

Effects of Different Putrescine Doses on Postharvest Fruit Quality of Jujube (*Ziziphus jujuba* Mill.)

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Research Article

Keywords: jujube, storage, putrescine, pomology, biochemical composition

Posted Date: November 7th, 2025

DOI: <https://doi.org/10.21203/rs.3.rs-7849152/v1>

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Additional Declarations: No competing interests reported.

Abstract

As the nutritional and health benefits of jujube fruit have become increasingly recognized, both its production and consumption have grown steadily. Moreover, jujube has gained attention in dietary regimens due to its rich phytochemical composition. However, similar to other fruit species, postharvest losses in yield and quality remain a major concern for jujube. To minimize these losses and extend the shelf life of marketable fruits, various postharvest treatments have been investigated. In the present study, different concentrations of putrescine (Control, 0.5, 1.0, and 1.5 mM) were applied to jujube fruits in order to reduce storage-related quality degradation and preserve bioactive compound concentrations. Fruits were stored for 30 days at + 4°C and 90% relative humidity. During storage, fruit weight loss, flesh firmness, decay rate, soluble solid content, pH, titratable acidity, fruit color, total protein, total antioxidant activity, total anthocyanin, and total phenolic contents were analyzed. At the end of the storage period, the highest weight loss was observed in the control group (1.63%), whereas the greatest flesh firmness was obtained in the 1.5 mM putrescine treatment (6.43 kg/cm²). Soluble solid content, pH, and titratable acidity were highest in the control group, with respective values of 29.55%, 4.89, and 0.28%. Similarly, the control group exhibited the highest total antioxidant activity (38.92%). The 0.5 mM putrescine treatment resulted in the highest total protein and anthocyanin contents (1.92% and 9.34 mg/L, respectively), while the total phenolic content was highest in both the control and 0.5 mM treatments (0.72 mg/g). Overall, the findings indicate that postharvest application of putrescine at different concentrations positively influenced the maintenance of fruit quality attributes in jujube.

1. Introduction

Jujube (*Ziziphus jujuba* Mill.) is a drupe-bearing species belonging to the Rhamnaceae family, comprising more than 135 species worldwide (Pandey et al. 2010). The cultivation of jujube fruit dates back approximately 7,700 years in China, from where it spread along the Silk Road to various regions including India, Iran, Afghanistan, and Central Asia (Tatari et al. 2016).

Because freshly harvested jujube fruits are highly perishable, they are often dried to extend their shelf life (Du et al. 2013). Dried jujubes are rich in phenolic compounds, while fresh jujube fruits are notable for their thin peel, crisp texture, and high nutritional value (Cui et al. 2008). The concentrations of these bioactive compounds responsible for many of the health-promoting effects of jujube have been shown to vary among genotypes (Gao et al. 2012; Chen et al. 2013; Gao et al. 2013).

The jujube plant offers several agronomic and nutritional advantages, including high vitamin C content, applications in traditional medicine, an extended flowering period, and remarkable tolerance to drought and salinity. These attributes have contributed to the increasing global popularity of fruit (Liu et al. 2020). Due to its strong antioxidant capacity, jujube provides health benefits ranging from liver protection to anticancer effects, as well as promoting and maintaining skin health (Vahedi and Bozari 2008). Fruit quality and appearance are critical parameters influencing marketability (Crisosto and Kader 2002).

Both the leaves and fruits of jujube contain polysaccharides, vitamins, minerals, phenolic compounds, antioxidants, and antimicrobial components in varying proportions (Yılmaz 2019; Ji et al. 2020; İkinci et al. 2022). Several bioactive compounds found in jujube have demonstrated anticarcinogenic properties (Hasan et al. 2014; Tahergorobi and Ford 2014; Hürkan, 2019). Furthermore, jujube fruits are rich in proteins, fats, carbohydrates, and dietary fiber (İkinci et al. 2022). The accumulation of phenolic compounds has been reported to reach its highest level during the fruit's ripening stage (Gündüz and Saraçoğlu 2014), indicating that maturity has a significant impact on the fruit's nutritional and functional properties.

The total phenolic, flavone, and flavonoid contents have been found to differ among jujube fruits at various maturity stages (Liu and Zhao 2009; Wang et al. 2016). To reduce postharvest quality losses and extend storage life, several preservation treatments have been investigated. Among these, putrescine is considered a promising growth regulator for maintaining postharvest quality and biochemical integrity in fruits.

Therefore, the present study aimed to investigate the effects of different putrescine applications on the postharvest fruit quality of jujube (*Ziziphus jujuba* Mill.) during cold storage.

2. Materials and Methods

2.1. Plant Material

Jujube (*Ziziphus jujuba* Mill.) fruits were obtained from a commercial orchard located in Ankara, Türkiye. Fruits were immersed for 5 minutes in putrescine solutions at concentrations of 0 (control), 0.5, 1.0, and 1.5 mM. Control fruits were dipped in distilled water only. Following treatment, the fruits were placed in perforated plastic boxes (10 fruits per box) and stored at + 4°C with 90% relative humidity for 10, 20, and 30 days. Additionally, untreated fruits were analyzed at day 0 to represent the initial condition.

2.2. Physical and Pomological Measurements

Fruit weight was recorded using a digital balance with a sensitivity of 0.01 g, and weight loss was calculated using the formula:

$$\text{Weight loss (\%)} = \frac{(\text{Initial weight} - \text{Final weight})}{\text{Initial weight}} \times 100,$$

Fruit firmness was measured using a hand penetrometer after peeling the skin from five randomly selected fruits. The soluble solid content (SSC) of the fruit juice was determined using a handheld refractometer. pH values were measured with a digital pH meter, and titratable acidity (TA) was determined by titration of 10 mL of fruit juice with NaOH and expressed as malic acid equivalents.

Color parameters (L^* , a^* , b^* , Chroma, and Hue angle) were determined using a colorimeter (3NH NR60CP). The decay rate was visually evaluated by dividing the fruits into four equal parts and expressing the proportion of decayed fruits as a percentage.

2.3. Biochemical Analyses

Total Phenolic Content (TPC): Determined according to the method described by Singleton et al. (1999) using Folin–Ciocalteu reagent, and results were expressed as mg gallic acid equivalents per gram (mg GAE/g). Total Anthocyanin Content (TAC): Measured following the method of Di Stefano et al. (1989) and expressed as mg malvidin-3-glucoside equivalents per liter (mg/L). Total Protein Content: Determined according to the procedure described by Bradford (1976). Total Antioxidant Activity (DPPH): The free radical scavenging activity was measured according to the DPPH method described by Blois (1958), and results were expressed as percentage inhibition (%).

2.4. Statistical Analysis

The experiment was arranged in a completely randomized factorial design with three replications, each consisting of 10 fruits. The effects of the factors (storage time, putrescine concentration, and their interactions) were evaluated using two-way analysis of variance (ANOVA). When the F-test indicated significant differences, mean separations were performed using Fisher's Least Significant Difference (LSD) test.

3. Results and Discussion

In this study, changes in pomological properties and bioactive compounds of jujube fruits during storage were monitored following postharvest application of putrescine. Putrescine treatments significantly influenced fruit quality parameters, with the effects varying according to both concentration and storage duration. Overall, as storage time increased, weight loss, decay rate, and general quality deterioration tended to rise, while putrescine treatments effectively reduced these losses to a certain extent.

3.1. Weight Loss (%): The effect of putrescine treatments on fruit weight loss was found to be significant ($P < 0.001$). The highest weight loss (1.23%) occurred in the control group, while the lowest (0.63%) was observed in fruits treated with 1.5 mM putrescine (Fig. 1). The impact of storage duration on weight loss was also significant, with the lowest value (0.54%) measured on day 10 and the highest (1.22%) on day 30. Weight loss increased progressively during storage; however, putrescine treatments effectively minimized losses compared with the control group. This indicates that putrescine partially suppresses the respiration- and transpiration-related losses commonly observed in climacteric fruits (Mitcham et al. 1997). Similar findings have been reported for jujube (Kavas and Dalkılıç 2015; Yıldız 2018) and cherry (Bal 2012).

3.2. Fruit Firmness (kg/cm^2): Storage time significantly affected fruit firmness. The lowest firmness value ($3.08 \text{ kg}/\text{cm}^2$) was recorded on day 20, while the highest ($6.50 \text{ kg}/\text{cm}^2$) occurred on day 10 (Fig. 1). In general, firmness values were better preserved in lower putrescine concentrations (particularly 0.5

mM) throughout storage. Previous studies have also shown a decline in jujube fruit firmness during cold storage (Gök et al. 2017), consistent with observations in banana (Marjan et al. 2018) and plum (Pérez-Vicente et al. 2002). Similarly, in mango, putrescine treatments delayed the softening of fruit tissues (Razzaq et al. 2014).

3.3. Decay Rate (%): The effect of putrescine treatments on decay rate was not statistically significant. The highest decay rate (21.11%) was recorded in fruits treated with 1.5 mM putrescine (Fig. 1). However, storage duration had a highly significant effect ($P < 0.001$), with no decay detected on day 10 (0.00%) and the highest decay rate (46.67%) on day 30. The incidence of decay increased notably after day 20, with the highest decay observed in the 1.0 mM treatment. Similar studies have reported that extended storage periods increased visible deterioration in persimmon (Kulan 2020), while in cherry, putrescine reduced decay rate by nearly 50% compared to the control (Bal 2012). In pomegranate, lower putrescine concentrations were found to be more effective in reducing decay incidence (Waskar et al. 2015).

3.4. Soluble Solid Content (%): Putrescine treatments significantly affected soluble solid content (SSC) ($P < 0.05$). The highest SSC (27.24%) was found in the control group, while the lowest (23.68%) was measured in the 1.0 mM treatment (Fig. 1). The effect of storage duration was also significant, with the highest SSC (26.34%) recorded on day 10. Overall, SSC values ranged between 20.70% and 29.35%, with the control group exhibiting the highest concentrations. These results were slightly higher than those reported in a previous study (Ecevit et al. 2008), whereas SSC levels in jujube at different ripening stages have been reported as 12.80–18.30% (Gündüz and Saraçoğlu 2014) and 20.02% (Galindo et al. 2015). In mango, putrescine treatments led to SSC reductions (Jawandha et al. 2012), while in peach, they were reported to increase SSC (Abbasi et al. 2019).

3.5. pH: The effect of putrescine treatments on fruit pH was not significant. The highest pH value (4.53) was observed in the control group (Fig. 1). However, storage duration had a significant effect ($P < 0.001$), with the highest pH (4.69) measured at day 0. pH values increased during storage, particularly in the control treatment. Similar trends have been reported in strawberries (Khosroshahi et al. 2017) and apricot (Davarynejad et al. 2013), although other studies have found stable pH levels in jujube during storage (Gök et al. 2017).

3.6. Titratable Acidity (%): The effect of putrescine on titratable acidity (TA) was not significant. The highest TA value (0.39%) was recorded in the 0.5 mM treatment, whereas the lowest (0.36%) occurred in both the control and 1.0 mM groups (Fig. 1). The effect of storage duration on TA was significant ($P < 0.001$), with the highest value (0.61%) at day 0. The interaction between storage time and treatment was also significant ($P < 0.05$). As shown in Table 3.2, the TA content measured at 0.61% after harvest reached its highest value (0.68%) in the 1.5 mM treatment on day 10. Akbolat et al. (2008) reported an average TA value of 0.33% in jujube. In the present study, TA values declined during storage, with variable responses to putrescine concentrations. This trend is consistent with findings in apricot (Davarynejad et al. 2013) and plum (Valero et al. 2011), whereas in peach (Khosroshahi and Esna-Ashari 2008) and mandarin (Ennab et al. 2020), putrescine applications were shown to increase TA.

3.7. Fruit Color: The highest L^* (24.51) and a^* (14.43) values were observed in the 0.5 mM putrescine treatment. The effect of storage duration on the a^* value was also found to be significant ($P < 0.05$), with

the highest a^* value (15.51) recorded on day 30. In addition, the highest b^* value (16.36) was found in the control group, while the highest Chroma (21.98) and Hue (48.52) values were detected in the 0.5 mM and control treatments, respectively (Fig. 2).

Throughout storage, fluctuations were observed in all color parameters (L^* , a^* , b^* , Chroma, and Hue). Lower doses of putrescine were found to better preserve fruit color, particularly by maintaining higher L^* and Chroma values. These findings are consistent with previous studies on persimmon (Koyuncu et al. 2005) and jujube (Keleş 2020).

3. 8. Total Protein Content (%): The effect of putrescine treatments on the total protein content of the fruits was found to be non-significant, with the highest value recorded in the control group (1.92%). However, the effect of storage duration was significant ($P < 0.001$), and the highest total protein content (1.94%) was observed on the 10th day. Furthermore, the interaction between storage time and treatment was significant ($P < 0.05$), with the highest protein content (1.96%) detected in fruits treated with 0.5 mM putrescine on the 10th day. Overall, total protein content tended to increase with prolonged storage (Fig. 3). Nevertheless, these values were lower than those reported by other researchers for certain jujube genotypes (Akbolat et al. 2008; Ecevit et al. 2008).

3. 9. Total Antioxidant Capacity (DPPH, % Inhibition): Putrescine treatments significantly affected the total antioxidant capacity of jujube fruits ($P < 0.05$). The highest antioxidant activity (35.99%) was found in the control group, while the lowest (20.66%) occurred in the 0.5 mM treatment (Fig. 3). Storage duration also had a significant effect, with the highest antioxidant capacity (34.69%) recorded on the 10th day. In general, DPPH radical scavenging activity varied among treatments and tended to decrease during storage. The highest values were obtained at the 10th day under low putrescine concentrations. These findings are lower than those reported for jujube fruits cultivated in Pakistan (Riaz et al. 2021).

3. 10. Total Anthocyanin Content (mg/L): The effects of putrescine treatments on the total anthocyanin content of jujube fruits were not statistically significant. Overall, fluctuations were observed among treatments, with the highest anthocyanin content (9.28 mg/L) recorded at 1.0 mM putrescine, and the highest value by storage time (8.25 mg/L) on the 30th day. The interaction between treatment and storage time was also significant, with the maximum level (11.58 mg/L) obtained on the 20th day under the 1.0 mM treatment (Fig. 3). Similar findings have been reported in *Prunus salicina* cv. Friar, where putrescine application reduced anthocyanin content (Guan and Duo 2010), whereas increases were observed in peach fruits (Awad 2013).

3. 11. Total Phenolic Content (mg/g): The effect of putrescine treatments on total phenolic content (TPC) was found to be significant ($P < 0.05$). The highest TPC values (0.75 mg/g) were observed in the control and 0.5 mM putrescine treatments (Fig. 3). Storage duration also significantly influenced TPC ($P < 0.001$), with the highest value (0.78 mg/g) recorded on the 10th day. Total phenolic content showed fluctuations during storage, with the highest concentration maintained at low doses (0.5 mM) on the 10th day. Previous studies have shown that TPC in jujube fruits varies across maturity stages (Wang et

al. 2010; Tepe 2020), with a tendency to decrease in certain genotypes during ripening (Wu et al. 2012). Similarly, reductions in phenolic content were reported in cherries (Bal 2012).

Principal Component Analysis (PCA)

According to the principal component analysis (PCA) results, the first principal component (PC1) accounted for 41.8% of the total variance, while the second component (PC2) explained 26.5%, together representing 68.3% of the total variability in the dataset. Examination of the PCA biplot revealed that different concentrations of putrescine and storage durations had distinct effects on the quality parameters of jujube fruits. In the plot, the control groups were positioned in the same direction as fruit firmness and total anthocyanin content, indicating that these parameters exhibited higher values at harvest time. Conversely, fruit weight loss and decay rate were closely associated with the 30th-day control group, representing the quality deterioration that occurred during prolonged storage. Color parameters (L, a, b, Chroma, and Hue) were clustered along the positive PC1 axis, suggesting that different concentrations of putrescine had a pronounced impact on the color characteristics of jujube fruits. In addition, DPPH radical scavenging activity and total phenolic content were aligned with the 1.5 mM treatment on the 20th day, indicating that this concentration was more effective in maintaining antioxidant capacity during storage. Moreover, total protein and soluble solid content appeared to be relatively less influenced by the treatments. Overall, the PCA results demonstrated that the application of different putrescine concentrations significantly affected the physical, chemical, and biochemical quality attributes of jujube fruits throughout the storage period. In particular, the 1.0 and 1.5 mM treatments exhibited the most favorable effects in preserving overall fruit quality (Fig. 4).

Heat Map Analysis

The heat map analysis (Fig. 5) visually illustrates the changes in quality parameters of jujube fruits under different putrescine concentrations and storage durations. According to the results, a distinct clustering pattern was observed among samples and variables. Harvest-time samples (Control and 0.5–1.5 mM) exhibited high positive values, particularly in fruit firmness, total anthocyanin content, and color-related parameters (L, a, b, Chroma, and Hue). This indicates that jujube fruits possessed optimal color and texture quality at harvest. In contrast, fruit weight loss and decay rate were markedly higher in the 30th-day control and low-concentration treatment groups, reflecting more pronounced quality degradation in these samples. DPPH radical scavenging activity and total phenolic content, on the other hand, were found to be higher in the 1.0 and 1.5 mM treatments, particularly on the 20th and 30th days, suggesting that higher putrescine concentrations were more effective in maintaining antioxidant capacity during storage. Meanwhile, protein, titratable acidity (TA), and soluble solid content (SSC) exhibited a relatively uniform distribution across treatments, indicating that these parameters remained comparatively stable during storage. Cluster analysis further revealed that the samples were primarily grouped according to storage duration and treatment concentration, highlighting the substantial influence of putrescine dose on the physicochemical characteristics of jujube fruits. Overall, the heat map data demonstrated that the 1.0 and 1.5 mM putrescine applications were more effective in preserving fruit quality throughout the

storage period, distinguishing these groups positively from the others. The heat map provides a detailed visualization of how fruit quality attributes changed and clustered across the 30-day storage period under each treatment. The color scale represents high and low content levels for each parameter.

These results confirm that putrescine applications can effectively reduce postharvest losses in jujube fruits, particularly by maintaining firmness, color, and bioactive compounds. However, the magnitude of this effect depends on both treatment concentration and storage duration, with lower doses showing comparatively greater success in mitigating quality loss. These findings underscore the potential of putrescine as a promising postharvest treatment for minimizing quality deterioration in jujube fruits.

4. Conclusion and Recommendations

This study aimed to determine the effects of different putrescine doses on the postharvest storage performance of jujube fruits. Postharvest putrescine treatments were evaluated in terms of pomological traits and changes in the bioactive compounds of jujube genotypes. Throughout the storage period, putrescine applications positively influenced several fruit quality parameters and helped to reduce postharvest losses. According to the findings, weight loss was more pronounced in the control fruits, while soluble solid content (SSC) and total antioxidant capacity were higher in untreated samples. The 0.5 mM putrescine treatment was found to be more effective in maintaining fruit firmness, peel color, total protein, and total phenolic content. The 1.0 mM concentration provided better protection against decay rate and total anthocyanin loss, while the 1.5 mM dose was more effective in preserving titratable acidity (TA), weight loss, and fruit firmness.

Overall, the results indicate that jujube fruits can be stored for up to 30 days at 90% relative humidity with minimal quality loss when treated with 0.5 mM putrescine. Further studies on putrescine concentration and its interaction with different storage conditions are recommended to enhance understanding and optimize postharvest preservation strategies for jujube fruits.

Declarations

Author Contributions: Conceptualization, methodology, formal analysis, writing-review and editing, M.K.G.; resources, writing, B.Y. All authors have read and agreed to the published version of the manuscript.

Funding and Acknowledgements: This article contains a section of the master's thesis prepared by Büşra Yılmaz under the supervision of Mustafa Kenan Geçer. The study was funded by Bolu Abant İzzet Baysal University Scientific Research Projects Unit under grant number 2023-TYL-6.12.57-0024.

Data Availability Statement: The data used for this research can be obtained from the relevant author upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

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Figures

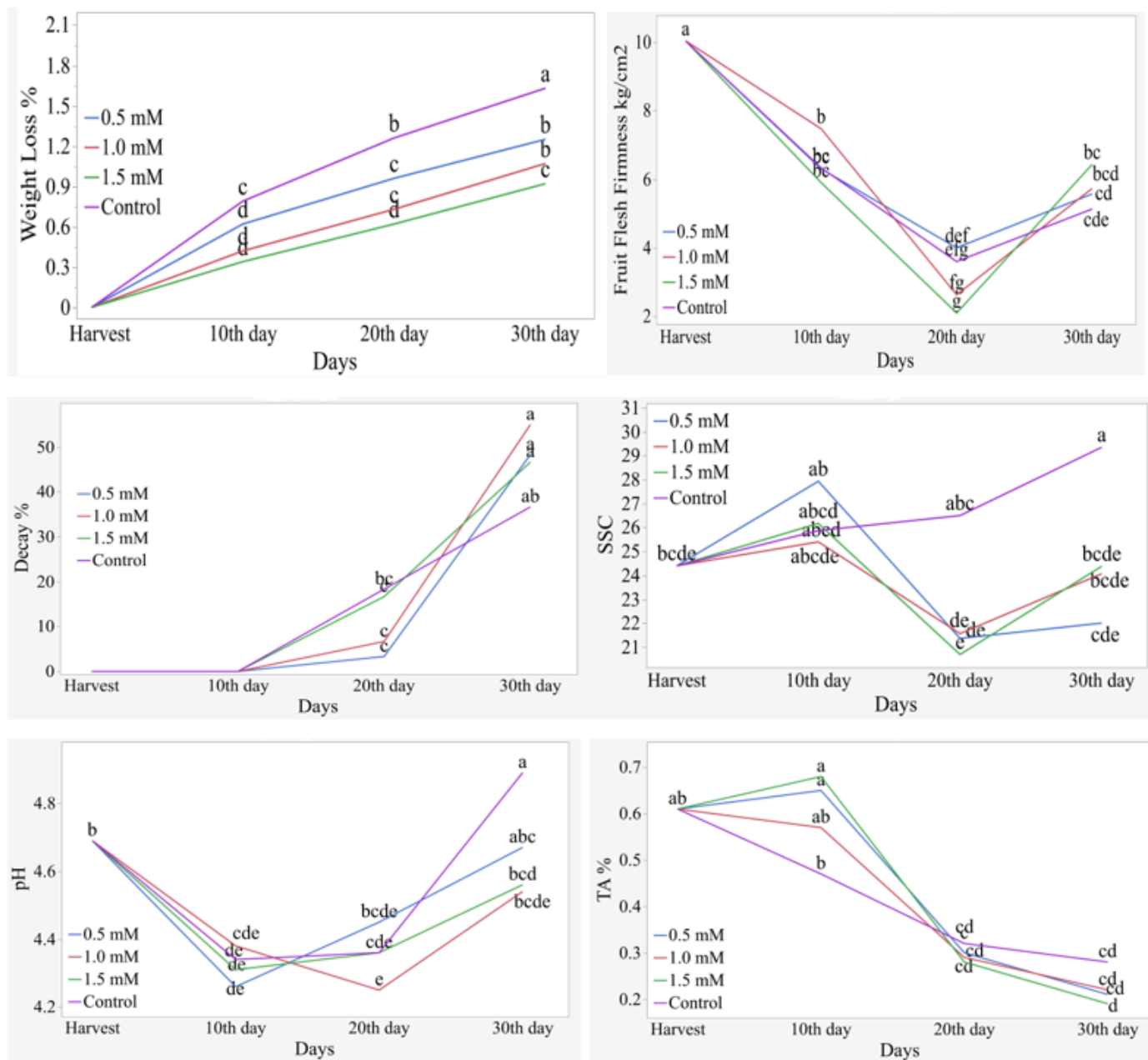


Figure 1

Effects of different putrescine concentrations on fruit weight loss, flesh firmness, decay rate, and soluble solid content of jujube fruits. Different letters within the same column indicate statistically significant differences at $p \leq 0.05$.

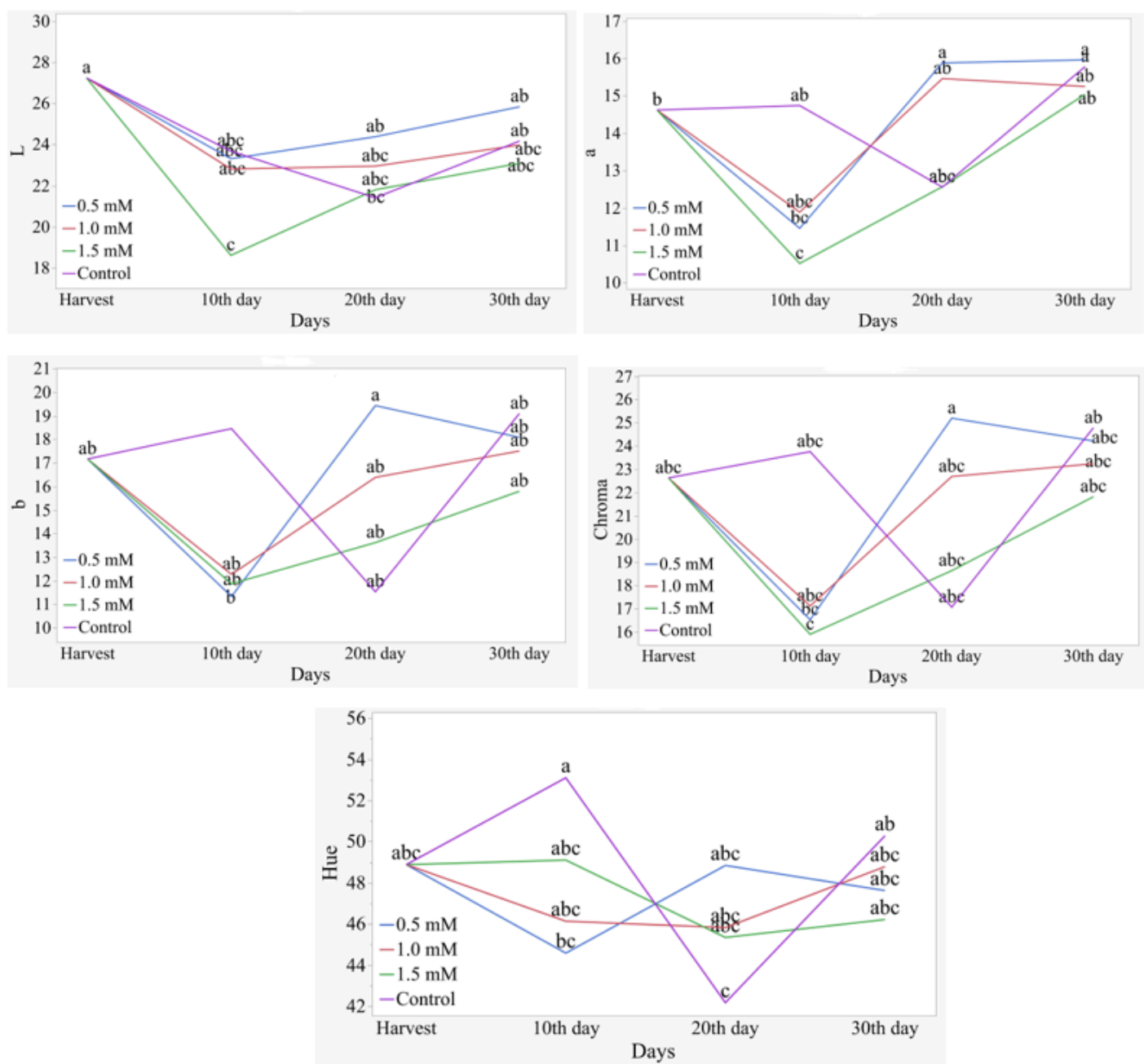


Figure 2

Effects of different doses of putrescine treatments on fruit color parameters. Different letters within the same column indicate statistically significant differences at $p \leq 0.05$.

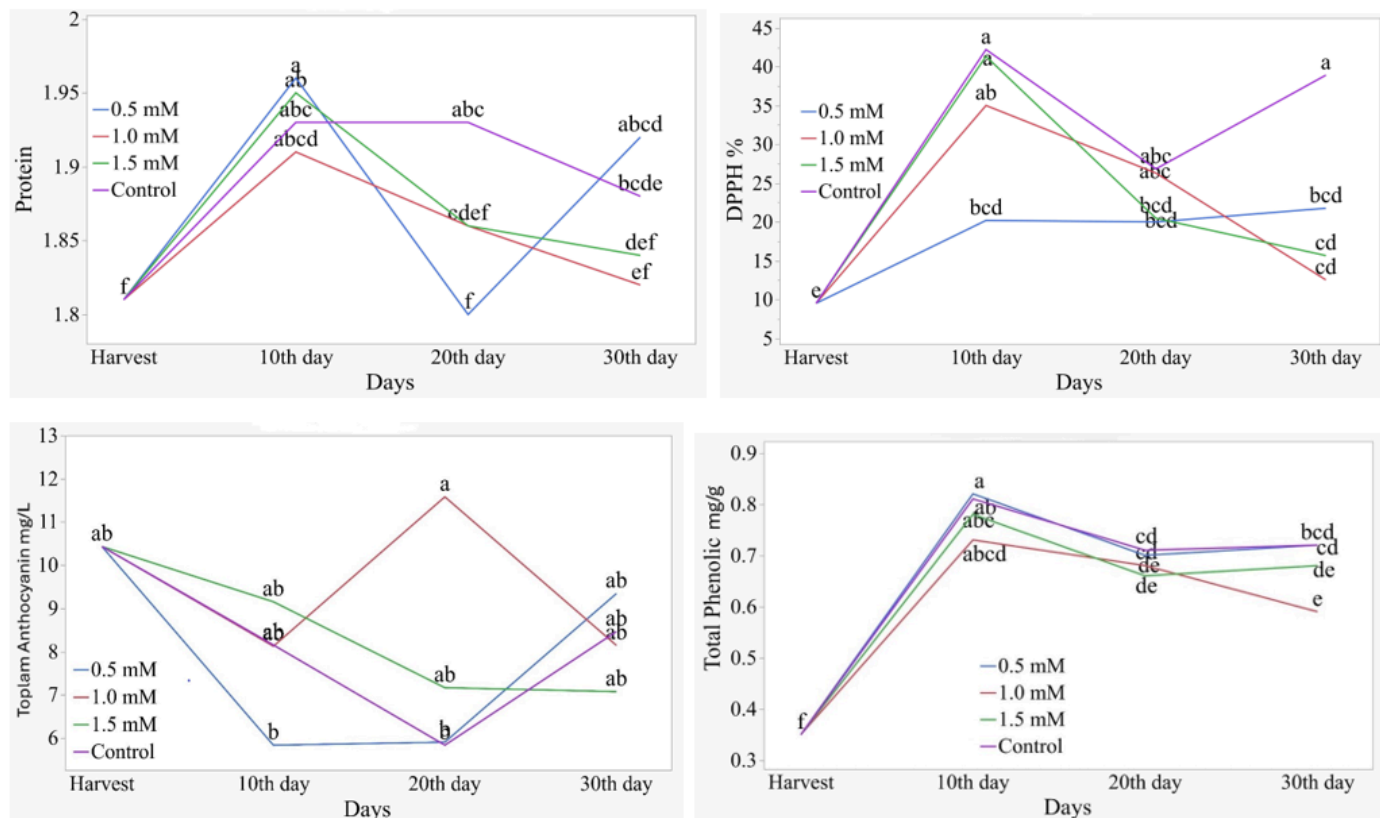


Figure 3

Effects of different putrescine concentrations on total protein, total antioxidant capacity, total anthocyanin, and total phenolic contents of jujube fruits. Different letters in the same column indicate statistically significant differences at $p \leq 0.05$.

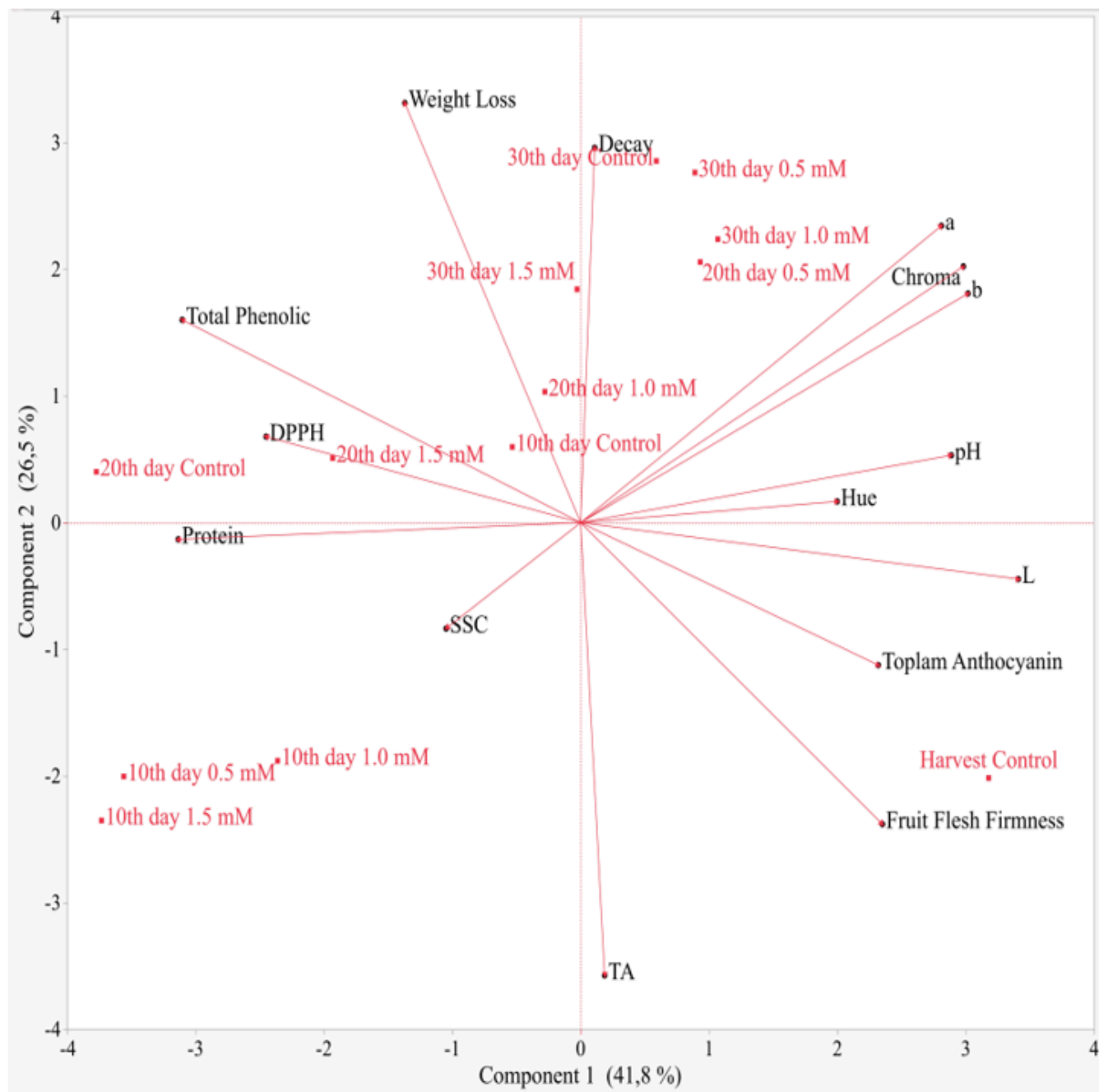


Figure 4

Principal component analysis (PCA) illustrating the correlations among fruit weight loss, decay rate, flesh firmness, soluble solid content (SSC), pH, titratable acidity (TA), color parameters, DPPH activity, total protein, total antioxidant capacity, total anthocyanin, and total phenolic content in jujube fruits.

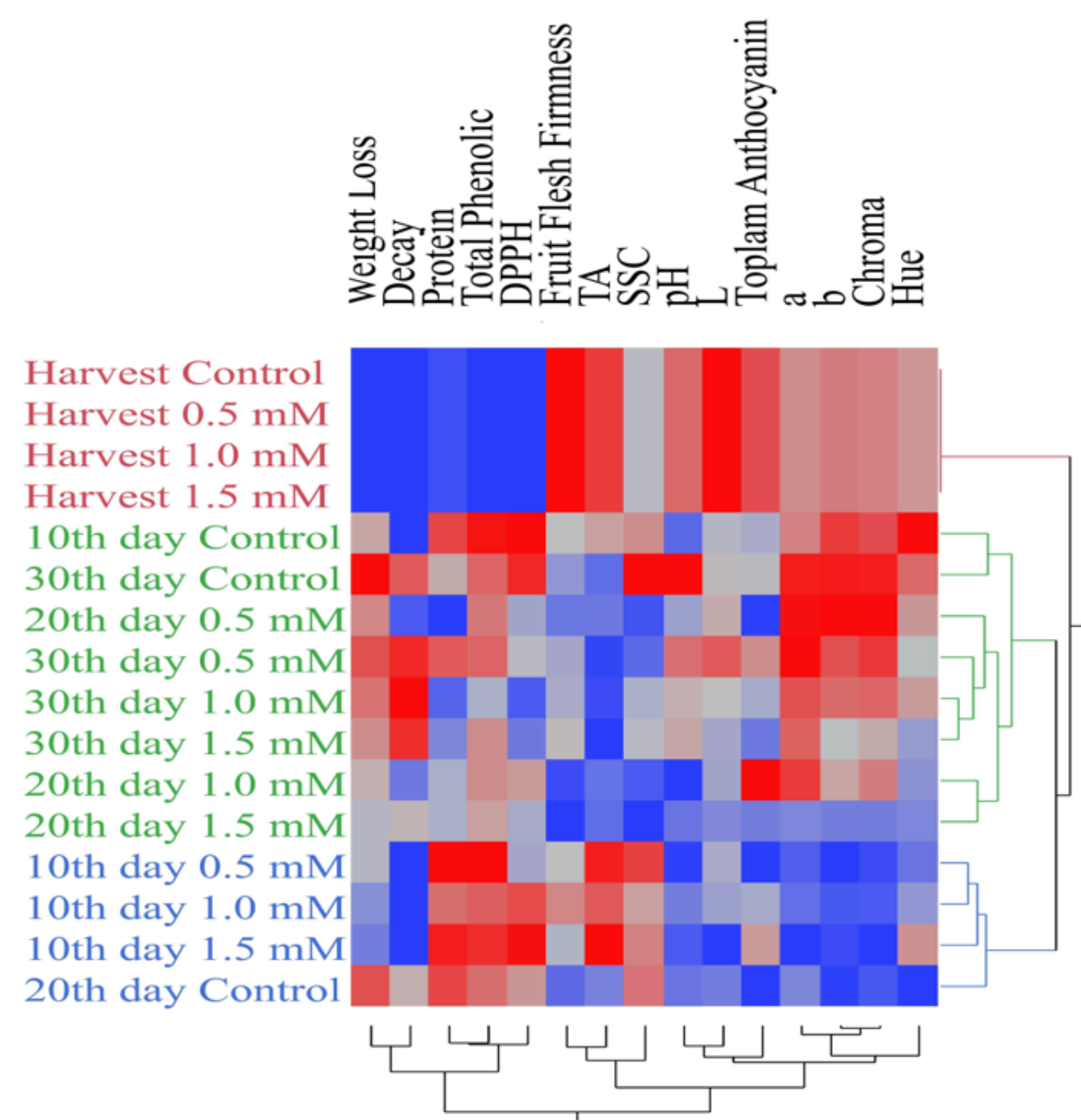


Figure 5

Cluster distribution of genotypes based on fruit weight loss, decay rate, flesh firmness, soluble solid content (SSC), pH, titratable acidity (TA), color parameters, DPPH activity, total protein, total antioxidant capacity, total anthocyanin, and total phenolic contents. *: The color scale from blue to orange represents values ranging from low to high.