



Melatonin Mitigates Postharvest Enzymatic Browning and Preserves Quality in Cut *Narcissus tazetta* 'Shahla-e-Shiraz'

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Abstract

Petal browning is the primary limiting factor compromising the postharvest quality of narcissus (*Narcissus tazetta* L.) cut flowers. This study investigated the effects of melatonin (0.25 and 0.50 mM, each in 2% sucrose), compared with a control (distilled water) and sucrose alone (2%), on color stability, browning development, water status, membrane integrity, and browning-related enzyme activities of cut narcissus flowers during vase life. Melatonin treatment reduced the total color change (ΔE) and delayed the progression of petal browning throughout the vase period. The lowest polyphenol oxidase (PPO) and peroxidase (POD) activities were observed in flowers treated with 0.25 mM melatonin. Furthermore, treatment with 0.25 mM melatonin resulted in higher relative fresh weight (RFW), relative water content (RWC), and membrane stability index (MSI) compared with untreated flowers. Principal component analysis (PCA) revealed that PC1, explaining 58%

of the total variance, was positively correlated with quality parameters and negatively correlated with ΔE and browning, confirming the integrated protective role of melatonin. These findings demonstrate that melatonin treatment preserves the appearance quality of cut narcissus flowers by delaying senescence and the browning process, offering a promising and eco-friendly postharvest approach for maintaining the commercial value of cut flowers.

Keywords: browning, color change, cut flower, membrane stability, postharvest quality.

1 Introduction

Narcissus (*Narcissus tazetta* L.) is one of the most important ornamental bulbous plants and holds a special place in the global floriculture industry owing to its beauty and rich fragrance. However, its short vase life after harvest and the occurrence of petal browning are among the most important commercial challenges associated with this species [1, 2]. *Narcissus tazetta* is one of the most widely cultivated narcissus species in Iran, and postharvest quality deterioration—particularly



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petal browning—represents a major challenge for its commercial production [3]. The characteristic yellow-white coloration of *N. tazetta* petals is primarily attributable to its carotenoid and flavonoid composition [4]. After harvesting, fresh weight loss, flower senescence, reduced water absorption, loss of petal turgor, excessive transpiration, and reduced water potential collectively decrease the appearance quality and vase life of cut flowers, lowering their economic and ornamental value [5]. The limited turgor and heightened sensitivity to petal browning in *N. tazetta* are primary contributors to its suboptimal postharvest quality. Over the years, various treatments such as citric acid and salicylic acid [6] as well as γ -aminobutyric acid (GABA) [2] have been applied to increase the vase life of narcissus cut flowers. However, the effect of melatonin on petal browning and related physiological parameters in *Narcissus tazetta* has not yet been investigated.

Enzymatic browning, a biochemical process that significantly compromises the postharvest quality of horticultural crops, leads to discoloration and a consequent reduction in market value. This phenomenon is primarily attributable to the oxidation of phenolic compounds, which can be exacerbated by various environmental conditions [7]. In fruits and vegetables, this process is catalyzed during storage mainly by polyphenol oxidase (PPO) and peroxidase (POD). PPO catalyzes the oxidation of phenolics into *o*-quinones, which subsequently polymerize into melanins, causing browning. Additionally, POD contributes to browning by utilizing hydrogen peroxide to further oxidize phenolic compounds [8, 9]. Therefore, the preservation of flower quality, the delay of senescence, and the extension of vase life necessitate the development and application of suitable and cost-effective strategies.

Researchers frequently recommend using natural, safe, and environmentally friendly treatments to improve the postharvest quality of horticultural crops. Mazrou et al. [10] reported that melatonin application to cut roses at a concentration of 0.2 mM nearly doubled the vase life compared with the control and effectively maintained relative water content (RWC) and membrane stability index (MSI). In *Alstroemeria*, melatonin treatment at concentrations of 100 and 200 μ M increased relative water content, relative fresh weight, and membrane stability, while reducing electrolyte leakage, lipid peroxidation, and H_2O_2 production [11]. Lezoul et al. [12] reported that a melatonin concentration of 0.1 mM maintained the

initial levels of bioactive compounds, antioxidant activity, fresh weight, and membrane stability index, improving the vase life of cut carnation ‘Baltico’ flowers. By mitigating ion leakage and stabilizing cell membranes, melatonin contributes to the preservation of water uptake and minimization of water loss, ultimately resulting in the maintenance of flower turgor [13].

Although other treatments such as citric acid and salicylic acid [6] and gibberellin [14] have been investigated for *Narcissus tazetta*, the efficacy of melatonin in enhancing vase life quality, particularly with respect to preventing enzymatic browning, remains understudied. While previous research has focused on the effects of melatonin on other cut flowers such as anthurium [15] and carnation [12], this study examines the specific impact of melatonin on *Narcissus tazetta*, including browning-related enzyme activities. A significant knowledge gap exists regarding the potential benefits of melatonin in maintaining the vase life quality of cut *Narcissus tazetta* flowers. This research contributes to a deeper understanding of the role of melatonin in preserving the postharvest quality of cut flowers, particularly *Narcissus tazetta*, and provides valuable insights for developing novel strategies to extend vase life and reduce postharvest losses in this species. The findings of this study may be beneficial for floriculture producers and commercial growers involved in the postharvest handling of cut flowers.

2 Materials and Methods

2.1 Procedure and Experimental Design

Flower spikes of *Narcissus tazetta* L. ‘Shahla-e-Shiraz’ were harvested in Shiraz, Iran (latitude: 29°36′37.12″ N; longitude: 52°31′52.07″ E), at the commercial maturity stage known as the “goose-neck” stage, and immediately transported to the laboratory. To ensure uniformity in the experimental setup, flowers with an equal number of buds, a similar size, and a comparable growth stage were selected. The stems were recut underwater to a length of 35 cm and placed in separate beakers, where they remained for the duration of the experiment. Each beaker contained 500 mL of a solution corresponding to one of the following treatments: distilled water (control), 2% sucrose solution, 0.25 mM melatonin solution combined with 2% sucrose, and 0.50 mM melatonin solution combined with 2% sucrose. Each treatment was performed in triplicate. The flowers were maintained at a temperature of 20 ± 2 °C and a relative humidity of

$60 \pm 5\%$ throughout the experiment. Melatonin and other chemicals used in this study were obtained from Merck and Sigma-Aldrich.

2.2 Vase Life and Visual Quality

The vase life of the flower spikes was recorded from Day 0 (the day of transfer to the holding solution). Senescence was defined as the stage at which 50% of the flowers exhibited a loss of turgor, resulting in wilting or petal browning [1]. The flowers were visually evaluated every three days based on a scoring system (Table 1).

Table 1. Scoring system for evaluating the visual quality of cut *Narcissus tazetta* flowers.

Score	Description	Criteria
4	Excellent	Turgid, inflorescence present, bright and fresh appearance
3	Good	Turgid, petals intact, no spots
2	Fair	Dehydrated, light brown petal margins
1	Poor	Dehydrated, petal in-rolling, browning petals

2.3 Determination of Physicochemical Characteristics

The physical and chemical characteristics of narcissus flower petals were evaluated at 0, 3, 6, and 9 days of vase life.

2.3.1 Color Measurement

The color of the petals was measured using a colorimeter (Minolta CR-400, Japan). Measurements were done in triplicate. The extracted values were the CIE L^* (100 = white, 0 = black), a^* (−green, +red) and b^* (−blue, +yellow) coordinates in the range of 400–700 nm. The browning index (BI ; Equations (1) and (2)) and the total color difference (ΔE ; Equation (3)) were calculated from the L^* , a^* and b^* values as presented below. These were employed to assess differences in color change between treated and control samples [16].

$$BI = \frac{100(x - 0.31)}{0.17}, \quad (1)$$

where

$$x = \frac{a^* + 1.75 L^*}{5.645 L^* + a^* - 3.012 b^*}, \quad (2)$$

$$\Delta E = [(L_t^* - L_0^*)^2 + (a_t^* - a_0^*)^2 + (b_t^* - b_0^*)^2]^{1/2}, \quad (3)$$

where the subscripts 0 and t denote the values measured on Day 0 and on sampling day t , respectively.

2.3.2 PPO and POD Activities

A 0.5 g frozen petal sample was homogenized in phosphate buffer (KH_2PO_4 , 50 mM, pH 7.5) containing ethylenediaminetetraacetic acid (EDTA) at a final concentration of 0.1 mM and insoluble polyvinylpolypyrrolidone (PVPP; final concentration: 1% w/v). Immediately after extraction, the samples were centrifuged for 15 min at $15,000 \times g$ at 4°C and the activities of these enzymes were determined in the supernatant.

PPO PPO activity was assessed following the procedure of Kar and Mishra [17]. The reaction mixture contained the enzymatic extract, phosphate buffer (50 mM, pH 7) and pyrogallol solution (20 mM). The absorbance at 420 nm was read after 3 min with a UV-visible spectrophotometer. The results are reported in units per mg of fresh weight ($\text{U mg}^{-1} \text{FW}$).

POD The activity of peroxidase was assayed following the method of Chance and Maehly [18] with some changes. The reaction mixture comprised guaiacol (161 μL), phosphate buffer (pH 7.5), H_2O_2 (17 μL) and the enzyme extract. The change in absorbance at 470 nm due to guaiacol oxidation was recorded over 2 min. The results are expressed as units per mg of fresh weight ($\text{U mg}^{-1} \text{FW}$).

2.3.3 Membrane Stability Index (MSI)

MSI was measured based on the electrolyte leakage method, as described by Singh et al. [19] with some modifications. One gram of petal tissue in 10 mL of distilled water was incubated at $40 \pm 2^\circ\text{C}$ for 1 h and the conductivity (C_1) was measured using an EC meter (Tetracon 325). The test tubes were then autoclaved for 15 min at 120°C . The conductivity of the solution was read once more (C_2) after the solution had cooled. The MSI was calculated as follows:

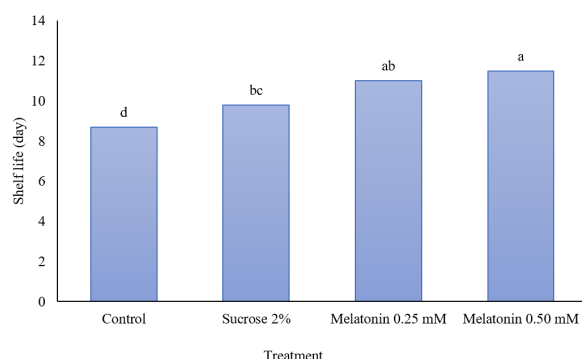
$$MSI (\%) = \left[1 - \frac{C_1}{C_2} \right] \times 100. \quad (4)$$

2.3.4 Relative Fresh Weight

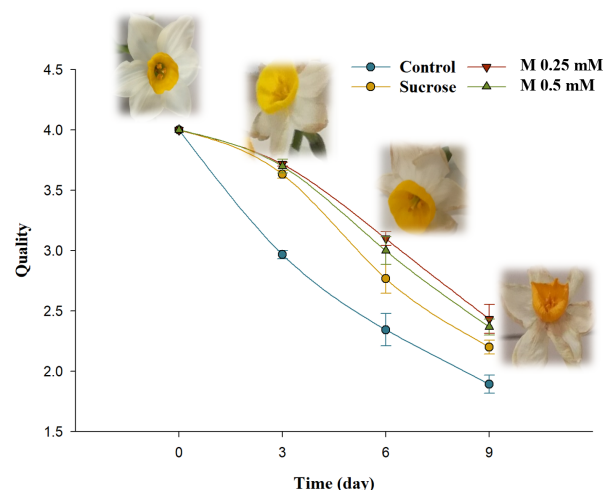
The relative fresh weight (RFW) of the stems was determined using the following formula [20]:

$$RFW (\%) = \frac{W_t}{W_0} \times 100, \quad (5)$$

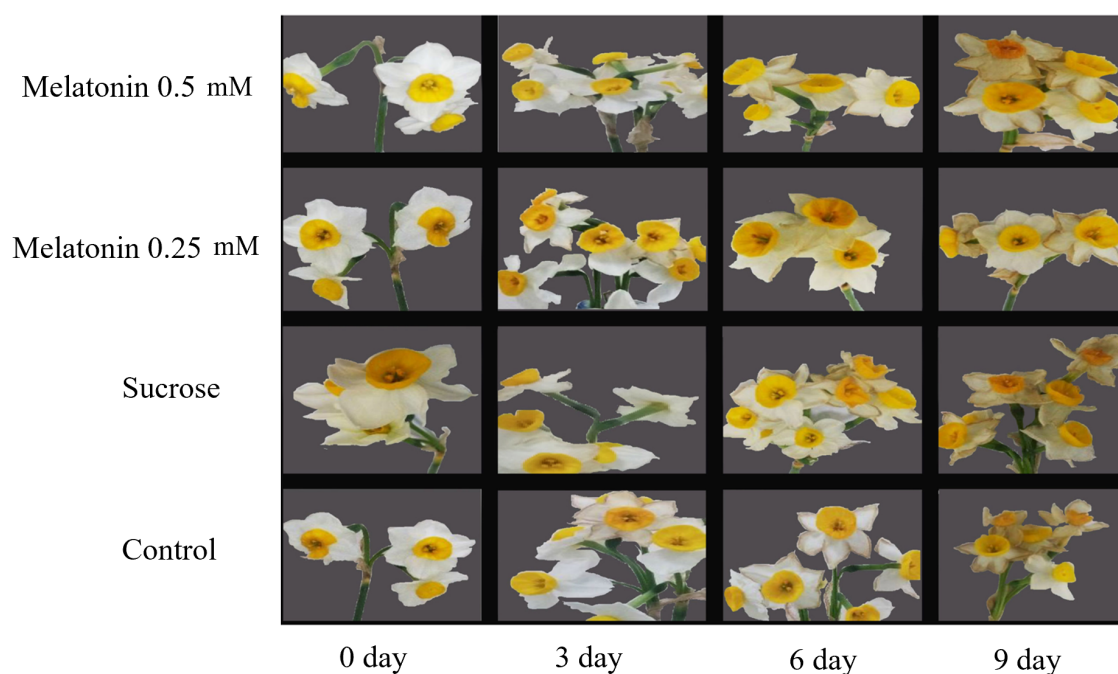
where W_t is the weight of the stem (g) on day t ($t = 0, 3, 6$ and 9) and W_0 is the weight of the same stem (g) on Day 0.



(a)



(b)



(c)

Figure 1. Effects of melatonin on vase life (a), quality (b) and visual appearance (c) of cut *Narcissus tazetta* L. ‘Shahla-e-Shiraz’ flowers during storage at $20 \pm 2^\circ\text{C}$ and $60 \pm 5\%$ relative humidity. Values are means $\pm$ SE from three replicates ($n = 3$).

2.3.5 Relative Water Content (RWC)

The RWC of the petals was assayed using the method described by Chakrabarty et al. [21] and calculated based on the following formula:

$$RWC (\%) = \frac{FW - DW}{TW - DW} \times 100, \quad (6)$$

where *FW* is the fresh weight of the petal, *TW* is the turgid weight of the petal after being saturated for 24 h with distilled water, and *DW* is the oven-dry weight of the petal after being heated to 70°C for 24 h.

2.3.6 Flower Diameter

The flower diameter was measured as the maximum width of each cut flower using a digital caliper with a precision of 0.01 mm.

2.4 Statistical Analysis

Data were subjected to a two-way analysis of variance (ANOVA) using a factorial arrangement based on a completely randomized design (CRD), considering treatment ($df = 3$) and storage time ($df = 3$) as fixed factors, along with their interaction (treatment

$\times$ time, $df = 9$). Means were compared using Duncan's multiple range test (DMRT) at $p \leq 0.05$. Correlations between the assessed traits were analyzed using Pearson correlations ($p < 0.05$ and $p < 0.01$) with the R package gplots. A principal component analysis (PCA) was then used to determine the correlations among parameters and to identify the principal components describing the most variation in the dataset. Statistical analyses were performed using SPSS version 16.0, and the graphs were generated using SigmaPlot version 14.0.

3 Results

3.1 Vase Life and Quality

Melatonin treatment extended the vase life of cut narcissus flowers compared with the control (8.7 days). The 0.50 mM melatonin concentration gave the longest vase life (11.5 days), which was significantly longer than that of both the control and the sucrose-treated flowers (9.8 days). Similarly, 0.25 mM melatonin markedly increased vase life to 11.0 days, which was significantly longer than the control but did not differ significantly from the sucrose treatment or from the 0.50 mM melatonin treatment (Figure 1(a)).

A progressive deterioration in visual quality was observed during storage, with the control samples exhibiting a more severe decline than the treated ones. Although no significant differences were observed among the melatonin treatments on Day 9 of storage, melatonin-treated flowers consistently demonstrated superior quality compared with the control (Figure 1(b,c)).

3.2 Color Parameters

Petal browning developed rapidly in the control samples, reaching a maximum browning index (BI) of 54.3 by the end of storage (Figure 2(a)). Melatonin-treated cut flowers maintained lower BI values than the control samples throughout the entire storage period. At the end of storage, the lowest BI (33.8) was observed in cut flowers treated with 0.25 mM melatonin.

The ratio of L^* relative to its initial value (L^*/L_0^*) declined sharply across all treatments during storage (Figure 2(b)). However, the control samples exhibited a more rapid decline compared with the other treatments. At the end of the experiment, the lowest L^*/L_0^* ratio was recorded in the control samples, whereas the highest was observed in the 0.50 mM melatonin treatment. No significant difference was

detected between the sucrose-treated and 0.25 mM melatonin-treated samples.

The petal color changed during storage at 20 ± 2 °C. The highest total color change (ΔE) was detected in the control samples, and the lowest ΔE value at the end of storage was observed in flowers treated with 0.25 mM melatonin (Figure 2(c)). Although the 0.50 mM treatment achieved the highest lightness retention (L^*/L_0^*), the 0.25 mM treatment showed lower overall color change (ΔE) and browning index (BI), suggesting that the two concentrations differentially affected the lightness and chromatic components of petal color.

3.3 Enzyme Activity

PPO activity progressively increased during the storage period; however, cut narcissus flowers treated with melatonin exhibited lower activity compared with the control and sucrose-treated groups. At the end of storage, the highest PPO activity was observed in the control samples, reaching approximately threefold the level found in melatonin-treated flowers (Figure 3(a)).

Across all treatments, POD activity initially declined before sharply increasing after Day 3 of storage. However, cut narcissus flowers treated with 0.25 mM melatonin maintained lower POD activity than both the control samples and the 0.50 mM melatonin-treated flowers (Figure 3(b)).

Correlations between the browning index and PPO or POD activities across different treatments are shown in Figure 3(c,d). The strongest correlation between PPO activity and the browning index was observed in the 0.50 mM melatonin treatment ($R^2 = 0.98$), whereas the weakest was recorded in the 0.25 mM melatonin treatment ($R^2 = 0.89$). Similarly, the strongest ($R^2 = 0.90$) and weakest ($R^2 = 0.61$) correlations between the browning index and POD activity were observed in the 0.50 mM and 0.25 mM melatonin treatments, respectively.

3.4 Relative Water Content

The RWC of the petals remained relatively stable or increased slightly during the first three to six days of storage (Figure 4(a)). However, on Day 9 of storage, it decreased abruptly and reached its lowest level. At the end of storage, the 0.25 mM melatonin-treated samples had a significantly higher RWC than the other treatments.

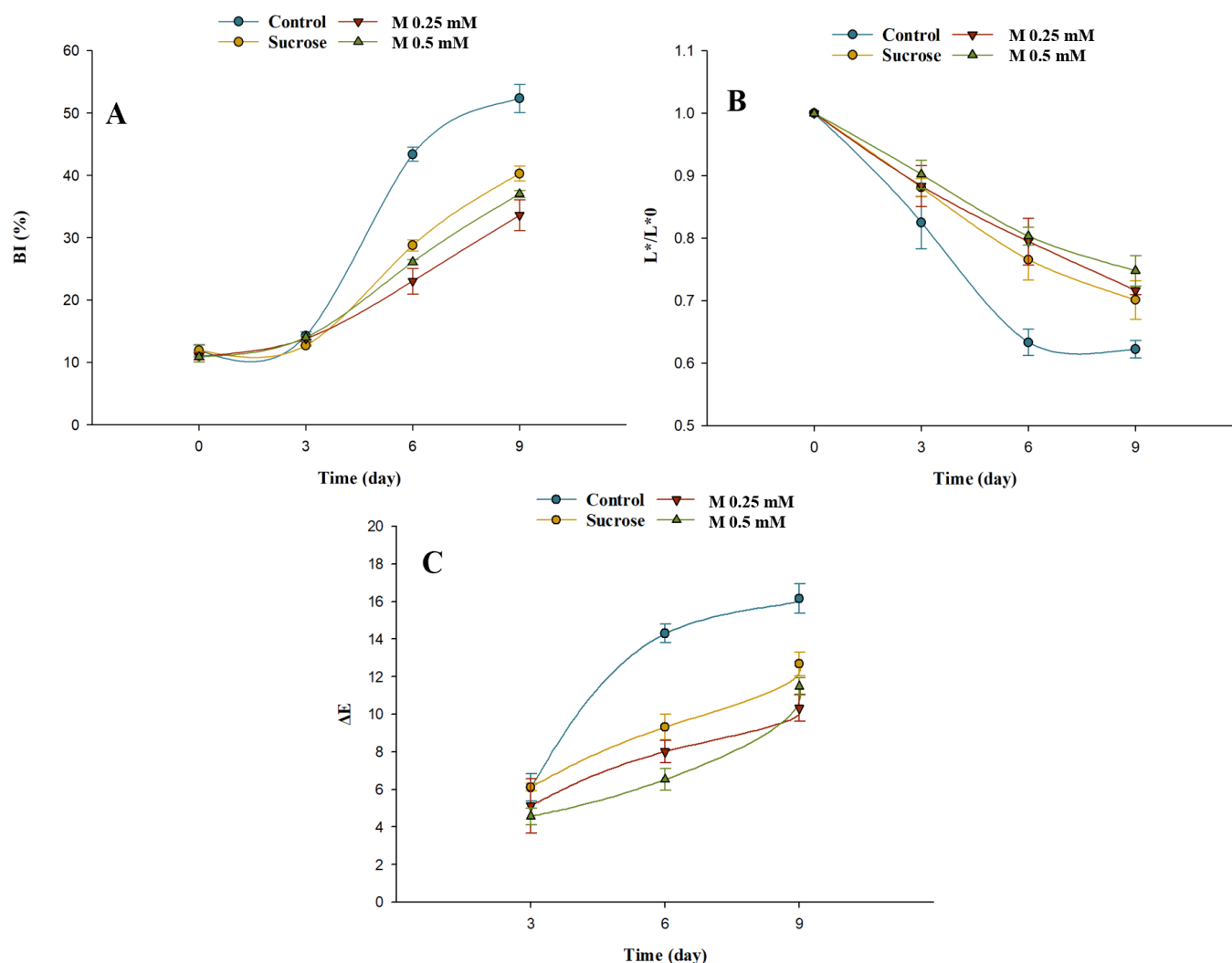


Figure 2. Effects of melatonin on the browning index (BI) (a), L^*/L_0 value (b) and total color change (ΔE) (c) of cut *Narcissus tazetta* L. 'Shahla-e-Shiraz' flowers during storage at 20 ± 2 °C and $60 \pm 5\%$ relative humidity. Values are means $\pm$ SE from three replicates ($n = 3$). Statistical analysis was performed using Duncan's test.

3.5 Relative Fresh Weight

The RFW of all samples progressively decreased during storage at 20 °C. However, flowers treated with 0.25 mM melatonin exhibited lower weight loss than those in the other treatments. At the end of the experiment, the control and 0.25 mM melatonin-treated flowers recorded the lowest and highest RFW, respectively. No significant difference was observed between the sucrose-treated and 0.50 mM melatonin-treated samples (Figure 4(b)).

3.6 Membrane Stability Index

All samples exhibited a decline in MSI during storage. However, melatonin-treated flowers maintained a higher MSI than the control group throughout the storage period. At the end of storage, the 0.25 mM melatonin-treated samples displayed a significantly

higher MSI compared with the control (Figure 4(c)).

3.7 Diameter

During storage at 20 °C, the diameter of cut narcissus flowers gradually decreased. However, the melatonin-treated samples had a larger diameter than the control samples. The control cut flowers had the smallest diameter at the end of the experiment (Figure 4(d)).

3.8 PCA and Pearson Correlations

The effect of melatonin on narcissus postharvest quality was assessed using principal component analysis (PCA). PCA is a well-known method for reducing dataset dimensionality into a few composite variables and illustrating the similarities and differences among measured parameters. Two principal components (PCs) accounted for 86.9% of

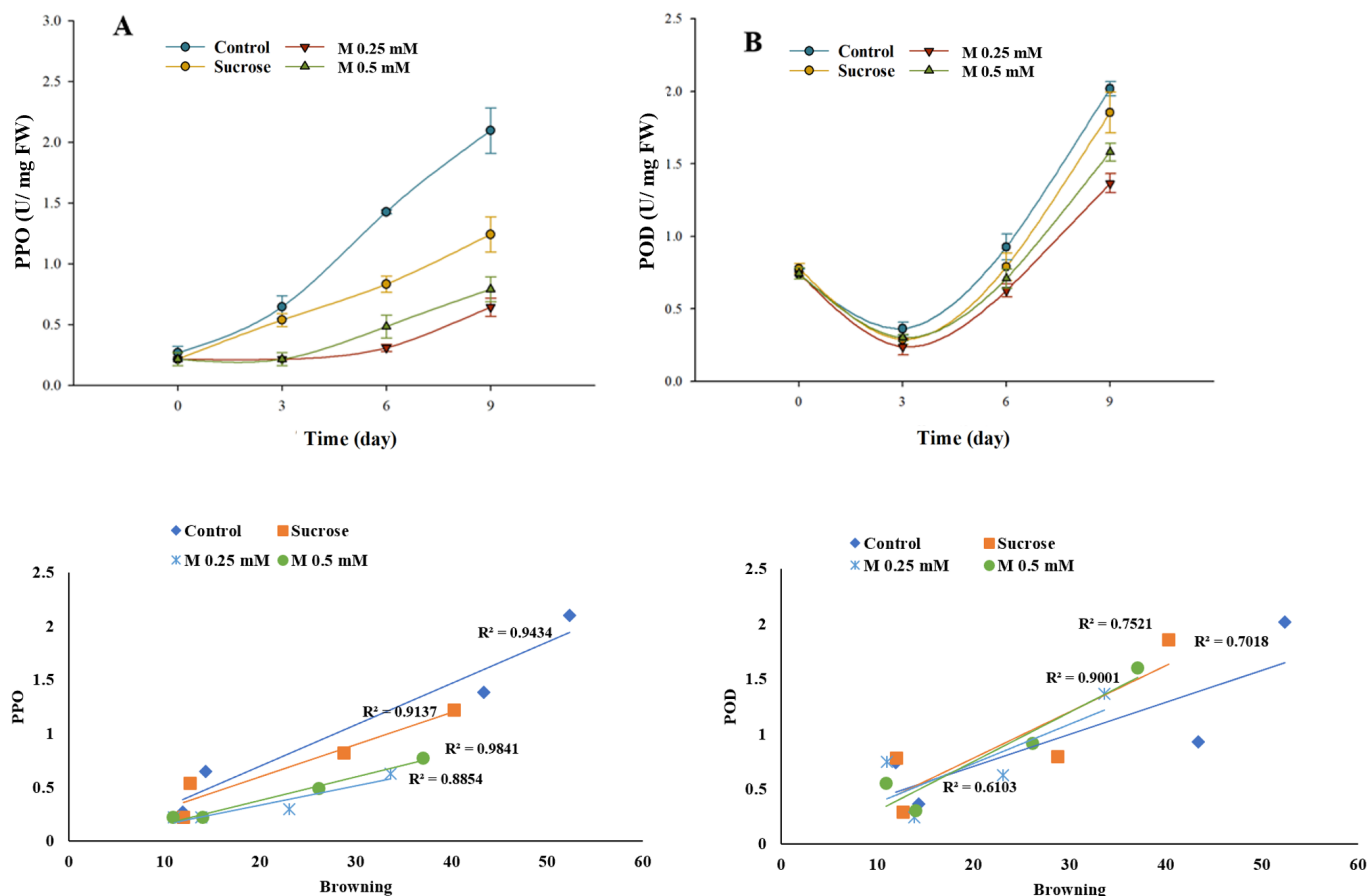


Figure 3. Effects of melatonin on polyphenol oxidase (PPO) (a) and peroxidase (POD) (b) activities, and correlations between browning and enzyme activities (c,d) of cut *Narcissus tazetta* L. 'Shahla-e-Shiraz' flowers during storage at 20 ± 2 °C and 60 ± 5% relative humidity. Values are means ± SE from three replicates ($n = 3$). Statistical analysis was performed using Duncan's test.

the total variance in the dataset, according to the eigenvalues of the covariance matrix. Specifically, PC1 explained 58.0% of the variation, while PC2 described 28.9% of the variance. PC1 was positively correlated with L^* , visual quality, and flower diameter, and negatively correlated with ΔE , browning index, and PPO activity. RFW and RWC were positively correlated with PC2, whereas POD activity was negatively correlated with PC2 (Figure 5).

The Pearson correlation matrix illustrated positive (in blue) and negative (in red) correlations among the evaluated traits of cut narcissus flowers during storage (Figure 6). Visual quality showed a significant positive correlation with flower diameter ($r = 0.928$, $p < 0.01$) and normalized L^* ($r = 0.926$, $p < 0.01$). Conversely, quality was significantly negatively correlated with ΔE ($r = -0.933$, $p < 0.01$). A significant negative correlation was also observed between RWC and POD activity ($r = -0.919$, $p < 0.01$). Browning index was positively correlated with ΔE ($r = 0.942$, $p < 0.01$)

and negatively correlated with quality ($r = -0.934$, $p < 0.01$), diameter ($r = -0.912$, $p < 0.01$), and L^* ($r = -0.891$, $p < 0.01$) (Figure 6).

4 Discussion

Postharvest quality loss in cut flowers is driven by interconnected physiological processes, particularly petal senescence, wound-induced stress responses, and impaired water balance, together with physical water loss leading to dehydration, wilting, and diminished ornamental value [22]. In general, melatonin-treated flowers in this study showed better quality compared with the control samples. Melatonin has been reported to improve the quality of cut flowers by reducing oxidative stress and maintaining membrane stability and flower color [10]. Petal browning caused by senescence is a critical factor reducing the postharvest quality and vase life of cut flowers. The color status of cut narcissus flowers was evaluated by measuring the L^* value and browning

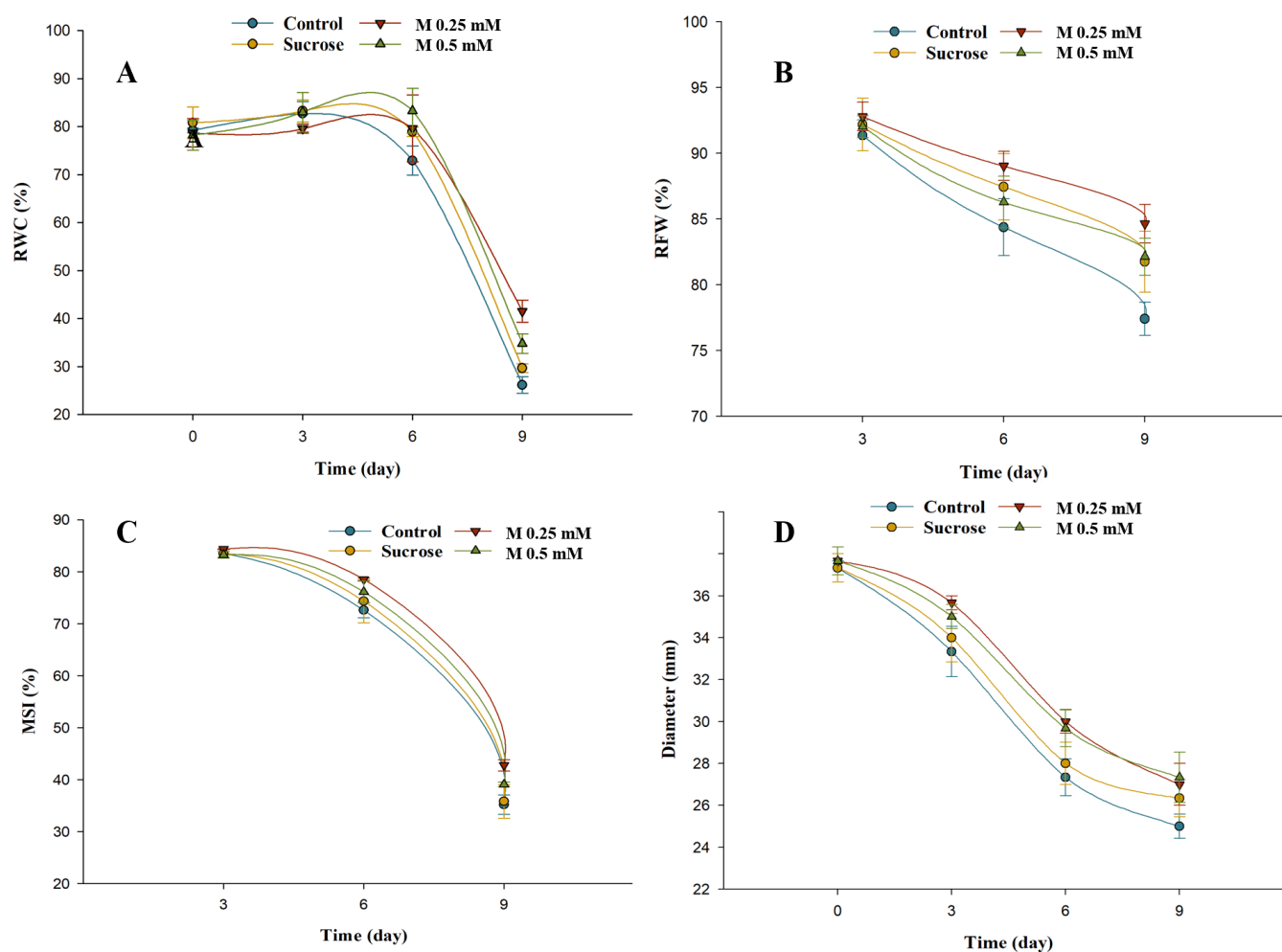


Figure 4. Effects of melatonin on relative water content (RWC) (a), relative fresh weight (RFW) (b), the membrane stability index (MSI) (c), and diameter (d) of cut *Narcissus tazetta* L. 'Shahla-e-Shiraz' flowers during storage at 20 ± 2 °C and $60 \pm 5\%$ relative humidity. Values are means $\pm$ SE from three replicates ($n = 3$). Statistical analysis was performed using Duncan's test.

index (BI). In the present study, melatonin-treated flowers exhibited a significantly lower browning index than the control group. Color preservation mediated by melatonin may be attributed to the inhibition of PPO and POD activities (responsible for enzymatic browning), the retention of anthocyanin and flavonoid contents, and the suppression of membrane lipid peroxidation, which prevents the release of pigment-degrading enzymes [11, 23]. In *Alstroemeria* flowers, Hosseini et al. [11] reported that melatonin increased the total anthocyanin content of petals and prevented pigment degradation. In narcissus petals, the characteristic yellow-white color is mainly due to the presence of carotenoids and flavonoids [4]. The preservation of this color by melatonin can be attributed to maintaining plastid membrane integrity (the storage site of carotenoids) and inhibiting oxidative enzymes (PPO and POD). Furthermore, a meta-analysis by Madebo et al. [24]

demonstrated that melatonin significantly increased total phenolic, flavonoid, and anthocyanin contents, which directly contributed to preserving the color and visual quality of horticultural produce postharvest. These findings align closely with the results of the present study, demonstrating that melatonin effectively preserved the color of cut narcissus petals.

Phenolic compounds are generally located inside the vacuoles, whereas the oxidative enzymes are located in the cytoplasm. During postharvest stress, cellular compartmentalization is disrupted and the enzymes come into contact with phenolic compounds to form brown quinones [25]. PPO and POD are key enzymes driving the oxidation of phenolic substrates, particularly simple phenols, and the subsequent formation of browning pigments. Melatonin plays a crucial role in preserving cell membrane integrity, thereby restricting contact between these enzymes

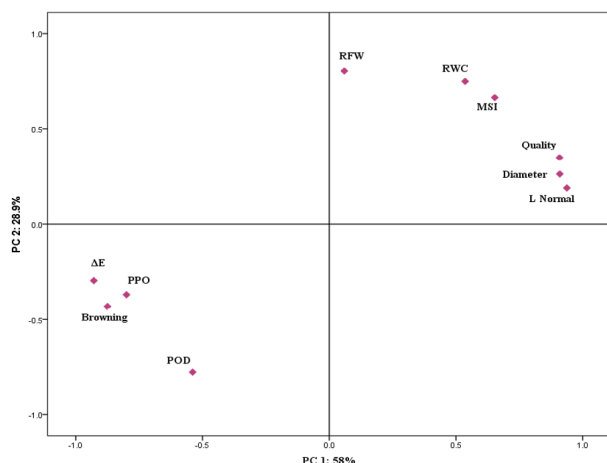


Figure 5. Principal component loading plot of physicochemical traits of cut *Narcissus tazetta* L. 'Shahla-e-Shiraz' flowers treated with melatonin during storage at 20 ± 2 °C and $60 \pm 5\%$ relative humidity.

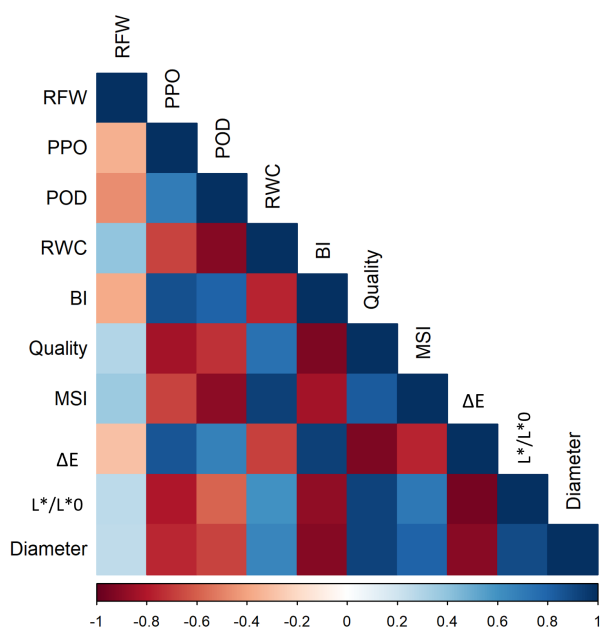


Figure 6. Correlations among the evaluated parameters of cut *Narcissus tazetta* L. 'Shahla-e-Shiraz' flowers treated with melatonin during storage using the Pearson method. ΔE , total color difference; BI, browning index; PPO, polyphenol oxidase; POD, peroxidase; RFW, relative fresh weight; RWC, relative water content; MSI, membrane stability index.

and phenolic substrates, which ultimately slows the browning process [26–28]. Cut anthurium flowers treated with melatonin have been found to display increased phenylalanine ammonia-lyase (PAL) activity and decreased PPO activity during storage. By enhancing PAL activity and suppressing PPO activity, melatonin helps preserve the quality and appearance of the flowers by facilitating the production

of desirable phenolic compounds while reducing enzymatic browning [15, 23].

The gradual decrease in RWC and RFW in control petals during the storage period indicates disruption in water relations and increased moisture loss, which is a basic sign of postharvest senescence [29–31]. Water relations in petals and other floral tissues are critical determinants of cut flower postharvest quality and vase life. After harvest, the balance between stem water uptake and transpiration is readily disrupted, primarily due to xylem occlusion or excessive transpirational water loss, leading to a sustained negative water balance. Consequently, this imbalance induces petal dehydration, loss of turgor, incomplete flower opening, and wilting, ultimately diminishing both ornamental quality and commercial value [22, 32].

The preservation of RWC and RFW by melatonin in the present study is consistent with the findings of previous studies on cut roses: Mazrou et al. [10] reported that pulse treatment with melatonin (0.2 mM) significantly inhibited the decrease in RWC and attributed this effect to the regulation of stomatal closure and reduced transpirational loss. In a similar study, Hosseini et al. [11] demonstrated in *Alstroemeria* flowers that melatonin at concentrations of 100 and 200 μ M significantly increased RWC and RFW. Furthermore, the decline in water content in melatonin-treated petals during storage was non-significant, whereas control petals exhibited a marked reduction. Wang et al. [33] reported that melatonin maintained water balance in cut chrysanthemum by reducing water loss by 56.75% on the 10th day compared with the control. In addition, melatonin prevents water loss through damaged membranes by reducing oxidative stress and maintaining cell membrane integrity [10]. The decrease in fresh weight in control petals of *Narcissus* can be attributed to a combination of factors including reduced water absorption due to vascular occlusion, increased transpiration, and cellular structural damage due to membrane lipid peroxidation [31, 34].

Fresh weight loss is one of the main causes of flower wilting, which is caused by increased respiration rates and decreased water uptake [35]. In the current research, we demonstrated that the application of melatonin maintained the fresh weight of flowers and retarded senescence. The balance of transpiration and water uptake in cut flowers influences senescence. Melatonin can reduce transpiration through the

induction of stomatal closure [36]. Consistent with our findings, Lezoul et al. [12] also reported that melatonin significantly maintained the fresh weight of cut carnation flowers over an extended period. Additionally, melatonin treatment has been shown to reduce the stomatal aperture in the lower epidermis of cut roses. While control flowers exhibited fully open stomata, those treated with melatonin displayed marked stomatal closure. This suggests that exogenous melatonin application regulates stomatal movement, thereby contributing to the preservation of postharvest quality [10].

The results of the present study demonstrated that melatonin significantly enhanced the membrane stability index (MSI) of cut narcissus petals and inhibited the increase in cell membrane permeability. The cell membrane is a primary target of oxidative stress-induced damage during the postharvest period. The accumulation of reactive oxygen species (ROS) leads to membrane lipid peroxidation and increased electrolyte leakage, both of which reflect the loss of membrane structural and functional integrity [34, 37]. The preservation of MSI by melatonin in the present study is consistent with the results of several studies. Mazrou et al. [10] showed in cut roses that melatonin preserved membrane integrity by reducing H_2O_2 accumulation and lipid peroxidation and significantly improved the membrane stability index. In *Alstroemeria* flowers, Hosseini et al. [11] confirmed that melatonin reduced electrolyte leakage and malondialdehyde (MDA) content and increased membrane stability. As a direct antioxidant, melatonin scavenges reactive oxygen species ($O_2^{\bullet-}$, H_2O_2 and $\bullet OH$) before they come into contact with membrane lipids [38]. In addition, melatonin increases the activity of antioxidant enzymes including superoxide dismutase (SOD), catalase (CAT) and ascorbate peroxidase (APX), which are responsible for the conversion of superoxide to H_2O_2 and then to water and oxygen [39]. Melatonin also strengthens the non-enzymatic antioxidant protection of the membrane by maintaining the content of phenols and flavonoids [23].

5 Conclusion

The present study demonstrates that exogenous melatonin application effectively mitigates petal browning and preserves the postharvest quality of *Narcissus tazetta* cut flowers. Melatonin treatment at 0.25 mM was more effective in maintaining RFW, RWC, and MSI. However, statistical analysis

revealed no significant differences between the two concentrations for most of the measured traits, indicating comparable overall efficacy. Given the absence of significant differences between the two concentrations and considering the economic advantages of lower application rates, melatonin at 0.25 mM is recommended as the optimal concentration for practical postharvest application. This treatment offers a cost-effective and eco-friendly strategy for extending the decorative longevity and commercial value of cut narcissus flowers. Future studies should explore the molecular mechanisms underlying melatonin-mediated regulation of browning-associated gene expression and evaluate its efficacy under commercial storage and transport conditions.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The authors declare no conflicts of interest.

AI Use Statement

The authors declare that Gemini was used for language editing and grammar correction. The authors have carefully reviewed, revised, and verified the AI-assisted output and take full responsibility for the content of the manuscript.

Ethical Approval and Consent to Participate

Not applicable.

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