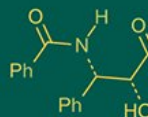


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Influence of green postharvest treatments on biochemical quality retention of litchi fruits during cold storage

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Abstract

Litchi is a high value fruit crop with excellent market potential; however, rapid deterioration of biochemical quality during postharvest storage limits its storage life and marketability. Therefore, the present study was conducted to evaluate the effect of eco-friendly postharvest treatments on the biochemical quality of litchi fruit cv. Rose Scented during cold storage. The fruits were subjected to different postharvest treatments, including hot water treatments at 45 and 55 °C for 40 s, gamma irradiation at 1 kGy, 2% NaCl, 5% oxalic acid, tap water dip and an untreated control. The treated fruits were stored at 4±1 °C and 90-95% relative humidity, and changes in biochemical quality were assessed at 5-day intervals up to 25 days of storage. Among the postharvest treatments, 5% oxalic acid was most effective in maintaining biochemical quality, recording the highest total soluble solids (TSS), titratable acidity and ascorbic acid content at the end of storage. At 25 days, oxalic acid treated fruits recorded 19.68 °Brix TSS, 0.27% titratable acidity and 36.15 mg/100 g ascorbic acid, compared with 15.98 °Brix, 0.18% and 25.85 mg/100 g, respectively, in untreated fruits. The TSS: acid ratio increased with storage advancement, with the lowest value recorded in oxalic acid-treated fruits, reflecting better retention of titratable acidity. Overall, 5% oxalic acid effectively delayed biochemical deterioration and maintained the quality of litchi fruits during cold storage, indicating its potential as an eco-friendly postharvest treatment for quality preservation.

Keywords: Litchi, postharvest treatments, oxalic acid, biochemical quality, cold storage

Introduction

Litchi (*Litchi chinensis* Sonn.) is an important subtropical evergreen fruit crop belonging to the Sapindaceae family. The fruit is highly valued for its attractive red pericarp, juicy aril, pleasant flavour and nutritional as well as medicinal properties. Owing to its popularity, it is known as the “Queen of Fruits” in India (Kumar, 2016a) [1]. The important litchi growing countries of the world are China, India, Australia, Thailand, Taiwan, Vietnam and South Africa. Approximately 90% of the world's litchi is being produced by the leading litchi producing countries, i.e., China, followed by India (Nath *et al.*, 2018) [2]. The other important litchi producing countries are Vietnam, Madagascar and Thailand (Mitra and Pan, 2020) [3]. It is now grown in more than 20 countries in the subtropical parts of the world (Zhao *et al.*, 2020) [4]. The total area under the crop in our country is 102, 000 hectares with a production of 600, 000 metric tonnes and a productivity of 5.88 metric tonnes/hectares. Bihar, West Bengal, Chhattisgarh, Assam, Uttar Pradesh, Uttarakhand, Punjab and Jharkhand are the major litchi producing states of India (MoA&FW, 2026) [5]. Additionally, it is grown on a small scale in the southern Nilgiris hills, Tripura, Orissa, Punjab, Himachal Pradesh and Assam. Due to its high popularity, it has a commercial demand in international trade. The fruit and its various kinds of processed products are always in demand, and the demand keeps on increasing both in the national and international markets (Kumar *et al.*, 2016b) [6]. Despite its high commercial value and consumer preference, the crop faces several postharvest challenges. The litchi crop faces the major challenge of a very short shelf life as it is highly perishable in nature. Therefore, its postharvest quality deteriorates rapidly. It is a non-climacteric fruit with a shorter than 48-hour shelf life at room temperature (Ghosh, 2001) [7].

Litchi fruits are highly susceptible to pericarp browning, desiccation and pathological decay, which leads to rapid quality deterioration. So, there is an urgent need for postharvest interventions that can maintain or retain the quality of the fruit, thereby increasing its marketability.

In the current scenario of consciousness towards health and the environment, one strategy to maintain postharvest quality of litchi can be the use of green postharvest treatments, which are completely eco-friendly and sustainable. The various green postharvest treatments include the use of heat treatment, irradiation, ozone, electrolysed water, natural plant extracts, GRAS (generally recognised as safe) compounds, organic and inorganic salts (González-Estrada *et al.*, 2020) [8]. These approaches are considered comparatively safer and environmentally sustainable. Green postharvest treatments are those that preserve and improve postharvest quality and extend the shelf life of fresh produce in a way that is both socially and environmentally acceptable to the industry and consumers at large. Consumers today want fresh goods free of chemical residues; thus, it is important to develop environmentally friendly solutions that can preserve fruit quality. Several studies have been conducted all over the world to prove their efficacy. Since food safety and quality are among the most important aspects, these green postharvest interventions may play a major role in ensuring safety and quality.

The use of green postharvest treatments does not cause any harm to the environment and can contribute to sustainable horticulture. The adoption of these technologies will not only benefit the growers and exporters to get a higher price for their safe and high-quality produce but also the end users, *i.e.*, the consumers, in safeguarding their health. Also, it will contribute towards the development of sustainable management practices for litchi by promoting environmentally friendly postharvest handling practices. Therefore, the present study aimed at evaluating the effect of various green postharvest treatments on biochemical quality retention of litchi fruits during cold storage.

Materials and Methods

The study was conducted at the Postharvest Laboratory, Department of Horticulture, G. B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, Uttarakhand, situated at 29°N latitude and 79.3°E longitude in the Tarai region at the foothills of the Himalayas.

Litchi fruits cv. 'Rose Scented' were procured from the Horticultural Research Centre, Patharchatta, G. B. Pant

University of Agriculture and Technology, Pantnagar. The fruits were harvested from selected healthy trees at optimum physiological maturity, characterised by a uniform red pericarp colour and a TSS: acid ratio of approximately 40 during the early morning hours. Harvested fruits were promptly transported in plastic crates immediately after harvest, where the fruits were first destalked, pre-cooled at 5 °C, sorted and graded to remove damaged, cracked and browned fruits, retaining only healthy and uniform fruits; washed with tap water, air-dried at room temperature (20-25 °C) for approximately 1 hour until the surface moisture had completely disappeared. The fruits were subsequently subjected to the respective postharvest treatments described below and then stored at 4±1 °C and 90-95% RH.

The study assessed the efficacy of green postharvest treatments, including T₁-hot water treatment at 45 °C for 40 s, T₂-hot water treatment at 55 °C for 40 s, T₃-gamma irradiation at 1.0 kGy, T₄-2% NaCl, T₅-5% oxalic acid, T₆-tap-water dip for 15 min, T₇-untreated control. The experiment was conducted in a factorial Completely Randomised Design with two factors, Factor A: postharvest treatment (7 levels); Factor B: storage interval (6 levels), thus, the experiment comprised 7 × 6 treatment combinations with three replications, and the results are expressed as the mean of three replications. The data were subjected to analysis of variance (ANOVA) appropriate for factorial CRD. Treatment means were compared using the critical difference (CD) at the 5% level of significance. Biochemical quality attributes were assessed at 5-day intervals up to 25 days of storage.

Total soluble solids (° Brix)

An Erma handheld refractometer with a range of 0-90 Brix was used to measure the fruit pulp's total soluble solids (TSS). The refractometer's prism surface was coated with a drop of homogenised pulp and the measurements were expressed in °Brix.

Titrateable acidity (% Citric acid)

The fruit's acidity was first assessed by filtering the juice from 5 g of the sample through a muslin cloth. Next, distilled water was added to dilute it to a known volume of 25 mL. The diluted juice was then titrated using phenolphthalein as an indicator against a standard NaOH solution. When a light pink colour appeared, it signalled the endpoint and was noted. The concentration of acidity in the fruit was indicated by the acidity value, which was given as a percent citric acid (Ranganna, 1986) [9].

$$\text{Acidity}\% = \frac{\text{Titre value} \times \text{Normality} \times \text{Eq. weight of citric acid} \times \text{Volume made} \times 100}{\text{Volume of sample taken} \times \text{Volume of aliquot taken} \times 100}$$

TSS: acid ratio

The total soluble solids value was divided by the titrateable acidity to determine the TSS: acid ratio.

Ascorbic acid (mg/100 g)

The 2, 6-dichlorophenol-indophenol visual titration method outlined by Ranganna (2001) [10] was used to measure the ascorbic acid content of litchi fruits. A mortar and pestle was used to crush 10 grams of pulp for analysis. A 100 mL volumetric flask was filled with filtered pulp juice. By adding a 3% metaphosphoric acid (HPO₃) solution, the final

volume was brought to 100 mL. To titrate against the dye (2,6-dichlorophenol-indophenol), a 10 mL aliquot was taken from the resultant solution. The titration was carried out until a light pink colour emerged and lasted for a minimum of 15 sec. The titre value, or volume of dye solution needed for the titration, was noted and utilised for additional computations. Measurement of the ascorbic acid concentration in the litchi fruit was provided by the ascorbic acid content, which was expressed as milligrams per 100 g of pulp on a fresh weight basis.

$$\text{Ascorbic acid (mg/100 g)} = \frac{\text{Titre value} \times \text{Dye factor} \times \text{Volume made up} \times 100}{\text{Volume of sample taken} \times \text{Volume of aliquot taken}}$$

Results

Total soluble solids (TSS)

Total soluble solids (TSS) was significantly influenced by the various postharvest treatments and storage interval (Table 1, Fig. 1). It was observed that TSS generally increased during the early and middle stages of storage and subsequently declined towards the end of the storage, with the extent of change varying among the treatments. At 0 day, TSS ranged from 17.11 to 17.28 °Brix. The highest TSS was consistently maintained by T₅ (oxalic acid), which increased from 17.20 °Brix at harvest to 19.89 °Brix at 20 days and remained high at 19.68 °Brix on the 25th day. T₂ also maintained comparatively high TSS, reaching 18.95 °Brix at 25 days. In contrast, the control (T₇) recorded the lowest TSS at the end of storage (15.98 °Brix), declining markedly after the 15th day. At 25 days, T₅ recorded the highest TSS (19.68 °Brix), whereas T₇ recorded the lowest (15.98 °Brix).

Titrateable acidity

Titrateable acidity of litchi fruits showed a progressive decline with advancement of storage, although the extent of decline varied among the postharvest treatments as depicted in Table 2 and Fig. 2. At the beginning of storage, acidity ranged from 0.36 to 0.37% among treatments. The decline was comparatively slower in T₅ (oxalic acid), which maintained the highest acidity throughout storage, decreasing from 0.37% at 0 day to 0.27% at 25 days. T₂ also retained comparatively higher acidity, with 0.25% recorded at 25 days. At the end of storage, acidity was highest in T₅ (0.27%), followed by T₂ (0.25%), T₃ (0.24%), T₁ (0.23%), T₄ (0.22%) and T₆ (0.20%). The lowest acidity was recorded in the control (T₇; 0.18%).

TSS: acid ratio

The TSS: acid ratio increased progressively with storage in all treatments as shown in Table 3 and Fig. 3. At 0 day, the ratio varied narrowly from 46.00 to 47.25, whereas substantially higher values were recorded at 25 days. The increase was most pronounced in the control and tap water treatments. At 25th day, the highest TSS: acid ratio was recorded in the control (T₇; 88.82), followed by T₆ (87.27), T₄ (82.37), T₁ (80.33) and T₃ (77.43). The lowest ratio at the end of storage was recorded in T₅ (71.32), followed by T₂ (75.96). Thus, T₅, which retained higher titrateable acidity during storage, exhibited the comparatively lower TSS: acid ratio at the end of storage.

Ascorbic acid

Ascorbic acid content declined progressively with advancement of storage in all treatments, but the magnitude of decline differed considerably among the postharvest treatments (Table 4, Fig. 4). At 0 day, ascorbic acid content ranged from 46.90 to 47.74 mg/100 g. T₅ (oxalic acid) showed the greatest retention of ascorbic acid throughout storage, decreasing from 47.67 mg/100 g at 0 day to 36.15 mg/100 g at the 25th day. T₂ and T₁ also retained comparatively higher ascorbic acid contents at the end of storage. On the 25th day, the highest ascorbic acid content was recorded in T₅ (36.15 mg/100 g), followed by T₂ (34.18 mg/100 g), T₃ (32.70 mg/100 g) and T₁ (31.34 mg/100 g).

The lowest values were recorded in T₇ (25.85 mg/100 g) and T₆ (26.52 mg/100 g).

Discussion

The present study demonstrated that postharvest treatments markedly influenced the biochemical quality of litchi fruit during cold storage. T₅ (5% oxalic acid) consistently showed better retention of TSS, titrateable acidity and ascorbic acid than the untreated control, while the control generally exhibited greater deterioration in quality.

Total soluble solids

The initial increase in TSS observed during storage may be associated with the hydrolysis of insoluble and complex polysaccharides into simpler soluble sugars as ripening progresses, accompanied by a decline in titrateable acidity (Mg *et al.*, 2019) [11]. The increase in soluble solids during the early stages of storage may also be attributed to enzymatic conversion of complex carbohydrates into soluble sugars, with the activity of sucrose phosphate synthase being suggested as one of the processes involved in this conversion (Megha *et al.*, 2021; Sinha *et al.*, 2021) [12, 13]. However, at the later stages of storage, the decline in TSS may occur because soluble sugars and organic acids are progressively utilised in respiratory and other metabolic processes (Adhikary *et al.*, 2021) [14]. Similarly, retention of soluble solids following oxalic acid treatment has been reported in mango (Zheng *et al.*, 2007) [15], peach (Razavi *et al.*, 2016) [16], apricot (Koyuncu *et al.*, 2018) [17] and lemon (Serna-Escobano *et al.*, 2021) [18]. In particular, better retention of TSS following oxalic acid application has been reported in apricot and mango [15, 17].

Titrateable acidity and TSS: acid ratio

The progressive decline in titrateable acidity observed during storage may be attributed to the utilisation of organic acids as respiratory substrates and their subsequent conversion into other metabolic compounds, including sugars, as storage advances (Hossain *et al.*, 2021) [19]. A similar decline in acidity with prolonged storage has been reported in citrus fruits, where the reduction in titrateable acidity was associated with the continued utilisation of organic acids during storage (Randhawa *et al.*, 2014) [20]. Comparable observations have also been reported in apricot, where titrateable acidity decreased with increasing storage duration, although oxalic acid treatment helped to retain comparatively higher acidity (Koyuncu *et al.*, 2018) [17]. The beneficial effect of exogenous oxalic acid in maintaining acidity may be related to its ability to delay the consumption of organic acids and thereby slow the reduction in titrateable acidity during storage (Zheng and Brecht, 2017; Ali *et al.*, 2020) [21, 22]. Similar effects of oxalic acid application have been reported in litchi, where fruits treated with oxalic acid retained higher titrateable acidity during prolonged low-temperature storage (Shafique *et al.*, 2016) [23]. Likewise, Eroglu *et al.* (2023) [24] reported improved retention of fruit quality following oxalic acid application in nectarine. More recently, Tekin *et al.* (2025) [25] also reported the positive role of oxalic acid in preserving fruit quality and maintaining the stability of acidic compounds during storage.

The TSS: acid ratio generally increased with advancement of storage, reflecting the progressive changes in soluble solids and titratable acidity during ripening and storage. The lower ratio under oxalic acid treatment may be associated with its ability to delay physiological deterioration and maintain the balance between soluble solids and organic acids during storage. Supporting this observation, Eroğul *et al.* (2023) ^[24] reported that oxalic acid application helped prevent excessive increases in the soluble-solids-to-acidity ratio in nectarine fruits, which was attributed to reduced respiration, decay and weight loss during storage.

Ascorbic acid

The decline in ascorbic acid content during storage may be

associated with the oxidative degradation of vitamin C, as ascorbic acid is susceptible to oxidation during postharvest storage (Alam *et al.*, 2009) ^[26]. Ascorbic acid is an important antioxidant in fruit tissues and contributes to delaying senescence by reducing oxidative stress and scavenging reactive oxygen species (ROS) (Razzaq *et al.*, 2015) ^[27]. The better retention of ascorbic acid following oxalic acid application may be associated with its ability to reduce oxidative deterioration and maintain higher endogenous ascorbic acid levels in fruit tissues (Ali *et al.*, 2020) ^[22]. Similar findings have been reported by Ehteshami *et al.* (2021) ^[28] in pomegranate and El-Gawad (2021) ^[29] in guava where exogenous oxalic acid helped maintain higher ascorbic acid concentrations during storage.

Table 1: Effect of green postharvest treatments on total soluble solids (°Brix) of litchi cv. Rose Scented during cold storage

Treatment	Storage Interval (Days)					
	0 d	5 d	10 d	15 d	20 d	25 d
T ₁	17.13	17.47	17.90	18.36	18.63	18.47
T ₂	17.28	17.55	18.18	18.99	19.24	18.95
T ₃	17.20	17.50	17.97	18.60	18.81	18.55
T ₄	17.11	17.75	18.06	18.47	18.39	18.08
T ₅	17.20	17.53	18.21	19.16	19.89	19.68
T ₆	17.12	17.41	17.68	18.03	18.04	17.40
T ₇	17.11	17.34	17.57	17.70	17.04	15.98
	SEm (±)			C.D. at 5 %		
Factor A	0.191			0.537		
Factor B	0.176			0.497		
Interaction A × B	0.467			-		

Factor A: Postharvest treatment, Factor B- Storage interval, CD- Critical difference, SEm- Standard error of mean.

Table 2: Effect of green postharvest treatments on titratable acidity (% Citric acid) of litchi cv. Rose Scented during cold storage

Treatment	Storage Interval (Days)					
	0 d	5 d	10 d	15 d	20 d	25 d
T ₁	0.37	0.36	0.34	0.31	0.27	0.23
T ₂	0.36	0.36	0.35	0.32	0.28	0.25
T ₃	0.37	0.36	0.34	0.30	0.28	0.24
T ₄	0.36	0.35	0.32	0.30	0.26	0.22
T ₅	0.37	0.37	0.36	0.33	0.31	0.27
T ₆	0.37	0.34	0.32	0.27	0.24	0.20
T ₇	0.37	0.34	0.31	0.27	0.22	0.18
	SEm (±)			C.D. at 5 %		
Factor A	0.003			0.009		
Factor B	0.003			0.008		
Interaction A × B	0.008			0.022		

Factor A: Postharvest treatment, Factor B- Storage interval, CD- Critical difference, SEm- Standard error of mean.

Table 3: Effect of green postharvest treatments on TSS: acid ratio of litchi cv. Rose scented during cold storage

Treatment	Storage Interval (Days)					
	0 d	5 d	10 d	15 d	20 d	25 d
T ₁	46.00	48.65	52.70	59.28	69.10	80.33
T ₂	47.25	48.78	51.45	58.88	67.21	75.96
T ₃	46.51	48.68	52.87	60.70	66.46	77.43
T ₄	46.77	50.33	55.43	61.65	69.85	82.37
T ₅	46.54	47.48	50.16	56.95	64.16	71.32
T ₆	46.27	50.30	55.26	65.40	75.34	87.27
T ₇	46.25	50.55	56.74	65.66	77.66	88.82
	SEm (±)			C.D. at 5 %		
Factor A	0.943			2.657		
Factor B	0.873			2.46		
Interaction A × B	2.31			-		

Factor A: Postharvest treatment, Factor B- Storage interval, CD- Critical difference, SEm- Standard error of mean.

Table 4: Effect of green postharvest treatments on ascorbic acid (mg/100 g) of litchi fruits during cold storage

Treatment	Storage Interval (Days)					
	0 d	5 d	10 d	15 d	20 d	25 d
T ₁	47.24	45.35	43.44	40.07	37.05	31.34
T ₂	47.74	45.95	44.88	42.31	39.71	34.18
T ₃	47.36	45.94	44.15	40.64	38.29	32.70
T ₄	47.21	44.98	41.94	38.36	34.27	28.60
T ₅	47.67	46.75	45.94	43.62	41.18	36.15
T ₆	46.90	43.66	40.29	36.90	31.62	26.52
T ₇	47.13	43.83	40.07	36.21	31.11	25.85
	SEm (±)			C.D. at 5 %		
Factor A	0.536			1.511		
Factor B	0.497			1.399		
Interaction A × B	1.314			-		

Factor A: Postharvest treatment, Factor B- Storage interval, CD- Critical difference, SEm- Standard error of mean.

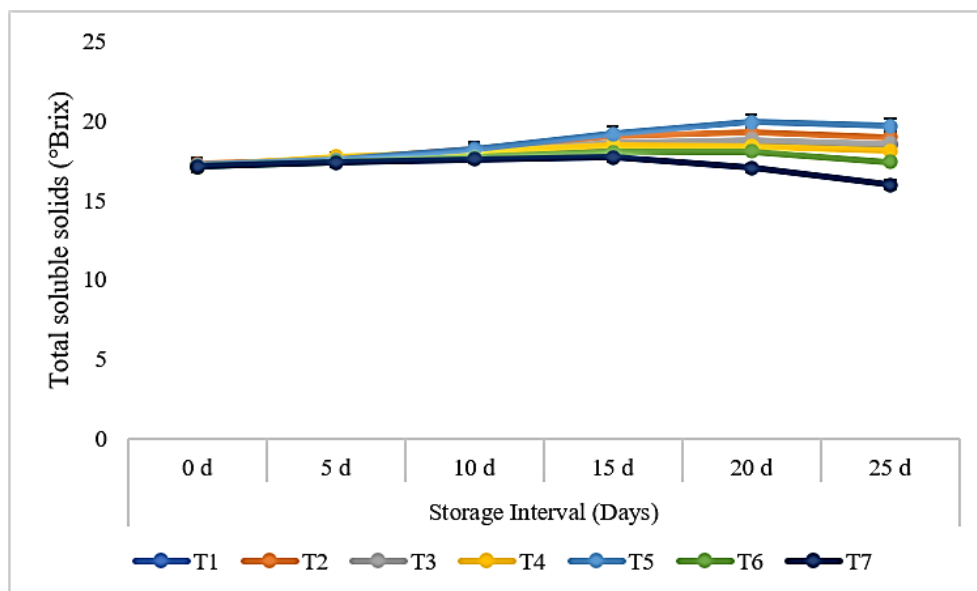


Fig 1: Effect of green postharvest treatments on total soluble solids (°Brix) of litchi cv. Rose Scented during cold storage

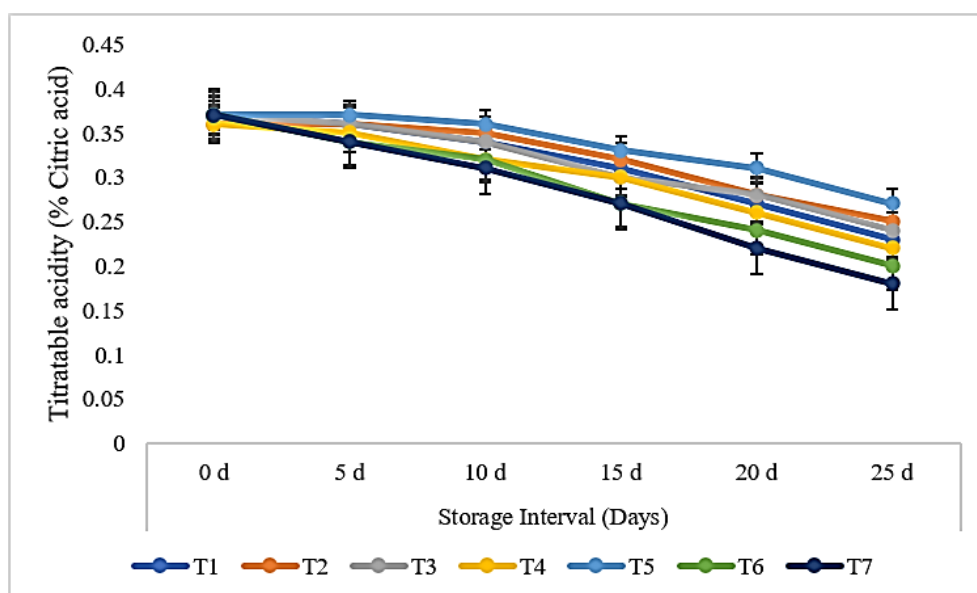


Fig 2: Effect of green postharvest treatments on titratable acidity (% Citric acid) of litchi cv. Rose Scented during cold storage

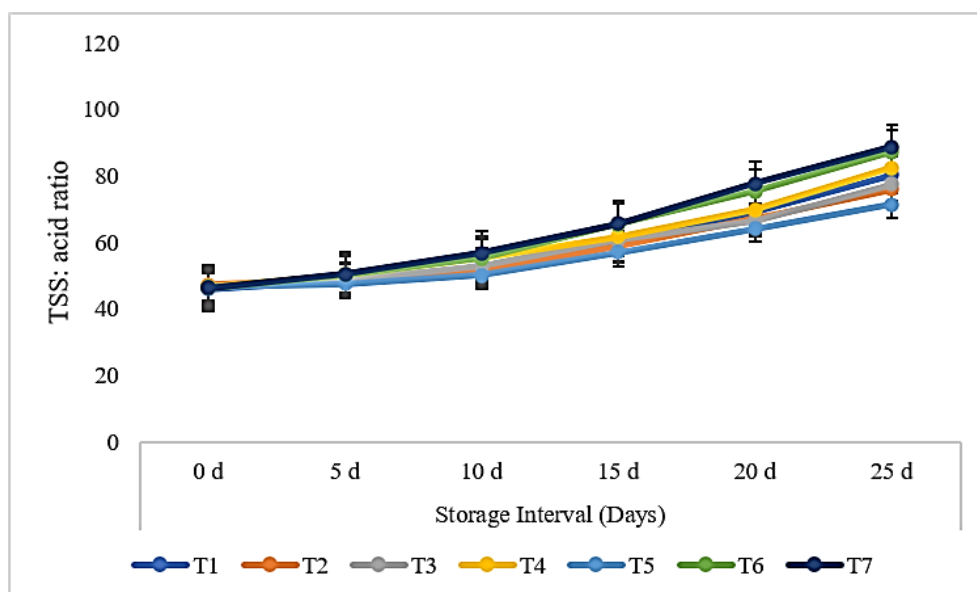


Fig 3: Effect of green postharvest treatments on TSS: acid ratio of litchi cv. Rose Scented during cold storage

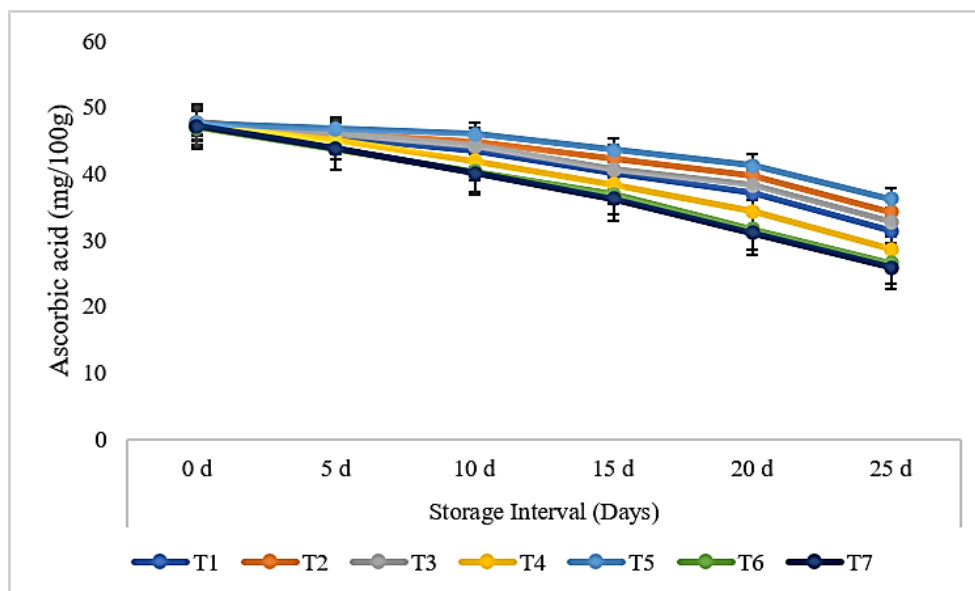


Fig 4: Effect of green postharvest treatments on ascorbic acid (mg/100 g) of litchi fruits during cold storage

Conclusion

The present study demonstrated that postharvest treatments influenced the biochemical quality of litchi fruits during cold storage. Among the treatments evaluated, 5% oxalic acid (T_5) was the most effective in maintaining fruit quality, as it retained higher TSS, titratable acidity and ascorbic acid throughout storage. On the 25th day, T_5 recorded the highest TSS (19.68 °Brix), titratable acidity (0.27%) and ascorbic acid content (36.15 mg/100 g), whereas the untreated control showed comparatively greater deterioration. The lower TSS: acid ratio under T_5 was associated with better retention of titratable acidity rather than excessive loss of soluble solids. Overall, 5% oxalic acid treatment showed potential for delaying biochemical deterioration and maintaining the quality of litchi fruits during cold storage.

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Conflict of Interest

All authors certify that they have no competing interests.

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