storage period, aligning with the findings of Zenginbal and Ozcan (2018) in kiwi fruit. The pH decreased with higher GA3 concentrations due to slower organic acid breakdown and reduced respiration and senescence rates. This result is consistent with observations by Chhetri and Ghimire (2023) in mango and Ghimire et al. (2021) in banana, where higher GA3 concentrations resulted in the lowest juice pH. Gibberellic acid appears to slow respiration and metabolic activity, thereby lowering juice pH (Jain and Mukherjee, 2000).

Contamination and decay significantly impact the shelf life of fruits. Sweet oranges from higher altitudes had longer shelf lives, likely due to their thicker peels, which act as barriers to moisture loss and microbial spoilage. GA3 treatment further extended shelf life, with higher concentrations showing the greatest effect. GA3 likely minimizes water loss by forming a protective barrier layer. Rao and Chundawat (1988) reported that GA3-treated fruits exhibited slower starch-to-sugar conversion, reduced peroxidase activity, and lower ethylene generation. Similarly, Hu et al. (2018) highlighted

the anti-senescent and anti-respirant properties of GA3, which inhibit catabolic activities and reduce water and weight loss during storage. These findings are consistent with studies by Paudel et al. (2020) and Chhetri and Ghimire (2023) in mandarin, Ghimire et al. (2021) in banana, Yadav et al. (2022) and Sakhale et al. (2009) in mango, and Hemalatha et al. (2015) in sweet orange, all of which demonstrated that GA3 treatment significantly extends the shelf life of fruits.

## Conclusions

The quality attributes and shelf life of sweet oranges were influenced by both orchard altitude and post-harvest treatment with $GA_3$. While fruits from different altitudes displayed non-significant variations in most quality parameters, specific trends were observed. Fruits grown at lower altitudes exhibited significantly lower physiological loss in weight and higher juice content, whereas those from higher altitudes showed significantly lower TSS: TA ratios, higher titratable acidity, and extended shelf life. The application of gibberellic acid at a concentration of 150 ppm yielded the most favorable results for preserving post-harvest quality and extending shelf life. However, the interaction between growing altitude and $GA_3$ treatment had no significant effect on the quality parameters of sweet oranges.

### Conflict of Interest

The authors indicate no conflict of interest in this work.

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## References

Arun GC, Ghimire K. 2019. Estimating post-harvest loss at the farm level to enhance Food Security: A Case of Nepal. International Journal of Agriculture Environment and Food Sciences 3, 127–136. DOI: 10.31015/jaefs.2019.3.3

Aryal S. 2022. Use of nano-zinc oxide as postharvest treatment for postharvest loss reduction and quality maintenance of sweet pepper (*Capsicum annum* L.) in Chitwan, Nepal. MSc. Thesis, Agriculture and Forestry University, Faculty of Agriculture, Rampur, Chitwan, Nepal.

Atia A, Abdelkarim D, Younis M, Alhamdan A. 2018. Effects of Gibberellic Acid (GA3) and Salicylic Acid (SA) postharvest treatments on the quality of fresh Barhi dates at different ripening levels in the Khalal maturity stage during controlled atmosphere storage. International Journal of Agriculture and biological Engineering 11(3), 211-219. DOI: 10.25165/j.ijabe.20181103.3760

Ayer DB, Shrestha GK. 2018. Altitudinal effects on fruit quality parameters of sweet orange (*Citrus sinensis* Osbeck). Nepalese Journal of Agricultural Sciences 16, 24-28.

Bhandari R, Acharya P, Sapkota P, Acharya M, Adhikari P, Upreti R. 2020. Effect of post harvest treatments on shelf life and quality of sweet orange (*Citrus Sinensis*) in GAASC, Gokuleshwor, Baitadi. Tropical Agroecosystems 1(2), 88-91. DOI:10.26480/taec.02.2020.88.91

Bhattarai DR. 2018. Postharvest horticulture in Nepal. Horticulture International Journal 2 (6), 458–460. DOI: 10.15406/hij.2018.02.00096

Brahmachari VS, Rani R. 2005. Shelf life extension in guava with pre-harvest spray of certain growth substances and polyethene wrapping. Haryana Journal of Horticultural Sciences 34 (1-2), 36-38.

Chhetri BP, Ghimire S. 2023. Post-harvest treatment of different concentrations of gibberellic acid on the physicochemical characteristics and shelf life of mango (*Mangifera indica* L. cv. Malda). 2nd International Conference on Horticulture, Nepal, 11, 15-22. DOI:10.13140/RG.2.2.19055.30887

Dashora LK, Mohammed S. 1988. Effect of 2,4-D, wax emulsion and their combination on shelf life of sweet orange (*Citrus Sinensis* Osbeck.) cv. Mosambi. South Indian Horticulture 36 (3), 172 – 176.

Devkota P, Khadka R, Gaire KR, Dhital PR. 2019. Effects of chemical additives on shelf life of tomato (*Solanum lycopersicum*) during storage. Journal of Agriculture and Forestry University, 3, 69 -76. DOI:10.5281/zenodo.5557988

Dhanaraj S, Krishnaprakash MS, Arvindaprasad B, Ananthakrishna SM, Krishnaprasad CA, Narasimham P. 1986. Effect of orchard elevation on maturity and quality of apples. Journal of Food Quality 9 (3), 129-142. DOI: https://doi.org/10.1111/j.1745-4557.1986.tb00783.x

Ghimire R, Yadav PK, Khanal S, Shrestha Ak, Devkota AR, Shrestha J 2021. Effect of different levels of gibberellic acid and kinetin on quality and self-life of banana (*Musa spp.*) fruits. Heliyon

7 (9), e08019. DOI: 10.1016/j.heliyon.2021.e08019

Ghosh SN, Tarai RK, Ahkawat TR. 2022. Plant Growth Regulators in Tropical and Sub-tropical Fruit Crops. Delhi: Narendra Publishing House. DOI: 10.1201/9781003300342

Gomez KA, Gomez AA. 1984. Statistical Procedures for Agricultural Research (2 ed.). (John Wiley and Sons, Ed.) New York.

Gracia A, Cantín CM. 2022. Effects of consumers' sensory attributes perception on their willingness to pay for apple cultivars grown at different altitudes: are they different? Foods 11, 3022. DOI: 10.3390/foods11193022

Guevara-Terán M, Gonzalez-Paramás AM, Beltrán-Noboa A, Giampieri F, Battino M, Tejera E, Alvarez-Suarez JM. 2023. Influence of altitude on the physicochemical composition and antioxidant capacity of strawberry: a preliminary systematic review and meta-analysis. Phytochemistry Reviews 22(6), 1567-1584. DOI: 10.1007/s11101-022-09834-z

Hemalatha V, Dilip babu J, Shiva Sankar A. 2015. Influence of growth regulators on the shelf life of sweet orange cv. Sathgudi. Journal Plant Archives 15 (2), 1101-1106.

Hu Z, Weijian L, Yali F, Huiquan L. 2018. Gibberellic acid enhances postharvest toon sprout tolerance to chilling stress by increasing the antioxidant capacity during shortterm cold storage. Scientia Horticultura 237, 184- 191. DOI:10.1016/J.SCIENTA.2018.04.018

Jadhao SD, Borkar PA, Borkar SL, Bakane PH, Murumkar RP. 2008. Effect of different treatments and packaging materials on biochemical changes during storage of kagzi lime. Asian Journal of Biological Sciences 3, 247-250.

Jain SK, Mukherjee S. 2000. Postharvest application of GA3 to delay ripening in mango *(Mangifera indica* L. cv. Langra). Journal of Eco-Physiology 4(1/2), 27-30.

Kaini BR. 2013. Package of Practices for Junar production and post-harvest management. Tinkune, Kathmandu, Nepal: JICA–Nepal & JCCU.

Kakade PB, Chavan BB, Kakde AM, Jadhav SS. 2021. Effect of different chemicals along with wax on physical parameters and shelf life of sweet orange cv. Nucellar. Indian Journal of Agriculture and Allied Sciences 7(4), 45-50.

Levy Y, Bar-Akiva A, Vaadia Y. 1978. Influence of irrigation and environmental factors on grapefruit acidity. Journal of American Society of Horticulture Science 103(1), 73-76. DOI: 10.21273/JASHS.103.1.73

Liu QY, Heying E, Tanumihardjo SA 2012. History, global distribution, and nutritional importance of citrus fruits. Institute of Food Technologists 2, 530-545. DOI: https://doi.org/10.1111/j.1541-4337.2012.00201.x

Mahmud TM, Al Eryani-Raqeeb A, Omar SS, Zaki AM, Abdul-Rahman AE. 2008. Effects of different concentrations and applications of calcium on storage life and physicochemical characteristics of papaya (*Carica papaya* L.). American Journal of Agricultural and Biological Science 3(3), 526-533
DOI: https://doi.org/10.3844/ajabssp.2008.526.533

Marpudi SL, Pushkala R, Srividya N. 2013. Aloe vera gel coating for post harvest quality maintenance of fresh fig fruits. Research Journal of Pharmaceutical, Biological and Chemical Sciences 4 (1), 878-887.

MoALD. 2023. Statistical Information on Nepalese Agriculture (2021-22). Ministry of Agriculture & Livestock Development, Planning and Development Cooperation Coordination Division, Government of Nepal, Singhadurbar, Kathmandu, Nepal.

Olabinjo OO, Ogunlowo AS, Ajayi OO, Olalusi AP. 2017. Analysis of physical and chemical composition of sweet orange (*Citrus sinensis*) peels. International Journal of Environment, Agriculture and Biotechnology 2(4), 2201- 2206. DOI: 10.22161/ijeab/2.4.80

Paudel A, Baral D, Acharya H, Dhital M. 2020. Effect of Post-Harvest Dipping and Various Packaging Materials on Quality Traits of Mandarin (*Citrus Reticulata* Blanco.). Acta Chemica Malaysia, 3, 14-20. DOI:10.2478/acmy-2019-0007

Rana MK. 2006. Ripening changes in fruits and vegetables-A review. Haryana Journal of Horticultural Sciences 35 (3-4), 271-278.

Rao DV, Chundawat BS. 1988. Ripening changes in Sapota Cv. Kalipati at ambient temperature. Indian Journal of Plant Physiology 31, 205-208.

Rokaya PR, Baral DR, Gautam DM, Shrestha AK, Paudyal KP. 2016. Effect of altitude and maturity stages on quality attributes of mandarin (*Citrus reticulata* Blanco). American Journal of Plant Sciences 7(06), 958.

Sadasivam S, Manickam A. 1991. Vitamins. Biochemical Methods. Coimbatore, India.

Sahithya BR, Manjunatha G, Kulapati H, BS S. 2015. Phytohormones and signal molecules for shelf life enhancement of Grand Naine banana fruit. The Bioscan 10, 141-145.

Saini RS, Sharma KD, Dhankhar OP, Kaudishk RA. 2001. Laboratory manual of analytical techniques in Horticulture. Jodhpur, India: Agrobios.

Sakhale BK, Pawar VN, Kapse BM. 2009. Studies on extension of shelf life of Kesar mango *(Mangifera indica* L.). Acta Horticulturae (ISHS) 820, 643-652. DOI:10.17660/ACTAHORTIC.2009.820.80

Shivani, Bhosale AM, Galande HR, Syed SJ. 2021. Studies on post harvest application of different chemicals on Plw, shelf life, ripening percent and spoilage percent of sapota cv. Kalipatti. The Pharma Innovation Journal 10(12), 1675-1681.

Sidhu GS, Dhillon WS, Mahajan BC. 2006. Effect of waxing and packaging on storage and shelf life of pear cv. Punjab Beauty. Haryana Journal of Horticultural Sciences 35 (1-2), 51-56.

Singh A, Abidi AB. 1986. Studies on physico-chemical attributes of some promising litchi (*Litchi chinensis* Sonn.) cultivars during ripening. New Delhi Journal of Agricultural Research 1, 70-73.

Streif J, Agar IT, Bangerth F. 1997. Effect of high CO (2) and controlled atmosphere (CA) on the ascorbic and dehydroascorbic acid content of some berry fruits. Netherlands: Postharvest Biology and Technology DOI:10.1016/S0925-5214(97)01414-2

Valero D, Martinez D, Riquelme F, Serrano M. 1998. Polyamine response to external mechanical bruising in two Mandarin cultivars. Hortscience 33, 1220–1223.

WCO. 2022. World Citrus Organization 2021-22 Statistics. World citrus organization.

Yadav M, Kumar N, Singh DB, Singh GK. 2010. Effect of post harvest treatments on shelf life and quality of Kinnow mandarin. Indian Journal of Horticulture 67 (2), 243-248.

Yadav S, Yadav SS, Adhikari N, Sah RK, Gupta S. 2022. Effects of gibberellic acid (GA3) on shelf life and physiochemical properties of mango (*Mangifera indica* L. var Bombay green). Archives of Agriculture and Environmental Science 7 (4), 541-548. DOI:10.26832/24566632.2022.0704010

Zeng Q, Dong G, Tian L, Wu H, Ren Y, Tamir G, Yu, H. 2020. High altitude is beneficial for antioxidant components and sweetness accumulation of rabbiteye blueberry. Frontiers in Plant Science 11, Article 573531.

Zenginbal H, Ozcan M. 2018. Effect of altitude on growth-development and fruit quality attributes of kiwifruit (*Actinidia deliciosa* Planch) cultivation. Pakistan Journal of Agricultural Science 55 (4), 843-851. DOI: 10.21162/PAKJAS/18.5417