Plant Archives Vol. 26, No. 2, 2026 pp. 3203-3208 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.2.444

ASSESSMENT OF FRUIT QUALITY PARAMETERS IN CHILLING INJURY INDUCED RED DRAGON FRUIT UNDER AMBIENT CONDITIONS

Kanaka Lakshmi M.[1], Vijay Rakesh Reddy S.[2*], Preethi Palpandian[2], Sudhakar Rao D.V.[2], Suneel Subray Hegde[1], Supriya M.S.[1] and Ashwija B.N.[1]

[1]Post Harvest Management, ICAR-Indian Institute of Horticultural Research, IARI Outreach Campus, Bengaluru-560089, India

[2]Division of PHT&AE, ICAR-Indian Institute of Horticultural Research, Bengaluru-560089, India

*Corresponding author: drrakesh.reddyiihr@gmail.com

(Date of Receiving-10-06-2026; Date of Revision-26-07-2026; Date of Acceptance-12-08-2026)

ABSTRACT

The present study was undertaken to determine the optimum low-temperature storage conditions for extending the storage life of dragon fruit while maintaining quality and minimizing chilling injury. Fruits were stored at three temperatures (3, 7 and 10°C) and evaluated for chilling injury, firmness, ascorbic acid, titratable acidity and betalain content during cold storage and subsequent exposure to ambient conditions. Fruits stored at 3oC exhibited superior retention of firmness, ascorbic acid, titratable acidity and betalain content compared with other storage temperatures. However, 3°C exhibited chilling injury symptoms during prolonged storage and intensified following transfer to ambient conditions. At 20th day of storage, fruits at 3°C showed lower losses of ascorbic acid and titratable acidity during subsequent ambient exposure, while betalain content was retained better. Storage at 7°C provided an effective balance between quality preservation and chilling injury prevention, maintaining relatively higher levels of firmness, ascorbic acid, titratable acidity and betalains without visible chilling injury. Hence, 7°C was identified as the most suitable storage temperature for maintaining postharvest quality and extending the storage potential of dragon fruit.

***Key words*:** Dragon fruit, chilling injury, shelf life, postharvest quality, marketability.

Introduction

Red-fleshed dragon fruit (*Selenicereus polyrhizus* L.) has emerged as a commercially significant tropical fruit in recent years. Its' vibrant red-purple coloration, mild flavour, and high antioxidant content attributed largely to betalain pigments and phenolic compounds has driven a steady expansion in global cultivation and export markets. Despite increasing consumer demand, postharvest losses remain a major constraint for producers and supply chain operators. The fruit is highly perishable, loses moisture rapidly after harvest, and is susceptible to mechanical damage during handling and transport. Under ambient tropical conditions, marketable shelf life is typically limited to five to seven days (Lata *et al*., 2024).

Cold storage is the most widely employed strategy for extending the postharvest life of fresh horticultural produce. By reducing respiration rates and slowing metabolic activity, low temperatures delay senescence, suppress pathogen development, and minimize moisture loss. However, the storage of fruits of tropical and subtropical origin at low temperatures is constrained by their inherent sensitivity to chilling injury (CI), a physiological disorder that occurs in fruits due to low temperatures below a critical species-specific threshold but above freezing (Balois-Morales *et al*., 2013; Nguyen *et al*., 2018). The symptoms of chilling injury develop not under low temperature storage but progressively developed during subsequent shift to ambient conditions (Nguyen *et al*., 2018). Common symptoms in affected fruits displayed surface pitting, peel discolouration, water-soaked lesions, bract wilting, and abnormal ripening (Nguyen *et al*., 2018; Castro, 2017).

In red-fleshed dragon fruit, the exact temperature threshold at which chilling injury symptoms first appear remains unknown. The interactions between storage temperatures and duration on the severity of chilling injury have also not been adequately characterized. Establishing this threshold is important to optimize cold chain management and predicting storage outcomes, but also to provide a practical baseline that researchers can use to evaluate the success of postharvest treatments. Hence, the present study was designed to determine the critical temperature threshold for chilling injury development in red-fleshed dragon fruit. Fruits were stored at 3, 7 and 10°C for 30 days, followed by transfer to ambient conditions to observe whether chilling injury symptoms developed during subsequent storage. Changes in biochemical parameters were analyzed at different intervals during cold storage and subsequent ambient storage to track the onset and progression of cold stress. By comparing fruit responses across the different temperature regimes, we aimed to identify the critical threshold at which chilling injury symptoms first appear and subsequently increase in severity. The findings establish a baseline for understanding the chilling sensitivity of this species and provide a reference point for future studies investigating strategies to mitigate chilling injury in red-fleshed dragon fruit.

Materials and Methods

Dragon fruit and chilling injury induction

Fully matured uniform size fruits dragon fruits were harvested from experimental station, ICAR-IIHR, Hirehalli and transported to fresh fruit handling lab, Division of Post Harvest Technology and Agri. Engineering, ICAR-IIHR, Bengaluru. The fruits were sorted and stored in 3°C, 7°C and 10°C (RH-90-95%) for 20 and 30 days, taken out and kept under ambient conditions and chilling injury symptoms started at 18th h and the fruits we stored upto 84 h under ambient conditions. The biochemical changes of these fruits were recorded in triplicates.

Dragon fruit quality parameters

Chilling injury index:

Chilling injury (CI) in fruits from each treatment was evaluated visually by estimating the proportion of the fruit surface exhibiting pitting or browning. The severity of injury was classified on a five-point scale as follows:

0 = no injury;

1 = 1–10% of the surface affected;

2 = 11–25% affected;

3 = 26–50% affected; and

4 = more than 50% affected. The chilling injury index (CII) was subsequently determined using the following formula.

Physiological loss in weight:

The weight of individual fruit sample in each treatment was recorded regularly using electronic balance (Make: Saurtorius; Model: BSA8201-CW) and the cumulative physiological loss in weight (PLW) was calculated with the following formula:

$$PLW\ (\%) = \frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100$$

Fruit firmness:

The firmness of the dragon fruit was measured as the force required for puncturing using an Instron-Universal testing machine (Model 4201, USA). A probe of 8 mm diameter was used, set at a cross head speed of 100 mm min^{-1} with 25 kg load using a 500 kg load cell. The firmness was calculated and expressed as kg/cm^2.

Total Soluble Solids:

Total soluble solids (TSS) content of fruit juice samples was measured using a hand-held refractometer (Make: Erma Optical Works Ltd., Tokyo, Japan; Range: 0–32°Brix) at room temperature (27±2°C).

Titratable acidity:

Total titratable acidity of fruit pulp samples were determined by the titration method as described by Ranganna (1986).

Ascorbic acid:

Ascorbic acid or Vitamin C content of fruit pulp samples were determined by the 2,6-dichlorophenol indophenol titration method as described by Ranganna (1986).

Betalain content:

For estimation of total betalain content, 1 g of fruit pulp in 25 ml methanol:aqueous (1:1) extract was collected, measured at 538 nm using a spectrophotometer (Sandate-Flores *et al.*, 2016) . Total betalain content was calculated and expressed as mg BCE 100 g^{-1} fresh weight (FW).

Statistical analysis

Observations recorded under different treatments in this experiment were analyzed using a completely randomized design (CRD), and the data were subjected to analysis of variance (ANOVA), and treatment means were compared using the Least Significant Difference (LSD) test at $P < 0.05$. All statistical analyses were carried out using the R software (Version 4.6.1) (Gopinath *et al.*, 2021).

Results and discussion

Chilling injury and Physiological loss in weight

The fruits stored at 3±1°C showed chilling injury symptoms at 20th day of storage (0.088), whereas the symptoms where prominently increasing from 18th h after shifting to ambient conditions and the index value ranged from 0.25 to 1.00 till 34 h. The chilling injury index of fruits at 30th day of low temperature (3°C) was 0.75 and the values reached 1.00 at its 42rd h of shifting to ambient conditions. At other storage temperatures (7°C & 10°C), no chilling injury symptoms were recorded under low temperatures or after shifting to ambient conditions (Fig. 1).

Physiological loss in weight (PLW) of fruits was recorded in all the treatments invariable to their low temperature storage conditions (Fig. 2). But 3°C temperature enhanced the reduction in PLW in 20 days as well as 30 days shifted fruits. Whereas, in other low temperature stored fruits, consistent PLW was recorded which is on higher side than that of 3°C storage. When fruits stored in lower temperatures, the lowest temperature always showed less PLW and this has been observed in many tropical fruit crops including dragon fruit (Castro, 2017; Tanpure *et al*., 2024).

Fruit firmness

The retention of firmness was recorded in fruits shifted from low temperatures (3°C, 7°C and 10°C,) to ambient conditions and gradual decline in firmness was observed in all treatments (Fig. 3) during ambient storage. Even then, highest retention of fruit firmness was recorded in 3°C stored fruits. At the 20th day of storage, the fruits maintained a firmness (7.61 kg/cm^2), which further decreased after shifting to ambient conditions, with values ranging from 6.73 kg/cm^2 to 3.10 kg/cm^2 during 18 to 34 h. At the 30th day of storage under 3oC, fruit firmness decreased 6.22 kg/cm^2, followed by a further reduction after shifting to ambient conditions, reaching 3.77 kg/cm^2 at 42 h. Fruits stored at 7°C and 10°C also exhibited a

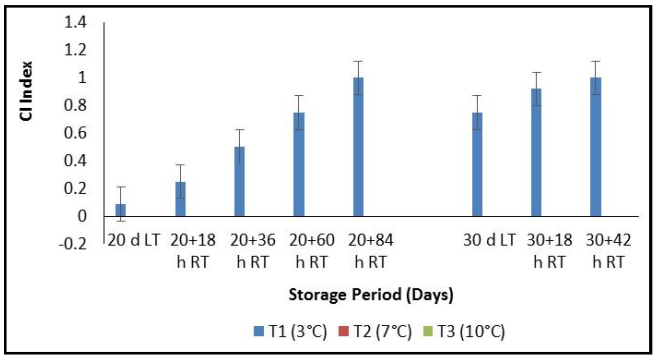


Fig. 1: Chilling injury index of room temperature shifted dragon fruits previous stored at different low temperatures.

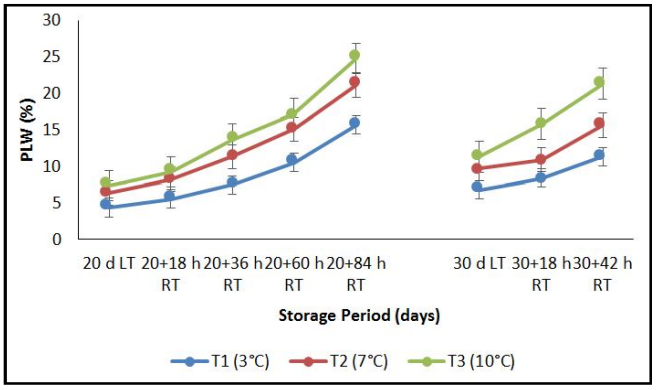


Fig. 2: Physiological loss in weight of room temperature shifted dragon fruits previous stored at different low temperatures.

gradual decline in firmness throughout the storage period and subsequent ambient exposure; however, the extent of firmness loss varied with storage temperature.

Total Soluble Solids

The Total Soluble Solids (TSS) of the fruits stored at low temperatures (LT) showed a gradual decline during storage, with a more pronounced reduction observed after shifting the fruits to ambient conditions (Fig. 4). The TSS value at 20th day of storage under 3°C was 15.87°Brix, which further decreased after shifting to ambient conditions, ranging from 15.17°Brix to 12.88°Brix at 18–34 h for 20 days LT samples. At 30th day of storage under low temperature (3°C), the fruits recorded a TSS value of 13.62°Brix, which further declined to 10.92°Brix after 42 h of shifting to ambient conditions. Fruits stored at 7°C and 10°C also exhibited a gradual reduction in TSS during storage. However, the rate of TSS loss was comparatively lower than that observed at 3°C (Fig. 4).

Titratable acidity

A progressive decline in titratable acidity was observed across all storage conditions, with the extent of decline influenced by storage temperature and subsequent exposure to ambient conditions (Fig. 5). During cold storage, fruits stored at 7°C retained the highest titratable acidity at 20 days (0.231%), followed by those stored at

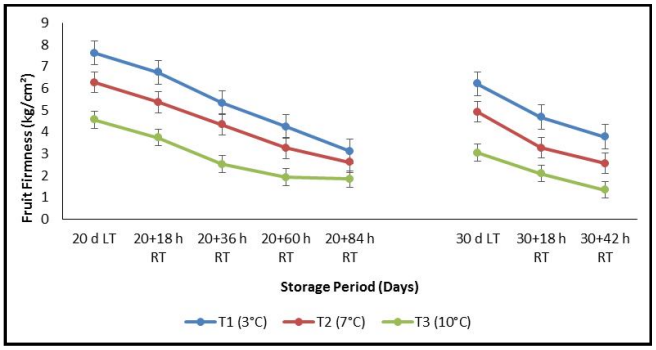


Fig. 3: Firmness of room temperature shifted dragon fruits previous stored at different low temperatures.

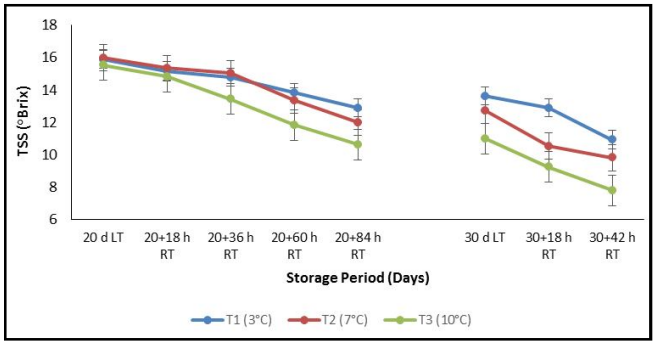


Fig. 4: TSS of room temperature shifted dragon fruits previous stored at different low temperatures.

3°C (0.211%), whereas fruits stored at 10oC recorded the lowest value (0.153%). The better retention of acidity at 3°C and 7°C may be attributed to reduced respiratory and enzymatic activities, thereby limiting the consumption of organic acids through the tricarboxylic acid (TCA) cycle (Nguyen *et al*., 2023). In contrast, the greater decline at 10°C may be associated with enhanced respiratory metabolism and accelerated organic acid catabolism (Castro, 2017; Balois-Morales *et al*., 2013). The greater retention of titratable acidity at lower storage temperatures is consistent with the findings of Lata *et al*., (2023), who reported better acidity retention at 6°C than at 10°C during storage. Overall, storage at 3°C and 7°C was more effective in preserving titratable acidity than 10°C, although prolonged storage and subsequent ambient exposure accelerated acidity loss.

Ascorbic acid content

A consistent decline in ascorbic acid content was observed across all storage temperatures, with the rate of decline increasing during subsequent exposure to ambient conditions. During cold storage, fruits stored at 7°C retained the highest ascorbic acid content at 20 days (7.82 mg/100 g), followed by those stored at 3°C (7.43 mg/100 g), whereas fruits stored at 10oC recorded the lowest value (6.18 mg/100 g). By the 30th day, the ascorbic acid content of fruits stored at 3°C and 7°C

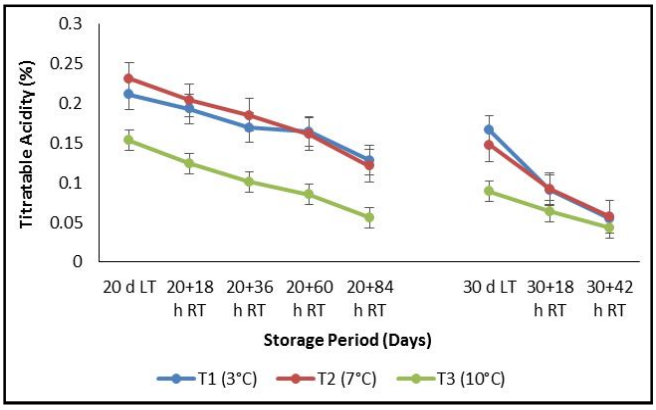


Fig. 5: Titrable acidity of room temperature shifted dragon fruits previous stored at different low temperatures.

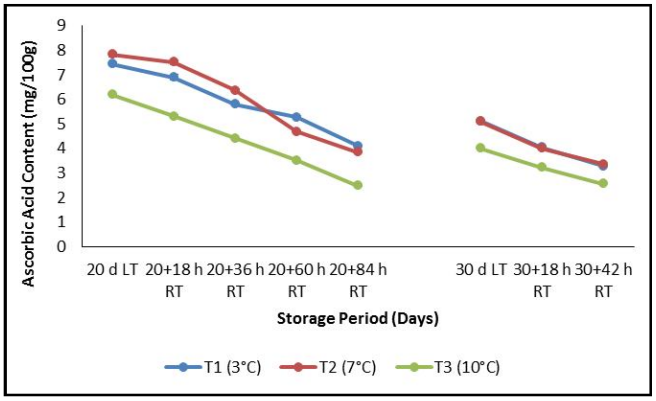


Fig. 6: Ascorbic acid of room temperature shifted dragon fruits previous stored at different low temperatures.

declined to 5.11 and 5.09 mg/100 g, respectively. Following transfer to ambient conditions, a further pronounced decline was observed, with fruits previously stored at low temperatures showing reductions of 39, 51 and 60%, respectively, after 84 h. The corresponding ascorbic acid contents were 4.11, 3.84 and 2.48 mg/100 g, respectively. Overall, fruits stored at 3 and 7°C exhibited better retention of ascorbic acid than those stored at 10°C, although the differences became less pronounced with prolonged storage (Fig. 6).

Betalain content

A consistent decline in betalain content was observed across all storage conditions, with the extent of degradation influenced by storage temperature and subsequent exposure to ambient conditions (Fig. 7). Fruits stored at 3°C consistently retained the highest betalain content, followed by those stored at 7°C, whereas fruits stored at 10°C exhibited comparatively greater losses. After 20 days of cold storage, fruits stored at 3°C showed a 13% reduction in betalain content after 84 h at ambient conditions, declining from 19.97 to 17.32 mg BCE/100 g, while fruits stored at 7°C and 10°C showed reductions of 18 and 16%, respectively. The better retention at lower temperatures may be attributed to suppression of temperature dependent degradation reactions such as

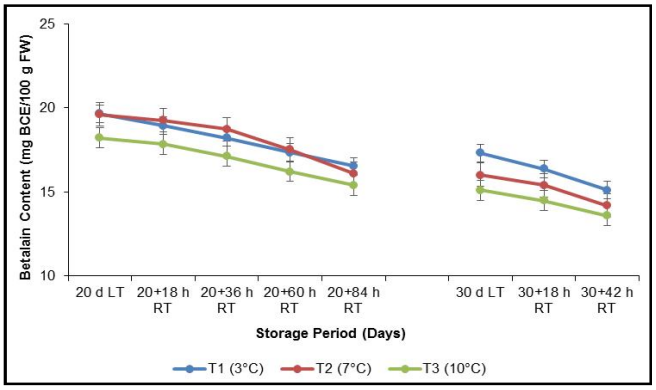


Fig. 7: Betalin content of room temperature shifted dragon fruits previous stored at different low temperatures.

hydrolysis, decarboxylation and cleavage of the aldimine bond in betanin (Woo, 2011). The further decline following transfer to ambient conditions indicates accelerated pigment degradation under higher temperature and oxidative conditions. However, refrigerated storage does not invariably result in betalain loss; Yong *et al*., (2018) reported a 57.2% increase in betacyanin content in red pitahaya after six days at 4°C. Overall, storage at 3°C was more effective in maintaining betalain content, whereas 10°C, despite minimizing chilling injury, was comparatively less effective for long-term pigment retention.

Conclusion

The study demonstrated that storage temperatures markedly influenced the postharvest quality, physiological responses and nutritional attributes of the fruits during prolonged cold storage and subsequent storage life at ambient conditions. Among the temperatures evaluated, 3°C provided better retention of firmness, ascorbic acid, titratable acidity and betalain content, indicating superior preservation of physico-chemical and bioactive qualities. However, fruits stored at 3°C developed chilling injury during prolonged storage, which became more pronounced following transfer to ambient conditions. Though 7°C can be considered the most suitable storage temperature for extending storage life while maintaining fruit quality and minimizing chilling injury, whereas 3°C may be useful for short term storage where maximum quality retention is prioritized and chilling injury can be managed.

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