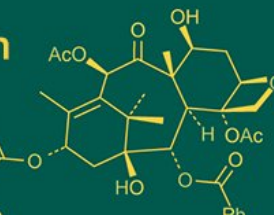


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(9): 1448-1456
www.biochemjournal.com
Received: 10-07-2026
Accepted: 15-08-2026

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Postharvest melatonin treatment modulates physico-chemical quality attributes and extends shelf life of mango (*Mangifera indica* L.) cv. Dashehari

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i9Sr.10026>

Abstract

Melatonin, a multifunctional indoleamine, has emerged as a promising postharvest treatment for delaying senescence and preserving quality in climacteric fruits. The present study evaluated the effect of postharvest melatonin application on the physico-chemical quality attributes of mango (*Mangifera indica* L.) cv. Dashehari stored under ambient conditions, over two consecutive years (2023-24 and 2024-25). Harvested fruits were treated with melatonin at 50, 100, 150, and 200 μ M, alongside an untreated control, and periodically analysed for changes in physiological loss in weight, firmness, total soluble solids (TSS), titratable acidity, ascorbic acid content, and sugar fractions (total, reducing, and non-reducing sugars). Melatonin treatment significantly delayed physiological loss in weight and retarded the decline in fruit firmness relative to control fruits, indicating suppression of ripening-associated senescence. Concentration-dependent effects were also evident in biochemical parameters, with melatonin-treated fruits showing slower increases in TSS and sugar content and a more gradual decline in titratable acidity and ascorbic acid during storage. Among the concentrations tested, 200 μ M melatonin produced the most pronounced effect, significantly influencing TSS, titratable acidity, ascorbic acid, and total sugar content compared with untreated fruits. These findings indicate that melatonin, particularly at higher concentrations, effectively retards ripening and helps preserve the nutritional and organoleptic quality of mango during ambient storage. Overall, the study demonstrates that postharvest melatonin treatment offers a practical, eco-friendly, and cost-effective strategy for extending shelf life, maintaining fruit quality, and enhancing the marketability of mango cv. Dashehari under ambient storage conditions.

Keywords: Melatonin, shelf life, physico-chemical quality, fruit ripening, titratable acidity, total soluble solids

Introduction

Mango (*Mangifera indica* L.), often referred to as the "King of Fruits," is cultivated widely across tropical and subtropical regions for its soft, juicy pulp, distinctive flavour, and rich nutritional composition (Shivakumar *et al.*, 2011; Peng *et al.*, 2023) [22, 24]. As one of the most economically important tropical fruit crops globally, mango occupies a central position in the horticultural economy of several countries, including India, which remains the world's largest producer. Beyond its commercial significance, the fruit is a valuable dietary source of antioxidants, including phenolics, carotenoids, and vitamins, that confer substantial health benefits and contribute to its growing demand in both domestic and export markets (Ma *et al.*, 2011; Akther *et al.*, 2023) [16, 1]. Among commercial cultivars, 'Dashehari' is a premium variety extensively grown in northern India, widely prized for its exceptional sweetness, characteristic aroma, and fiberless pulp, making it highly sought-after in both fresh fruit and processing industries (Kaur *et al.*, 2020) [12].

Despite its desirable quality attributes, mango presents considerable postharvest management challenges. Being a climacteric fruit, mango undergoes rapid ripening following harvest, a process driven by a sharp rise in respiration rate and a concomitant surge in autocatalytic ethylene biosynthesis (Xu *et al.*, 2019; Mubarak *et al.*, 2023) [25, 19]. This physiological cascade triggers a series of biochemical changes, including cell wall degradation, starch-to-sugar conversion, pigment development, and loss of organic acids, that collectively drive the ripening process forward. Under ambient storage conditions typical of most developing-country supply chains, this intense catabolic activity renders the fruit highly susceptible to

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physiological deterioration, premature softening, excessive weight loss, and microbial decay. Consequently, untreated mangoes typically exhibit a shelf life of only 5-7 days at ambient temperature, a limitation that severely constrains their marketability, storage duration, and potential for long-distance transport to distant or export markets (Kaur *et al.*, 2020; Bhardwaj *et al.*, 2022)^[12, 7]. These postharvest losses represent a significant economic burden, as a substantial proportion of harvested mango fruit is estimated to be lost between harvest and consumption, undermining both grower income and food security objectives.

Conventional postharvest management strategies, including synthetic chemical treatments such as fungicides and growth regulators, controlled/modified atmosphere storage, and low-temperature storage, have long been employed to delay ripening and extend fruit shelf life. However, cold storage is often impractical or economically unfeasible for smallholder farmers, and mango is additionally susceptible to chilling injury below certain threshold temperatures. Simultaneously, growing consumer and regulatory concern over synthetic chemical residues on fresh produce has intensified the global demand for safe, natural, and eco-friendly preservation alternatives that can be readily adopted at minimal cost (Almasoud *et al.*, 2024)^[2].

In this context, melatonin (N-acetyl-5-methoxytryptamine), a naturally occurring indoleamine originally characterized in animal systems and subsequently identified as a ubiquitous molecule in plants, has emerged as a potent pleiotropic regulator of plant growth, development, stress tolerance, fruit ripening, and senescence. Functioning as both an effective biostimulant and a broad-spectrum antioxidant capable of directly scavenging reactive oxygen and nitrogen species as well as upregulating endogenous antioxidant enzyme systems, exogenous melatonin application has demonstrated considerable efficacy in mitigating postharvest decay, alleviating chilling and oxidative stress, delaying senescence, and prolonging the storage life of a diverse range of horticultural commodities, including various fruits and vegetables (Badiche-El Hilali *et al.*, 2023; Hei *et al.*, 2025; Mandal *et al.*, 2025)^[6, 11, 17]. Owing to its low cost, biodegradability, and generally recognized safety, melatonin represents an attractive candidate for practical adoption in postharvest fruit handling systems, particularly in resource-limited settings where cold-chain infrastructure is unavailable.

The beneficial effects of melatonin on postharvest mango quality are closely linked to its regulation of key physical and biochemical attributes. Physically, melatonin has been shown to suppress the activity of cell wall-degrading enzymes responsible for flesh softening, while also reducing fruit respiration and transpiration rates, thereby limiting physiological weight loss and preserving external appearance and textural quality during storage (Mubarak *et al.*, 2023; Liu *et al.*, 2020)^[19, 15]. Biochemically, melatonin regulates carbohydrate metabolism, moderates the accumulation of total soluble solids and sugars, delays the decline in titratable acidity, and enhances retention of ascorbic acid through its synergistic antioxidant action, collectively preserving the flavour and nutritional quality of treated fruit (Rastegar *et al.*, 2020; Liu *et al.*, 2020; Hei *et al.*, 2025)^[23, 15, 11].

Although melatonin's beneficial effects have been documented across several fruit species, dose-dependent responses appear to vary considerably depending on

cultivar, fruit maturity, and storage conditions, and comprehensive information on its efficacy in Dashehari mango under ambient storage remains limited. Therefore, the present study was undertaken to evaluate the effect of postharvest melatonin application at varying concentrations (50-200 μM) on the physico-chemical quality attributes and storage life of mango cv. Dashehari under ambient conditions, with the aim of identifying an optimal concentration for practical postharvest application.

Material and methods

Plant material and treatments

The mango (*Mangifera indica* L.) cultivar 'Dashehari' was used in this research, which was conducted over two consecutive seasons in 2023-24 and 2024-25. The fruit reached physiological maturity, exhibiting a firmness of $12 \pm 1 \text{ kg cm}^{-2}$ and a total soluble solids (TSS) of $10 \pm 1^\circ \text{Brix}$. The fruits were harvested from the experimental field of ICAR- Central Institute for Subtropical Horticulture, Uttar Pradesh, India. The collected fruit was transported to the laboratory, where any damaged or defective fruits were separated from the primary batch. The fruits underwent disinfection using 200 ppm of sodium hypochlorite for 20 minutes, after which 180 fruits were randomly divided into five groups, each containing 36 fruits. The initial group was immersed in distilled water (T_1 - Control), whereas the subsequent four groups were immersed in 50 μM (T_2), 100 μM (T_3), 150 μM (T_4), and 200 μM (T_5) MT, respectively, for a duration of 40 minutes. Following a 2 hour air drying period at ambient temperature, the fruits were stored at $27 \pm 2^\circ\text{C}$ with a relative humidity of $75 \pm 2\%$. Observations were conducted at six-day intervals during the predicted shelf life at room temperature ($27 \pm 2^\circ\text{C}$, $75 \pm 2\% \text{ RH}$). Each observation was recorded in four replication and each replicate consisted of three fruits.

Observations recorded

Fruit length and fruit width were measured by vernier caliper (Mitutoyo 530-105 standard vernier caliper) and expressed in centimeter (cm). The fruit weight was measured with the help of electronic weighing balance and denoted in gram (g). The fruit volume was calculated by using water displacement method: Submerge the weighed fruit in a known volume of water in a graduated cylinder or overflow container. The physiological loss of weight was measured using an electronic weighing balance and measured in grams. The weight loss was measured every three days using 3 fruits from each treatment, compared with the initial weight, expressed in percentage.

Biochemical parameters of mango fruits were analyzed using standard laboratory procedures. Total soluble solids (TSS) were determined by extracting fruit juice through a muslin cloth and recording the readings with a portable ERMA hand refractometer at room temperature. The values were expressed as $^\circ\text{Brix}$ (A.O.A.C., 1994). Titratable acidity was estimated by titrating the fruit pulp against standard NaOH solution using phenolphthalein as an indicator, and the results were expressed as percentage citric acid and reducing sugar was estimated by Folin and Wu's method (AOAC, 1975)^[4]. Ascorbic acid content was estimated by the dye titration method using 2,6-dichlorophenol indophenol dye and expressed as mg per 100 g pulp (A.O.A.C., 1994)^[5]. Total sugar was estimated by the anthrone method (Hedge and Hofreiter, 1962). Analysis of

variance analysis of data was performed using SAS software ver. 9.1.

Result and Discussion

Fruit length and width (cm)

Figure 1 (a) and 1 (b) illustrates fruit length and width of mangoes of year 2023-24 and 2024-25. The data of fruit length and fruit width found non-significant in both years. In the year 2023-24, treatment T₁ had maximum length of fruit followed by the treatment T₄, whereas treatment T₃ resulted dimensions. Regarding fruit width, treatment T₁ had the maximum width while treatment T₂ had minimum width of fruit. In the year 2024-25, treatments T₂ and T₅ had almost same length of fruits and treatment T₄ resulting in the shortest fruits. Conversely, the pattern for fruit width remained highly consistent with previous year data, as treatment T₁ continued to yield the widest fruits and treatment T₂ consistently produced the minimum width of fruit.

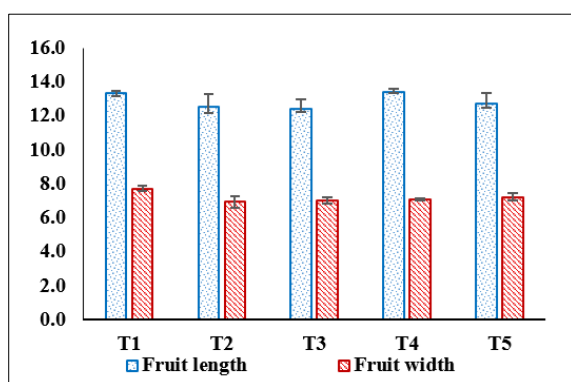


Fig 1(a): Fruit length and width of year 2023-24

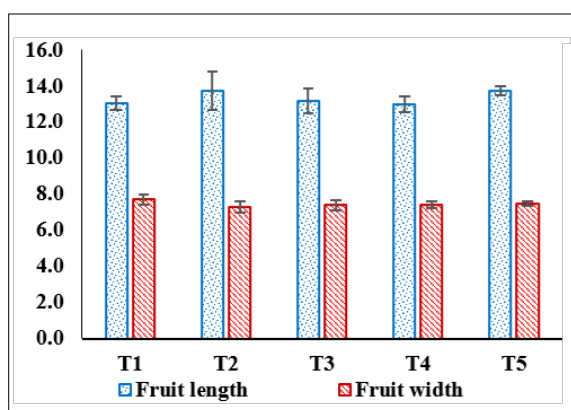


Fig 1(b): Fruit length and width of year 2024-25

Fruit weight (g)

The fruit weight data for the years 2023-24 and 2024-25 are presented in Figure 2(a) and 2(b), respectively. The data revealed no significant variation in fruit weight among the treatments. In 2023-24, all treatments recorded similar initial fruit weights on day 0. By day 6, treatment T₅ recorded the maximum fruit weight, whereas the minimum fruit weight was observed in T₄. However, by the final observation on day 12, T₅ had the maximum fruit weight, while T₁ recorded the minimum fruit weight. Similarly, in 2024-25, all treatments recorded comparable fruit weights on day 0. On day 6, the highest fruit weight was recorded in T₄, whereas the lowest was observed in T₃. By day 12, T₂

recorded the maximum fruit weight, while T₄ recorded the minimum fruit weight.

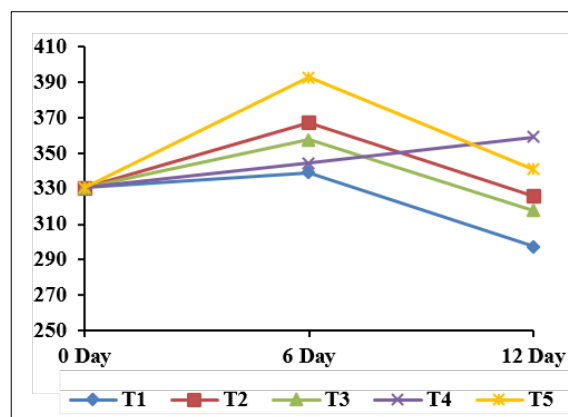


Fig 2(a): Fruit weight of treatments of year 2023-24

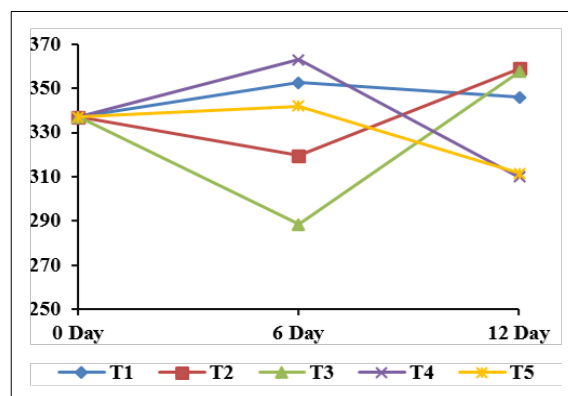


Fig 2(b): Fruit weight of treatments of year 2024-25

Fruit Volume (cm³)

The data of fruit volume of year 2023-24 and 2024-25 presented in figure 3(a) and 3(b), respectively. The data of fruit volume had no significant variation between the treatments. In the year 2023-24, on day 0, all treatment started with the same initial volume. By day 6, treatment T₅ recorded maximum fruit volume and minimum fruit volume recorded with treatment T₁. However, this trend shifted by the final data on day 12, T₄ had maximum fruit volume while T₁ had minimum fruit volume. During the year 2024-25, on day 0 all the treatments recorded similar fruit volume. On day 6, the highest volume of fruit was recorded with T₄ and minimum with the treatment T₃. On day 12, the T₂ have maximum and T₄ have minimum fruit volume recorded.

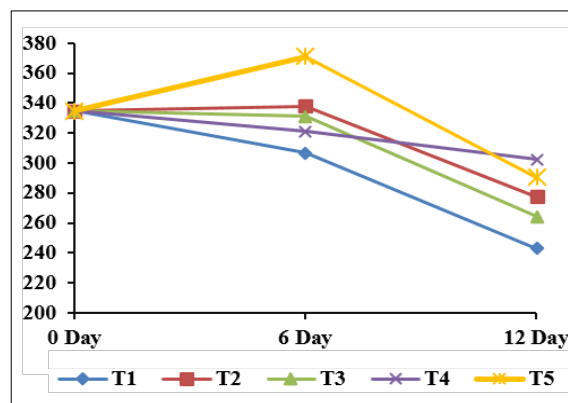


Fig 3(a): Fruit volume of treatments of year 2023-24

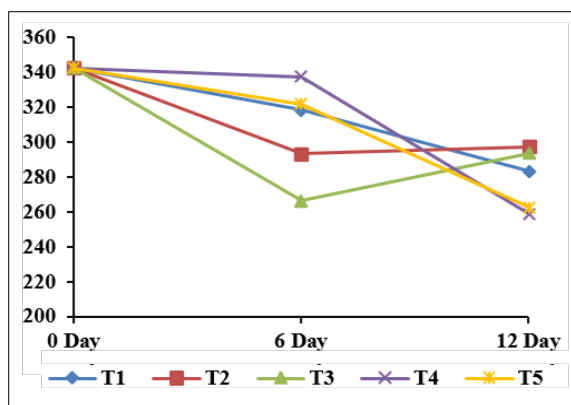


Fig 3(b): Fruit volume of treatments of year 2024-25

Fruit firmness (kg cm⁻²)

Figure 4 (a) and Figure 4(b) presented the data of fruit firmness for the years 2023-24 and 2024-25, respectively. The data had significant differences in between treatment in both year. In the year 2023-24, on day 0, all treatments started with an identical initial firmness. By day 6, treatment T₅ recorded the maximum fruit firmness, whereas the minimum fruit firmness was recorded with treatment T₁. This specific trend continued through the final observations on day 12, where T₅ retained the maximum fruit firmness while T₁ displayed the minimum fruit firmness. Similarly, during the year 2024-25, on Day 0 all the treatments recorded a uniform initial fruit firmness. On Day 6, the highest firmness of the fruit was registered with T₅ and the minimum with treatment T₁. On Day 12, treatment T₅ continued to have the maximum and T₁ had the minimum fruit firmness recorded.

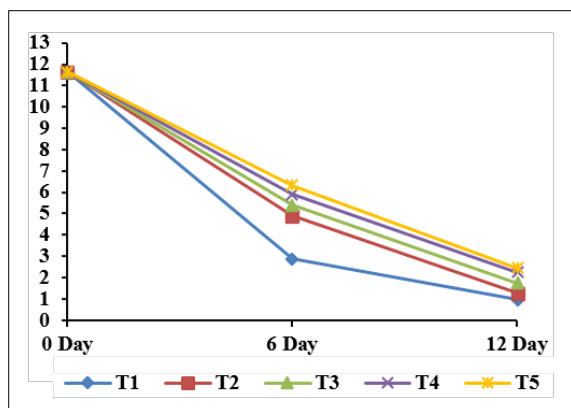


Fig 4(a): Fruit firmness of treatments of year 2023-24

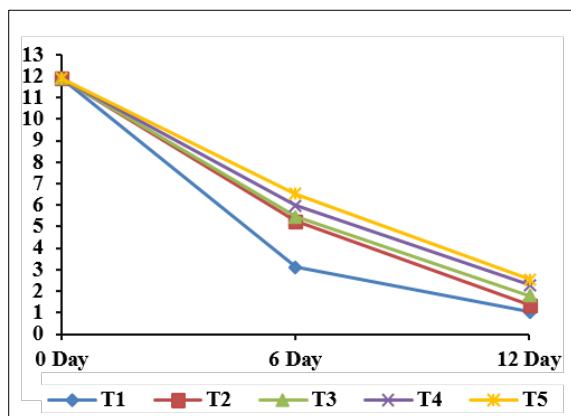


Fig 4(b): Fruit firmness of treatments of year 2024-25

Physiological loss of weight (%)

The physiological loss of weight (PLW) for both the 2024 (Figure 5a) and 2025 (Figure 5b) seasons showed a constant increasing trend, which signifies that the fruits experienced continuous moisture loss with an increased storage period. On 0 day, all evaluated treatments (T₁, T₂, T₃, T₄, and T₅) commenced with no physiological loss of weight. However, as the storage progressed to 6 day and through to the end of the storage period on 12 day, the distinct treatments maintained varying levels of weight loss. Treatment T₅ consistently maintained a lower physiological loss of weight than the other treatments throughout the evaluation. Conversely, treatment T₁ accelerated this moisture loss, recording the highest physiological loss of weight across all treatments at both the 6 day and 12 day intervals for both consecutive years.

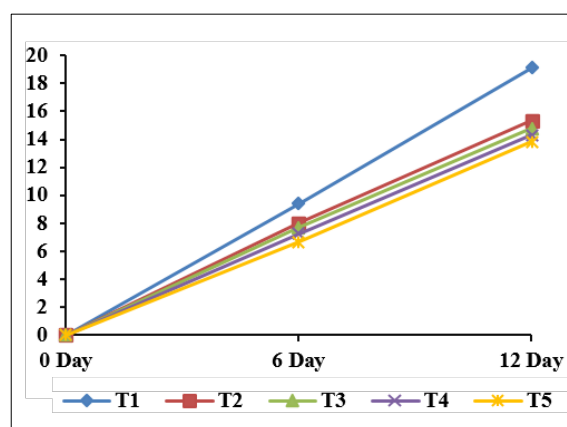


Fig 5(a): PLW of treatments of year 2023-24

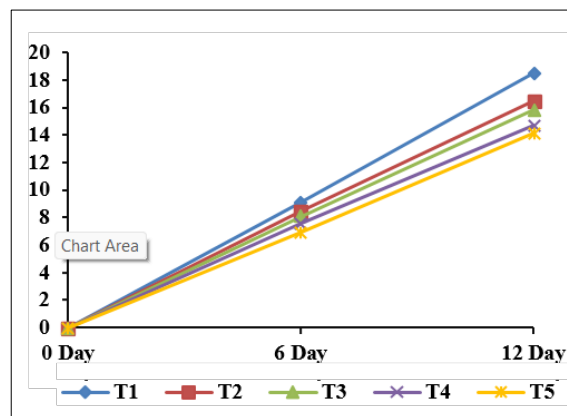


Fig 5(b): PLW of treatments of year 2024-25

Total Soluble Solid (° Brix)

Total soluble solids (TSS) increased progressively during the storage period across all evaluated treatments for both the 2023-24 (Figure 6 a) and 2024-25 (Figure 6 b) seasons, indicating the advancement of fruit ripening. On day 0, all treatments (T₁, T₂, T₃, T₄, and T₅) commenced with a uniform initial TSS level. As storage progressed to day 6, a rapid rise in TSS was observed, with treatment T₁ recording the highest accumulation and treatment T₅ registering the lowest. However, this trend shifted by the final evaluation on day 12. During this final stage, the maximum TSS was recorded in treatment T₂, while treatment T₁ exhibited the minimum TSS level for both consecutive years. The general increase in TSS during storage may be attributed to the hydrolysis of complex carbohydrates and the conversion of

starch and other polysaccharides into soluble sugars during the natural ripening process. Exogenous melatonin application has been identified as an effective postharvest strategy to modulate the accumulation of total soluble solids and delay the overall ripening process in fruits. Similar results of soluble solids during fruit ripening and improved postharvest quality of mango have been reported previously by Medina-Santamarina *et al.*, 2023; Mubarak *et al.*, 2023 and Al-Qurashi *et al.*, 2024^[18, 19, 3].

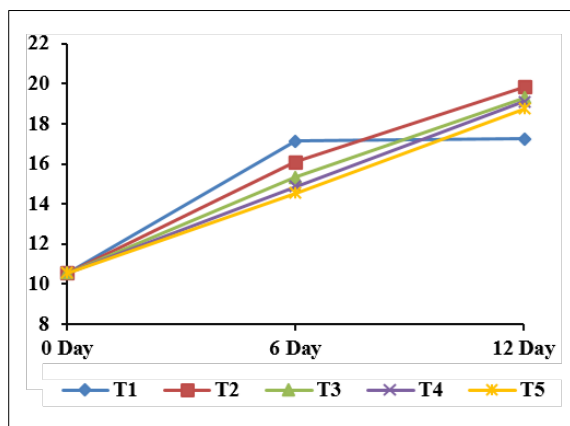


Fig 6(a): TSS of treatments of year 2023-24

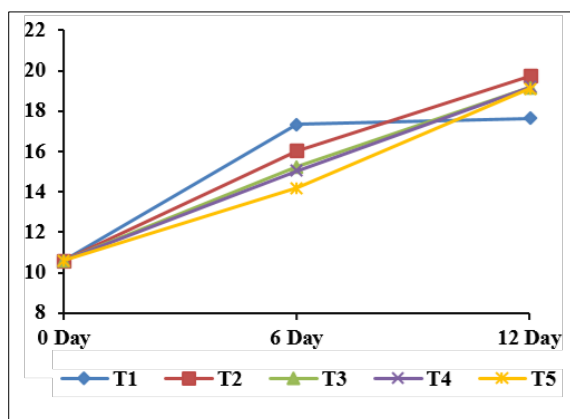


Fig 6(b): TSS of treatments of year 2024-25

Titrateable acidity (%)

Titrateable acidity decreased progressively during the storage period across all evaluated treatments for both the 2023-24 (Figure 7 a) and 2024-25 (Figure 7 b) seasons, reflecting the typical consumption of organic acids as the fruit ripens. On day 0, all treatments (T₁, T₂, T₃, T₄, and T₅) commenced with a uniform initial titrateable acidity level. As storage progressed to day 6, a rapid decline in acidity was observed across the board, with treatment T₅ recording the highest retention of titrateable acidity and treatment T₁ registering the lowest. However, this trend shifted by the final evaluation on day 12. During this final stage, the maximum titrateable acidity was recorded in treatment T₁, while treatment T₂ exhibited the minimum acidity level for both consecutive years. The general decrease in titrateable acidity during storage is primarily attributed to the continuous utilization of organic acids as metabolic substrates during the fruit's natural respiratory process. The results have conformity with the data of Almasoud *et al.*, 2024; Devi *et al.*, 2025 and Zhang *et al.*, 2025^[9, 2, 27].

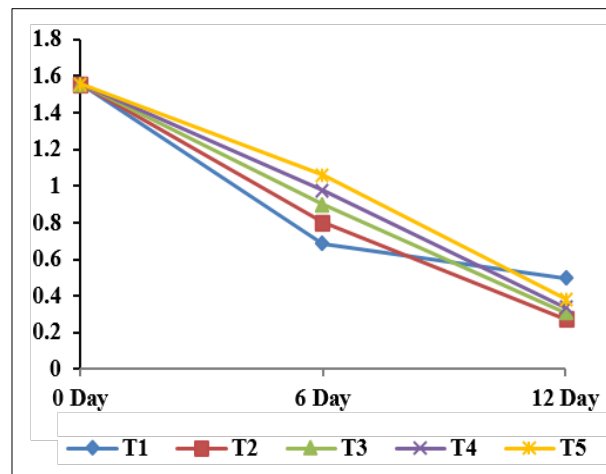


Fig 7(a): Titrateable acidity of treatments of year 2023-24

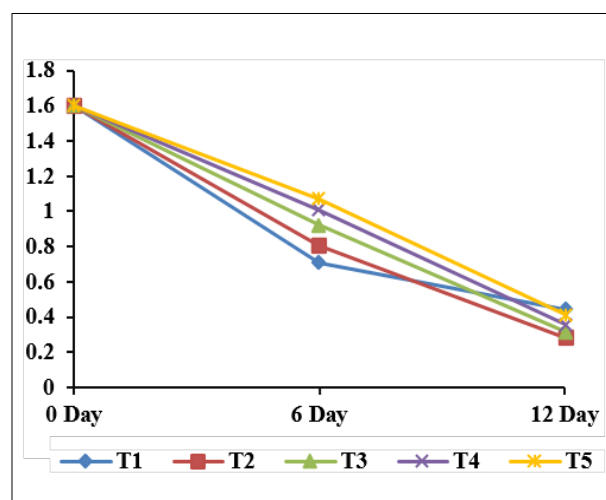


Fig 7(b): Titrateable acidity of treatments of year 2024-25

Ascorbic acid (mg per 100 g)

The ascorbic acid content decreased progressively during the storage period across all evaluated treatments for both the 2023-24 (Figure 8 a) and 2024-25 (Figure 8 b) seasons, reflecting the natural degradation of this essential antioxidant as the fruit ripens and matures. On day 0, all treatments commenced with a uniform initial ascorbic acid level. As storage progressed to day 6, a rapid decline in ascorbic acid concentration was observed across all experimental groups, with treatment T₅ recording the highest retention of ascorbic acid and treatment T₁ registering the most severe loss. This distinct pattern persisted through the final evaluation on day 12. During this terminal stage, the maximum ascorbic acid concentration was maintained in treatment T₅, while treatment T₁ exhibited the absolute minimum ascorbic acid level for both consecutive years. The general decrease in ascorbic acid during ambient storage is primarily attributed to oxidative breakdown and its continuous utilization in various physiological processes during fruit senescence. Similar modulations of ascorbic acid during fruit ripening and improved postharvest quality have been reported previously by Medina-Santamarina *et al.*, 2023; Mubarak *et al.*, 2023; Al-Qurashi *et al.*, 2024) and Almasoud *et al.*, 2024^[18, 19, 3, 2].

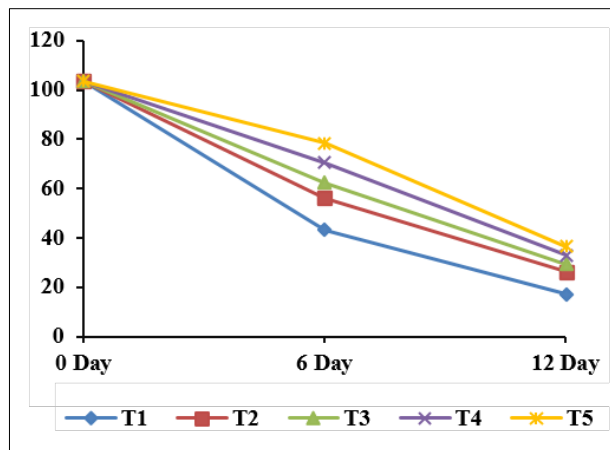


Fig 8(a): Ascorbic acid of treatments of year 2023-24

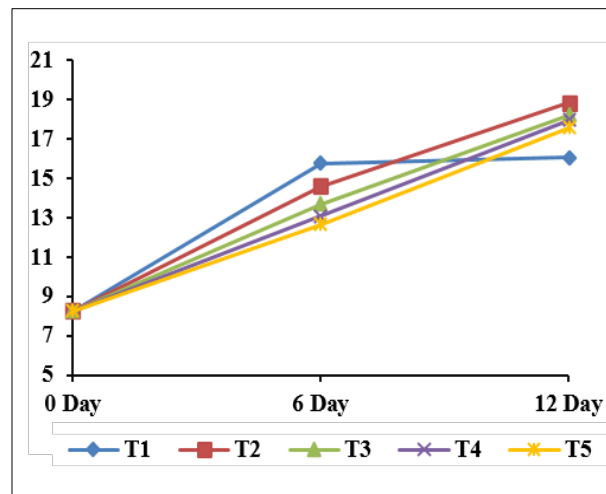


Fig 9(a): Total sugar of treatments of year 2023-24

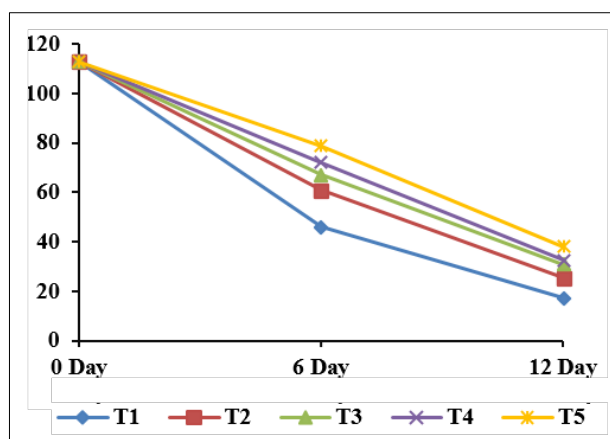


Fig 8(b): Ascorbic acid of treatments of year 2024-25

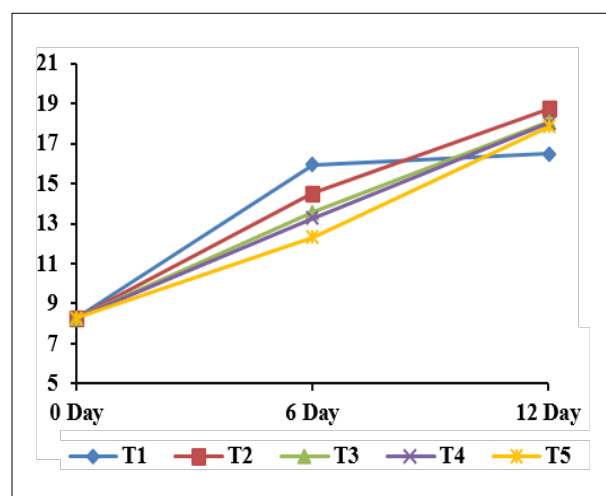


Fig 9(b): Total sugar of treatments of year 2024-25

Total sugar (%)

The total sugar content exhibited a continuous upward trend throughout the evaluation period across all experimental. The data for both the 2023-24 and 2024-25 presented in figure 9 (a) and figure 9 (b), respectively, reflecting the natural accumulation of sugars as the fruit progresses through the ripening stages. On day 0, every treatment group commenced with an identical baseline level of total sugar. As the storage period advanced to day 6, a swift elevation in total sugar was noted across the board, wherein treatment T₁ displayed the maximum accumulation, while treatment T₅ showed the most gradual increase, recording the minimum level.

However, this dynamic shifted significantly by the concluding observation on Day 12. At this final stage, the highest total sugar content was observed in treatment T₂, whereas treatment T₁ which had initially surged recorded the lowest overall sugar concentration for both consecutive years. The postharvest application of melatonin serves as an effective regulatory intervention to control the accumulation of total sugars during fruit ripening. During normal climacteric ripening, starch and other complex polysaccharides are rapidly hydrolyzed by specific enzymes into simple sugars, causing a sharp initial rise in total sugar content. These findings are in agreement with the results reported by Wang *et al.*, 2023; Singh *et al.*, 2024 and Zhao *et al.*, 2025 [29, 30, 31].

Reducing sugar (%)

The reducing sugar content exhibited a continuous upward trend throughout the evaluation period across all experimental treatments. The data for both 2023-24 and 2024-25 are presented in Figure 10 (a) and Figure 10 (b), respectively, reflecting the natural accumulation of simple sugars as the fruit progresses through the ripening stages. On day 0, every treatment group commenced with an identical baseline level of reducing sugar.

As the storage period advanced to day 6, a swift elevation in reducing sugar was noted across the board, wherein treatment T₂ displayed the maximum accumulation, while treatment T₅ showed the most gradual increase, recording the minimum level.

However, this dynamic shifted slightly by the concluding observation on day 12. At this final stage, the highest reducing sugar content was still observed in treatment T₂, whereas treatment T₁ which had initially shown a moderate increase recorded the lowest overall reducing sugar concentration for both consecutive years. These findings are in agreement with the results reported by Bhardwaj *et al.*, 2022; Njie *et al.*, 2022 and Yuan *et al.*, 2023 [7, 20, 26].

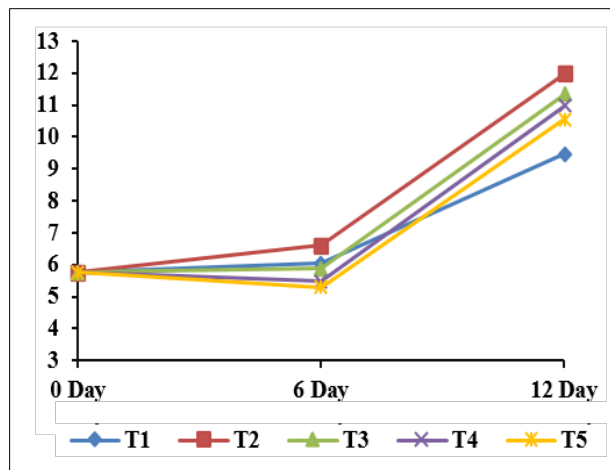


Fig 10(a): Reducing sugar of treatments of year 2023-24

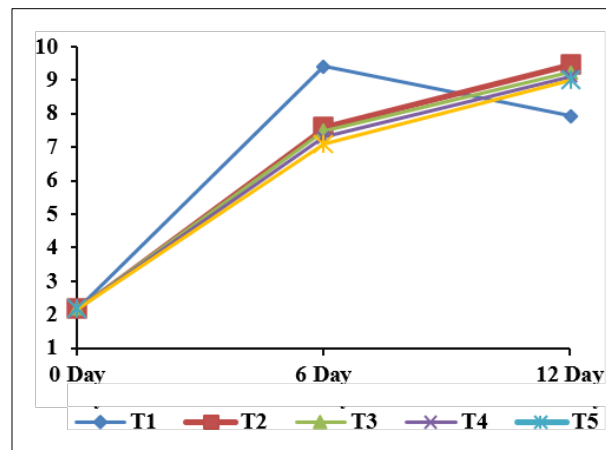


Fig 11(a): Non reducing sugar of treatments of year 2023-24

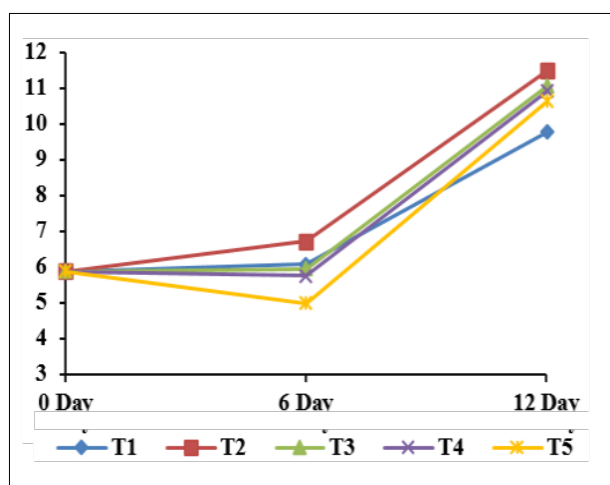


Fig 10(b): Reducing sugar of treatments of year 2024-25

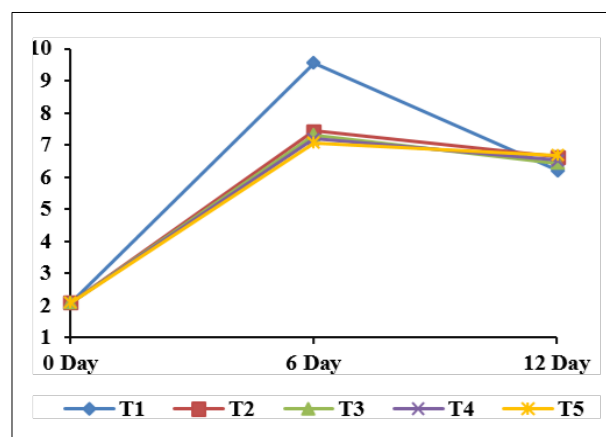


Fig 11(b): Non reducing sugar of treatments of year 2024-25

Non reducing sugar (%)

The non-reducing sugar content displayed dynamic fluctuations throughout the evaluation period across all experimental treatments. The data for the 2023-24 and 2024-25 seasons are presented in Figure 11 (a) and Figure 11 (b), respectively, reflecting the natural metabolic shifts as the fruit progresses through the ripening stages. On day 0, every treatment group commenced with an identical baseline level of non-reducing sugar.

As the storage period advanced to day 6, a swift elevation in non-reducing sugar was noted across the board for both years. During this interim stage, treatment T₁ displayed the maximum accumulation, while treatment T₅ showed the most gradual increase, recording the minimum level. However, this dynamic shifted significantly by the concluding observation on day 12, with the response varying between the two years.

In 2023-24, the levels of non-reducing sugars dropped for T₁ but continued to rise for T₂, T₃, T₄, and T₅, resulting in the highest concentration in T₂ and the lowest in T₁. In 2024-25, the non-reducing sugar content decreased across all treatments by day 12 compared to Day 6; at this final stage, treatment T₅ retained the highest level, while treatment T₁ recorded the lowest overall concentration. These findings are in agreement with the results reported by Chen *et al.*, 2023; Liu *et al.*, 2024 and Patel *et al.*, 2025 [8, 14, 21].

Conclusion

The findings of this study demonstrate that postharvest application of melatonin effectively enhances storage quality and extends the shelf life of mango cv. Dashehari under ambient conditions. Among the concentrations tested, 200 μ M (T₅) consistently produced the most pronounced beneficial effects. While basic physical attributes such as fruit weight, length, and volume showed non-significant variation across treatments, indicating melatonin does not alter fundamental fruit morphology, its influence on ripening-associated physiological and biochemical changes was substantial.

The 200 μ M treatment minimized physiological loss in weight and maintained superior firmness over the 12-day storage period, while also delaying the accumulation of total soluble solids and sugars and slowing the decline in titratable acidity and ascorbic acid relative to untreated fruits. This dual action, physical preservation coupled with biochemical stabilization, reflects melatonin's multi-targeted mode of retarding senescence, with the superior response at 200 μ M indicating a clear concentration-dependent effect. Overall, exogenous melatonin, particularly at 200 μ M, represents a highly effective, low-cost, and eco-friendly postharvest intervention for preserving the structural integrity and nutritional quality of Dashehari mango, offering practical value for extending marketability in regions lacking cold-chain infrastructure.

Acknowledgments

The authors are grateful to the Director, ICAR-Central Institute for Subtropical Horticulture (ICAR-CISH), Lucknow (U.P.), India, for providing the laboratory facilities necessary to carry out this research. The authors also wish to thank the Vice-Chancellor, Chandra Shekhar Azad University of Agriculture and Technology (CSAUA&T), Kanpur, for granting the opportunity to work at ICAR-CISH, Lucknow.

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