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Postharvest application of spermidine preserves nutritional quality and enhances post-harvest longevity of mango

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Research Article

Keywords: Amrapali, spermidine, physicochemical, postharvest longevity, senescence

Posted Date: August 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10443090/v1

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Additional Declarations: No competing interests reported.

Abstract

Mango (*Mangifera indica* L.) is one of the major tropical fruit crops with immense socioeconomic importance, faces significant post-harvest losses that undermine its commercial value chain. Spermidine (Spd), a naturally occurring triamine polyamine, known to regulate cell division, retard senescence, and modulate ethylene biosynthesis, was evaluated for its effect on physicochemical properties and postharvest longevity of mango var. Amrapali. The experiment was conducted with five treatments (1.0 mM, 1.5 mM, 2.0 mM, and 2.5 mM), with fruits assessed over 15 days of ambient storage. Spd application significantly improved all measured parameters over the untreated control. The fruits treated with 2.5 mM concentration consistently outperformed others, and was found statistically at par with fruits treated with 2.0 mM Spd for majority of the traits. The fruits treated with 2.5 mM Spd recorded higher preserved TSS (21°Brix), better titratable acidity retention (0.16%), elevated ascorbic acid (24.32 mg/100 g pulp), total phenolics (55.66 mg GAE/100 g), carotenoid content (11.76 mg/100 g), and antioxidant activity (0.71 µmol Trolox/g) at the end of storage period. The fruit firmness was better retained (7.66 N), weight loss minimized (24.16%compared to the 48.90% in control), and a substantial reduction in spoilage percentage was observed in the treated fruits. An extended marketable shelf life by six additional days over the control was observed, with all differences being statistically significant. The post-harvest application of the chemical spermidine is thereby, recommended as a novel approach for enhancing mango postharvest quality and minimizing quality deterioration in commercial production systems.

1. INTRODUCTION

Mango (*Mangifera indica* L.), acclaimed as "King of fruits", cultivated across more than 100 countries (Rajan et al. 2021) and accounted for over 50% of total tropical fruit production worldwide (Hussain etal.2025). Its origin can be traced back to the Indo-Burma region boasting a rich varietal wealth of over 1,000 varieties (Bini et al. 2024) differing in size, shape, color, and flavour. It is an excellent source of nutrition, containing various vitamins and minerals including vitamins A and C, carotenoids, and phenolic components with significant antioxidant potential (Celis et al. 2019). In India, it holds a deeply rooted place in India’s cultural and religious life, woven into rituals, traditions, and the everyday identity of millions across the country (Thakur et al. 2017), thereby leading global mango production, contributing nearly 45% of the world's supply (Saúco, 2023) with an annual production of approximately 228.37 lakh tonnes (Ministry of Agriculture and Farmers Welfare, 2024-25). The Bihar region ranks fourth in national mango production (National Horticulture Board, 2023-24) with production of 1,619.4 thousand metric tonnes (Department of Agriculture & Farmers, 2024-25) with Bhagalpur district being a prominent mango-growing hub. Among the popular cultivars, Amrapali is widely grown across South and Central Bihar, distinguished by its fiberless, juicy, sweet pulp, vivid orange-yellow skin, and late-maturing nature that extends the export season. However, the fruit is not known to be storage resistant because of its vigorous metabolism (Yuanet al. 1979).

Over the last thirty years, the land devoted to mango farming and the production volume have grown tremendously, yet when placed side by side with leading mango-producing nations around the world, India's yield per hectare still falls noticeably short of its potential (Singh et al. 2009). Despite its high commercial value, mangoes come under the category of highly perishable fruits, having a brief ripening period and low temperature sensitivity, thereby resulting in postharvest losses estimated between 25 and 40 percent from harvest to consumption. Furthermore, accelerated respiration, enhanced ethylene production, and rapid biochemical changes during ripening severely limit its shelf life (Salinas et al. 2024). These vulnerabilities take a serious toll, both on farmers and exporters alike, estimating the post-harvest losses to be around 25% to 40% of the global harvest every single year (Yeshiwas et al. 2026).

The Amrapali variety is known for its exceptionally rich flavor, vibrant colour, and impressive nutritional composition. However, it is particularly susceptible to postharvest deterioration owing to its thin skin, high sugar content, and faster ripening rate, which limits its export potential despite its superior flavor and nutritional profile (Kramchote, 2025). Since, the variety moves through its ripening stages rapidly as compared to other export varieties, it leaves a very narrow window for growers, packers and traders to handle the fruit safely before its quality begins to decline. Extending the shelf life of export mangoes is therefore critical to enable long-distance transportation, stabilize market prices, and enhance competitiveness in global markets.

Polyamines are aliphatic amines having low-molecular weight, obtained during the metabolic processes of living organisms (Razzaq et al. 2014). Among these, putrescine (PUT), spermidine (Spd) and spermine (SPM) promote higher biological activity, and have been established to play an important role in cell division, fruit development, ripening, tissue softening and post-ripening senescence (Malik and Singh, 2005; Khan et al. 2007).Spd application is an effective postharvest treatment that preserves the physicochemical characteristics of mango by maintaining acidity and antioxidant content (Hans et al. 2025), while also exerting anti-ethylene activity that delays senescence and ripening (Sharma et al. 2017). At the biochemical level, it stabilizes cell membrane integrity, therefore reducing electrolyte leakage and slowing down the breakdown of cellular structures that typically results in fruit aging (Modesti et al. 2019). This stabilizing effect directly influences firmer fruit texture, reduced weight loss and a more visually appealing appearance. Also, Spd has been proven to significantly mitigate the softening of mango pulp by inhibiting the activity of key cell wall degrading enzymes such as polygalacturonase and pectin methylesterase, (Hong et al. 2017). Despite its multifaceted potential, research studies on the impact of Spd on the postharvest performance of Amrapali mango remains limited in India. In view of these beneficial effects in improving fruit quality parameters and reducing postharvest losses across the supply chain, the present study was conducted to assess the influence of postharvest application of Spd treatment on the quality and shelf life of mango (*Mangifera indica* L.) var. Amrapali.

2. MATERIALS AND METHODS

2.1 Fruit material and Spermidine treatment

The research study was conducted in the Department of Horticulture (Fruit Science), Bihar Agricultural University. Fully matured mango var. Amrapali fruits were procured from the university orchard and used for the experiment. The harvested fruits were carefully graded, maintaining uniformity in maturity, size, colour, free from disease and pests and devoid of any kind of mechanical damage. Freshly harvested fruits were dipped immediately after harvest for 5 minutes in solution of 0 mM (control), 1 mM, 1.5 mM, 2 mM and 2.5 mM. After air drying, the fruits were stored in ambient room conditions at 25 ± 2°C and 65–70% relative humidity. Biochemical and post-harvest parameters were investigated following storage at 3-day intervals for a total of 15-days.

The biochemical analysis comprised of measuring the total soluble solids (TSS), titratable acidity, ascorbic acid content, total antioxidant activity, total phenolic content, and total carotenoid content.

2.2 Measurement of total soluble solids (TSS), titratable acidity (TA) and TSS:TA ratio

The TSS was determined with a hand refractometer by applying 2–3 drops of freshly extracted mango juice directly to the instrument's prism and the readings were recorded as ºBrix. Titratable acidity (TA) was determined by titrating 10 ml of mango juice with 0.1 N NaOH in the presence of phenolphthalein indicator until the end point was reached by appearance of a persistent light pink colour. The acidity was calculated from the observed titre value, and expressed by percentage of citric acid. The TSS:TA ratio was calculated by dividing the TSS value by the corresponding TA value.

2.3 Measurement of ascorbic acid and total carotenoid content

The ascorbic acid content was quantified by using 2,6-dichlorophenol indophenol (DCPIP) titrimetric method. A 5 g of pulp sample was homogenized in 5% metaphosphoric acid, centrifuged, and then filtered. The clear extract was titrated with 0.1 mM DCPIP solution until a characteristic light pink end point was reached. The ascorbic acid content was measured using a standard calibration curve and expressed as mg/100 g pulp.

The total carotenoids were estimated by spectrophotometric analysis after extraction with acetone and petroleum ether. A 5 g sample of mango pulp was homogenized in 50 ml of chilled acetone, carefully filtered through Whatman No.1 filter paper, and extracted repeatedly until it turned colourless. The pooled filtrates were then adjusted to final volume of 50 ml with petroleum ether and the absorbance was measured at wavelength of 452 nm. The estimated total carotenoid content was expressed as mg/100g.

2.4 Measurement of total phenolic content and total antioxidant activity

The total phenolic content was measured from mango pulp extracts using the Folin-Ciocalteu method. For extraction, 5 g of crushed mango fruit sample was mixed with 80% ethanol, followed by

centrifugation at the rate of 15,000 per minute for 10 mins at 24 ºC. The resulting supernatant was used for estimation. The reaction mixture was prepared by mixing 0.5 ml aliquot the extract with 2.5 ml of Folin-Ciocalteu reagent (1:10 diluted with distilled water) and 2 ml of 20% Na_2CO_3. Following preparation, the prepared mixture that was allowed to stand at room temperature for 30 mins to ensure colour development for characteristic blue-black solution. The absorbance was measured at 750 nm and gallic acid (0-800 mg/l) was used to generate the calibration curve. The data was calculated for 3 samples and expressed as mg GAE per 100 gm of sample.

The total antioxidant activity was analyzed by the CUPRAC (Cupric Reducing Antioxidant Capacity) assay. The assay mixture comprised 1 ml ammonium acetate (NH_4Ac) buffer (pH 7.0), neocuproine solution, along with 10^{-2} M copper (II) chloride solution, then followed by the addition of 100 µl of mango extract prepared in 80% ethanol and 1 ml of distilled water to obtain final volume of 4.1 ml. The reaction mixtures were incubated for one hour at ambient temperature, after which the absorbance value was recorded at 450 nm. The antioxidant activity was established from the calibration curve and valued as the product of molar absorptivity and the slope of calibration line.

2.5 Measurement of ripening rate, weight loss, spoilage and firmness

The ripening rate of mangoes was determined as a percentage to quantify the progression of fruit maturity over time. The ripening rate was measured using the difference between the current and initial ripeness index, divided by the total possible ripeness gain, and multiplied by 100.

Weight loss (expressed as percentage) was measured by weighing the percentage reduction from the initial sample weight at successive three days interval throughout ambient storage conditions, while spoilage percentage was determined based on visual symptoms such as fungal infection, rotting, browning, discoloration, and physiological breakdown. Fruits showing more than 50% yellowing of peel colour were considered ripened.

The storage behaviour of fruits was evaluated by recording fruit firmness, physiological weight loss percentage, spoilage percentage, and ripening behaviour during storage. Fruit firmness was evaluated with a penetrometer, using an 8 mm probe, inserted to a depth of 1 cm. Three readings were taken for each sample, and the average was expressed in Newtons (N).

2.6 Statistical analysis

The recorded data were analysed statistically using analysis of variance (ANOVA) based on Completely Randomized Design as outlined by Panse and Sukhatme (1967). The significance of differences among treatment means was assessed using Duncan’s Multiple Range Test (DMRT) at 5% significance level.

3. RESULTS AND DISCUSSION

3.1 *Effect of spermidine treatment on total soluble solids, titratable acidity and TSS:TA ratio*

Total soluble solids (TSS) quantify the concentration of dissolved soluble constituents, chiefly sugars, including organic acids, minerals, and other soluble components in fruit juice. The determination of TSS during storage facilitates to assess fruit quality, ripening and predict postharvest behaviour of mango fruits. The data depicted in (Table 3.1) shows that TSS increased from initial values of 12.0–12.3 ºBrix across all treatments. The control fruits exhibited a sharp increase of 20.8 ºBrix by day 6 but deteriorated thereafter, becoming unmarketable by day 9. In contrast, fruits dipped in 2.0 mM and 2.5 mM concentration of Spd demonstrated better performance, attaining maximum TSS values of 22.4 ºBrix and 22.8 ºBrix respectively at day 9, and maintaining acceptable quality levels of 20.8–21.0 ºBrix through day 15. The differences in the treatments were statistically significant. Previous investigations have indicated that Spd treatment inhibits the activity of amylase, which pivots a key role in hydrolysis of starch (Cheng et al. 2018). The gradual and sustained incline in TSS in treated fruits was observed due to the controlled starch-to-sugar conversion associated with delayed ripening, consistent with spermidine's role in modulating ethylene biosynthesis and maintaining climacteric metabolism (Lekshmi et al. 2025). (Noori et al. 2024) reported peak increase in total soluble solids content on day 75 in Spd treated grapes at 2 mM concentration, during 105 days of storage. A similar trend was recorded by (Zahedi et al. 2019), at 2 mM spermidine concentration during storage of mango cv. Langra.

Table 3.1
Influence of post-harvest treatment of spermidine on total soluble solids of mango

	Total soluble solids (ºBrix)					
	Storage days					
Treatment	**0**	**3**	**6**	**9**	**12**	**15**
Control	12.2	18.1	20.8	20.1	19.2	19.0
1 mM	12.1	17.8	17.3	20.4	20.2	19.5
1.5 mM	12.0	17.2	17.8	20.9	20.5	19.9
2 mM	12.0	16.5	18.1	22.4	21.2	20.8
2.5 mM	12.2	16.8	18.9[a]	22.8	21.6	21.0

Data represent the mean of three independent replicates. Within each column, values followed by different letters are significantly different ($p \leq 0.05$) as determined by Duncan's Multiple Range Test.

Organic acids are important metabolic intermediates that play a vital role as substrates for enzyme-catalysed reactions associated with aerobic respiration in plant cells. The reduction in titratable acidity over the course of ripening, contributes to a sweeter taste in the fruits. A significantly slower decline in

titratable acidity was recorded throughout the treatments during the storage period (Table 3.2). The control group demonstrated the most rapid reduction, falling to 0.64% at day 3and 0.24% by day 9, after which fruits became unmarketable. The Spd treated fruits with 2.0 mM and 2.5 mM conc. exhibited prolonged retention in acid content, maintaining 0.94–0.97% at day 3 and retaining 0.14–0.16% at day 15, indicating better preservation of biochemical constituents. The effects were statistically significant from day 3 onwards (CD at 5% = 0.1023–0.2281). The titratable acidity was maintained better at higher Spd concentrations due to reduced breakdown of organic acids during respiration and also because of spermidine's mitigated effect on production of ethylene and respiration rate during storage period (Zhang et al. 2025). (Akın et al. 2025) observed that application of spermidine resulted in significantly higher TA levels in raspberry fruits after 10 days of storage compared to control fruits. Similar findings have been reported in several fruit species, where polyamine treatments such as spermidine effectively preserved titratable acidity for certain periods in stored fruits (Davarynejad et al. 2013).

Table 3.2
Influence of post-harvest treatment of spermidine on titratable acidity of mango

	Titratable acidity (%)					
	Storage days					
Treatment	**0**	**3**	**6**	**9**	**12**	**15**
Control	1.02	0.64	0.38	0.24	0.12	0.07
1 mM	1.00	0.84	0.53	0.32	0.21	0.10
1.5 mM	1.01	0.88	0.62	0.34	0.26	0.12
2 mM	1.01	0.94	0.67	0.46	0.30	0.14
2.5 mM	1.00	0.97	0.70	0.44	0.31	0.16

Value indicates mean of three replicates. Different letters in the same column indicate significant differences at $p \leq 0.05$ (Duncan's Multiple Range Test)

The TSS/TA ratio is a vital maturity index for palatability. The control group showed a steep rise in TSS/TA ratio, with 271.43 by day 15. In contrast, fruits treated with higher concentration (2 mM and 2.5 mM) had a much more gradual rise (Table 3.3). This difference in the rate of increase suggests that fruits treated with Spd, had a positive effect in preserving acidity for longer period of time while keeping sugar accumulation in control, therefore showing delayed ripening and slower senescence.

Table 3.3
Influence of post-harvest treatment of spermidine on TSS:TA ratio of mango

	TSS:TA ratio					
	Storage days					
Treatment	0	3	6	9	12	15
Control	11.96	28.28	54.74	83.75	160.00	271.43
1 mM	12.10	21.19	32.64	63.75	96.19	195.00
1.5 mM	11.88	19.55	28.71	61.47	78.85	165.83
2 mM	11.88	17.55	27.01	48.70	70.67	148.57
2.5 mM	12.20	17.32	27.00	51.82	69.68	131.25

Data represent the mean of three independent replicates. Within each column, values followed by different letters are significantly different ($p \leq 0.05$) as determined by Duncan's Multiple Range Test.

3.2*Effect of spermidine treatment on ascorbic acid content and total carotenoid content*

Ascorbic acid (vitamin C) is a prominent bioactive antioxidant naturally present in fruits, playing a major role in the maintenance of nutritional aspect and increasing postharvest shelf life. The data in Table 3.4 shows an initial increase in ascorbic content during initial storage days followed by a gradual decline in all treatments. Initial values were uniform across treatments (22.12–22.28 mg/100 g). The fruits dipped in 2.0 mM and 2.5 mM conc. demonstrated improvement, reaching peak values of 24.88 and 25.14 mg/100 g respectively at day 9, and maintaining elevated levels of 23.98–24.32 mg/100 g through day 15. The retention in the total ascorbic content in the control peaked at 23.10 mg/100 g at day 6 and declined thereafter, becoming unmarketable beyond day 9. The positive effect of Spd on ascorbic acid retention could be associated with reduced ascorbate oxidase activity, that regulates the slow breakdown of ascorbic acid, resulting in better retention of the acid in ripening fruits (Zhang et al. 2018). Polyamines act as effective antioxidants, protecting ascorbic acid against oxidative losses during the postharvest storage. In kiwi, polyamine treatments of spermidine demonstrated higher ascorbic content in comparison with control (Shokrollah et al. 2015). Spermidine application enhanced the retention of ascorbic acid in strawberry fruits, with 1.5 mM identified as the most effective treatment (Mortazavi et al. 2012).

Table 3.4
Influence of post-harvest treatment of spermidine on ascorbic acid of mango

	Ascorbic acid (mg/100 g pulp)					
	Storage days					
Treatment	0	3	6	9	12	15
Control	22.19	23.06	23.10	22.78	22.34	21.92
1 mM	22.19	23.18	23.40	23.54	23.07	22.66
1.5 mM	22.18	23.76	23.80	23.90	23.41	22.98
2 mM	22.18	24.51	24.62	24.88	24.42	23.98
2.5 mM	22.19	24.74	24.86	25.14	24.78	24.32

Data represent the mean of three independent replicates. Within each column, values followed by different letters are significantly different ($p \leq 0.05$) as determined by Duncan's Multiple Range Test.

Carotenoids are primary pigments that contribute to the distinctive yellow, orange, and red colours exhibited by ripening fruits (Gross et al. 1991), thereby improving the visual appeal of mangoes in addition to functioning as Vitamin A precursors with potent antioxidant properties (Zhou et al. 2020). It serves as an important indicator of post-harvest quality, making their regulation critical for prolonging the storage period and maintaining visual appeal. The total carotenoid content recorded a notable increase during storage from uniform initial values of 2.23–2.25 mg/100 g across all treatments as shown in Table 6, indicating gradual fruit ripening and colour development. The 2.0 mM and 2.5 mM spermidine demonstrated superior carotenoid accumulation, reaching 10.76–10.95 mg/100 g at day 9 and continued increase to 11.56–11.76 mg/100 g at day 15. The control peaked at 10.50 mg/100 g at day 9 but became unmarketable in the following period. Spd has been reported to preserve chlorophyll by reducing its degradation during postharvest storage (Zheng et al. 2007). Recent studies suggest that apricots treated with Spd resulted in a smaller increase in carotenoid content than the control and other treatment groups during cold storage period (elwahab et al. 2025).

Table 3.5
Influence of post-harvest treatment of spermidine on total carotenoid content of mango

	Total carotenoid content (mg / 100g)					
	Storage days					
Treatment	0	3	6	9	12	15
Control	2.23	5.77	9.00	10.50	10.55	10.52
1 mM	2.24	5.89	8.40	9.53	11.47	11.22
1.5 mM	2.23	5.98	8.67	9.78	11.49	11.31
2 mM	2.24	6.80	9.56	10.76	11.23	11.56
2.5 mM	2.24	6.96	9.58	10.95	11.26	11.76

Data represent the mean of three independent replicates. Within each column, values followed by different letters are significantly different ($p \leq 0.05$) as determined by Duncan's Multiple Range Test.

3.3. *Effect of spermidine treatment on total phenolic content and total antioxidant activity*

Phenolic compounds are biologically active secondary metabolites that contribute significantly to the antioxidant capacity and health benefits of fruits. Natural phenolic compounds in mango comprises mangiferin, flavonoids and phenolic acids that augment antioxidant activity (Maldonado-Celis et al. 2023). During storage of mango fruits, the total phenolic content increased substantially in all treatments from uniform initial levels of approx. 36.13–36.15 mg GAE/100 g (Table 3.6). The fruits dipped in 2.5 mM conc. recorded the maximum phenolic content of 66.98 mg GAE/100 g at day 9, followed by conc. of 2.0 mM i.e. 54.72–55.66 mg GAE/100 g through day 15. The control showed a peak of 58.75 mg GAE/100 g at day 6 followed by a rapid decline and spoilage by day 9. The accumulation and retention of phenolic content in the treated fruits is associated with spermidine's role in stimulating secondary metabolite biosynthesis, activating the phenylpropanoid pathway, and enhancing antioxidant defence mechanisms during senescence (Xing et al. 2025). These findings are consisted with previous reports demonstrating that among the different spermidine concentrations, the 1.5 mM dose reduced phenolic compound losses compared to the control fruits in sweet cherry (Colak et al.2025). The phenolic compounds of spermidine treated bananas showed that 0.5 mM concentration of Spd had the lowest content of phenolic compounds, compared with control fruits, indicating that Spd delays the production of phenolic compounds in banana tissues (Nilprapruck et al. 2015).

Table 3.6
Influence of post-harvest treatment of spermidine on total phenolic content of mango

	Total phenolic content (mg GAE/100 g)					
	Storage days					
Treatment	0	3	6	9	12	15
Control	36.15	41.39	58.75	57.65	52.18	49.35
1 mM	36.14	45.76	62.22	64.02	56.67	51.84
1.5 mM	36.13	47.16	63.13	64.78	56.23	52.46
2 mM	36.15	48.65	64.03	65.26	66.53	54.72
2.5 mM	36.13	48.75	64.14	66.98	63.45	55.66

Data represent the mean of three independent replicates. Within each column, values followed by different letters are significantly different ($p \leq 0.05$) as determined by Duncan's Multiple Range Test.

The antioxidant capacity of fruit is primarily attributed to the presence of bioactive compounds including phenolics, flavonoids, ascorbic acid, anthocyanins, and other phhytochemicals. It serves as an index for evaluating the overall free-radical scavenging capacity of fruit tissue (Prakash et al. 2011). In the present study, a progressive incline in the total antioxidant activity was seen from initial uniform values of 0.37–0.39 µmol Trolox/g across all treatments (Table 3.7). The 2.0 mM and 2.5 mM spermidine demonstrated the highest antioxidant activity, reaching peak values of 0.83 and 0.86 µmol Trolox/g respectively at day 9, and retaining 0.71–0.72 µmol Trolox/g at day 15. The control peaked at 0.74 µmol Trolox/g at day 6 and declined thereafter. The treatment differences were statistically significant in the treatments.The enhanced antioxidant activity in the treated fruits is directly correlated with the higher phenolic and carotenoid contents observed in these treatments, confirming Spd's role in regulating the antioxidant defence mechanism and reducing ROS accumulation (Chen et al. 2025). Exogenous application of Spd improved the antioxidant capacity of sweet cherry fruits during refrigerated storage, thereby suppressing the ROS accumulation and protectin the cellular membranes from oxidative damage (QI et al. 2025).

Table 3.7
Influence of post-harvest treatment of spermidine on total antioxidant content of mango

	Total antioxidant content (µmol Trolox/g)					
	Storage days					
Treatment	0	3	6	9	12	15
Control	0.37	0.43	0.74	0.68	0.59	0.48
1 mM	0.39	0.47	0.53	0.76	0.70	0.63
1.5 mM	0.37	0.49	0.56	0.78	0.71	0.65
2 mM	0.38	0.51	0.64	0.83	0.75	0.72
2.5 mM	0.39	0.54	0.67	0.86	0.72	0.71

Data represent the mean of three independent replicates. Within each column, values followed by different letters are significantly different ($p \leq 0.05$) as determined by Duncan's Multiple Range Test.

3.4 *Effect of spermidine treatment on ripening rate, weight loss, spoilage and firmness*

Froma post-harvest storage point of view, ripening rate determines consumer acceptability by rendering fruit attractive and palatable through enhanced organoleptic characteristics such as aroma, flavor, texture, and colour (Nambeesan et al. 2008).In this study, post-harvest spermidine treatment in Amrapali mango notably delayed the rate of fruit ripening. The control fruits ripened rapidly, reaching 90.67% at day 6 and 100% by day 9. In contrast, fruits subjected with 2.0 mM and 2.5 mM Spd doses exhibited well-controlled ripening progression, recording only 40.0–41.16% at day 3 and 66.13–67.33% at day 6, attaining complete ripening only by day 12. The delay in ripening rate by spermidine is attributed to its competition with S-adenosylmethionine (SAM) (the precursor for ethylene and polyamine biosynthesis), thereby reducing ethylene production(Gomez-Jimenez et al. 2010).(Torrigianiet al. 2012) reported in his studies that peach fruits applied with Spd maintained firmer flesh owing to reduction in ethylene production.

Pectic substances are primarily responsible for maintaining firmness in fruits, and serve as a critical quality indicator of freshness and marketability and impacts product acceptability. The enzymatic system play a crucial role in attenuating the firmness during ripening process, therefore affecting the quality retention of fruits during storage (Sharma et al. 2017). The control group displayed the most rapid softening, declining to 6.90 N at day 6 and 4.23 N at day 9, after which fruits became unmarketable. The fruits dipped in 2.0 mM and 2.5 mM concentrations retained firmness more effectively, maintaining 13.24–13.56 N at day 6 and 7.35–7.66 N at day 15. A progressive decline in firmness of fruits was observed in all treatments from initial values of 21.70–21.90 N due to cell wall degradation during ripening. Previous studies have consistently reported improved firmness in fruits followed by polyamine

treatments. Among the important fruit commodities are apricot (Martinez-Romero et al. 2002), citrus, peaches (Bregoli et al. 2002) as well as pomegranate (Mirdehghan et al. 2007).The superior firmness maintenance in the treated fruits is attributed to suppressed expression and activity of cell wall hydrolytic enzymes, including polygalacturonase and cellulase (Negi et al. 2008), increased lignin and calcium binding in cell walls resulting in stronger cell structure and reduced ethylene production. Collectively, these effects reduce the rate of natural ripening and softening in the treated fruits during storage.

Weight loss is one of the key physiological traits in the postharvest preservation process of fruits. It occurs primarily through transpiration from fruit surface, respiratory carbon loss and other physiological processes accompanied by decline in firmness, visual appeal and marketability (Yang et al. 2025). During this study, there was a progressive increase in the weight throughout storage in all treatments, reflecting moisture loss and metabolic activity. The control was observed to have the highest weight loss of 16.87% at day 6 and 34.67% at day 9, after which fruits became unmarketable. It was that 2.0 mM and 2.5 mM Spd doses demonstrated superior moisture retention, recording significantly lower weight loss of 4.8–5.4% at day 3 and 12–13% at day 6, and maintaining acceptable weight loss levels of 24.1–24.4% at day 15 (Fig. 3.3). The treatment differences were statistically significant. Moreover, by reducing water loss from fruit surface, the Spd treated fruits effectively extended shelf life beyond the control group end point (34.67% at day 9) while the treated fruits remained within an acceptable weight loss range (24.45% – 24.16% with 2.0 mM and 2.5 mM respectively) even at day 15, which is 6 days longer than the controlbecame unmarketable. Research findings indicate that application of polyamines like spermidine contributes to improved membrane stability and fluidity, thereby reducing water loss and minimizing weight loss in stored fruits (Mirdehghan et al. 2007).(Orman et al. 2023) recorded that application of increasing doses of Spd effectively mitigated weight loss in nectarine fruits throughout the storage period. The differences between the treated fruits and the control were statistically significant ($p < 0.05$). Strawberries treated with 1.0 and 1.5 mM Spd exhibited a significant reduction in weight loss percentage compared with the control, during 12 days of storage (Jalali et al. 2023).

Spoilage is a major limiting factor in shelf life duration, arising due to fungal decay and progressive loss of membrane integrity observed during ripening. During storage, the spermidine treated fruits showed less spoilage. The control fruits showed early and rapid spoilage progression, recording 24.44% at day 3, 68.89% at day 6, and maximum spoilage of 78.67% by day 9, rendering fruits completely unmarketable thereafter. In sharp contrast, fruits dipped in 2.0 mM and 2.5 mM concentration showed zero spoilage up to day 3, only 5.56% and 3.33% at day 6, and maximum spoilage of only 48.89% and 44.44% respectively at day 15, effectively extending the marketable shelf life by 6 additional days over the control. Previous research in prunes has established that the significant reduction in spoilage percentage in Spd-treated fruits is attributed to its multifaceted role in stabilizing cellular membranes, reduction in oxidative stress (Zhang et al. 2025), increasing antioxidant enzyme activity, and suppressing the expression of ACC oxidase and ACC synthase, the two key enzymes regulating ethylene biosynthesis (Khan et al. 2024), thereby slowing ripening and delaying microbial invasion and tissue breakdown during storage.

4. CONCLUSION

Post-harvest treatments significantly influenced the physic-biochemical quality parameters including the total soluble solids, titratable acidity, ascorbic acid content, phenolic content, antioxidant capacity assay, total carotenoid content, ripening rate, weight loss, spoilage and firmness in the stored fruits. The application of spermidine (Spd) at 2.0 mM and 2.5 mM effectively extended Amrapali mango shelf life by 6 days under ambient storage, by slowing the ripening process, maintaining firmness, minimizing weight loss, and conserving nutritional quality. Among treatments, 2.5 mM emerged as the most viable and economically feasible concentration. The quality of treated fruits were maintained throughout the 15-day storage period as observed across all biochemical and post-harvest quality parameters.

Declarations

Author Contribution

Methodology, Investigation, Writing-original draft: J. S.; Conceptualization, Writing-review & editing, Supervision, Validation: P. S.; Conceptualization, Writing-editing, Supervision: K. B.; Resources, Supervision: D. L.; Writing-editing, Supervision: P. K.; Statistical Analysis: F. H.; Writing-editing: K. K.; Writing-editing: D. R. S.

Acknowledgement

Authors duly acknowledge the financial assistance by Bihar Agricultural University, Sabour, Bhagalpur.

References

1. Abd Elwahab, S. M., Abdallatif, A. M., & El-Saeed, S. A. E. (2024). Improving the postharvest shelf life of apricot fruits (Prunus armeniaca L. cv. Amal) using preharvest application of spermidine, salicylic acid and sodium nitroprusside. *Journal of Applied Horticulture*, *26*(4), 493–499. https://doi.org/10.37855/jah.2024.v26i04.93
2. Akın, M., Eyduran, S. P., Çelik, K., Taş, A., & Gundogdu, M. (2025). New Approaches in Cold Storage of Fruits: Impact of Postharvest Spermidine and Salicylic Acid Applications on Phenolic Compounds and Quality Characteristics of Raspberry Fruits. *Food Science & Nutrition*, *13*(6), e70389. https://doi.org/10.1002/fsn3.70389
3. Alonso-Salinas, R., López-Miranda, S., Pérez-López, A. J., & Acosta-Motos, J. R. (2024). Strategies to delay ethylene-mediated ripening in climacteric fruits: Implications for shelf lifeextension and postharvest quality. *Horticulturae*, *10*(8), 840. https://doi.org/10.3390/horticulturae10080840
4. Bini, K., Krishnan, A. G., Jacob, J., Supriya, R., & Thomas, K. S. (2024). Mango: The king of the tropics. In Economically Important Trees: Origin, Evolution, Genetic Diversity and Ecology (pp. 299–324). Singapore: Springer Nature Singapore https://doi.org/10.1007/978-981-97-5940-8_8

5. Bregoli, A.M.; Scaramagli, S.; Costa, G.; Sabatini, E.; Ziosi, V.; Biondi, S.; Torrigiani, P. Peach (*Prunus persica*) fruit ripening: Aminoethoxyvinylglycine (AVG) and exogenous polyamines affect ethylene emission and flesh firmness. *Physiol. Plant.* 2002, *114*, 472–481.
6. Chen, D., Liu, L., Gao, Z., Zhao, J., Yang, Y., & Shen, Z. (2025). Preservation of Fruit Quality at Postharvest Through Plant-Based Extracts and Elicitors. *Horticulturae*, *11*(10), 1186. https://doi.org/10.3390/horticulturae11101186
7. Chen, D., Shao, Q., Yin, L., Younis, A., & Zheng, B. (2019). Polyamine function in plants: metabolism, regulation on development, and roles in abiotic stress responses. Frontiers in plant science, 9, 1945. doi: 10.3389/fpls.2018.01945
8. Cheng, Y., Y. Jiang, B. Li, Y. Zheng, S. Li and S. Lei, 2018. Spermidine delays 'Cuiguan' pear (Pyrus pyrifolia Nakai) postharvest ripening and senescence by regulating ethylene biosynthesis and antioxidant metabolism. Food Chem., 240: 1141–1148. https://doi.org/10.37855/jah.2024.v26i04.93
9. Colak, A. M., Peral Eyduran, S., Tas, A., Altun, O., Gundogdu, M., & Ozturk, B. (2025). The role of spermidine in postharvest fruit physiology: Effects on quality characteristics and metabolite content of sweet cherry fruit during cold storage. *ACS omega*, *10*(10), 10567–10578. https://doi.org/10.1021/acsomega.4c11222
10. Davarynejad, G. H., M. Zarei, M. E. Nasrabadi, and E. Ardakani. 2015. "Effects of Salicylic Acid and Putrescine on Storability, Quality Attributes and Antioxidant Activity of Plum cv. 'Santa Rosa'." *Journal of Food Science and Technology* 52: 2053–2062. https://doi.org/10.1007/s13197-013-1232-3
11. Galán Saúco, V. (2023, September). World mango production and trade. In XIII International Mango Symposium 1415 (pp. 1–18).
12. Gomez-Jimenez, M. C., Paredes, M. A., Gallardo, M., Fernandez-Garcia, N., Olmos, E., & Sanchez-Calle, I. M. (2010). Tissue-specific expression of olive S-adenosyl methionine decarboxylase and spermidine synthase genes and polyamine metabolism during flower opening and early fruit development. *Planta*, *232*(3), 629–647. https://doi.org/10.1007/s00425-010-1198-6
13. Gross, J. (1991). Carotenoids. In *Pigments in vegetables: chlorophylls and carotenoids* (pp. 75–278). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4615-2033-7_3
14. Hans, S., Kour, K., Bakshi, P., Bajaj, K., Reshi, M., & Choudhary, A. (2025). Preharvest putrescine application modulates physicochemical attributes and extends the shelf life of mango fruits under cold stored conditions. *Journal of Food Measurement and Characterization*, *19*(2), 1432–1445. https://doi.org/10.1007/s11694-024-03056-x
15. Hong, P. N., & Lee, C. (2017). Roles of pectin methylesterases and pectin methylesterase inhibitors in plant physiology. *Journal of Agricultural, Life and Environmental Sciences*, *29*(1), 1–17. https://doi.org/10.12972/jales.20170001
16. Hussain, S., Nahar, K., Rajwana, I.A., Ercisli, S., & Ahmad, S. (Eds.). (2025). Handbook of Research on Mango Fruit: Postharvest Science, Production, Nutrition, and Processing Technology (1st ed.). Apple

Academic Press.

17. Jalali, P.; Zakerin, A. R.; Aboutalebi-Jahromi, A. H.; Sadeghi, H. Improving postharvest life, quality and bioactive compounds of strawberry fruits using spermine and spermidine. *Braz. J. Biol.* 2023, *83*, e273886, DOI: 10.1590/1519-6984.273886
18. Khan, A. S., & Singh, Z. (2007). Methyl jasmonate promotes fruit ripening and improves fruit quality in Japanese plum. The Journal of Horticultural Science and Biotechnology, 82(5), 695–706. https://doi.org/10.1080/14620316.2007.11512293
19. Khan, S., Alvi, A. F., Saify, S., Iqbal. N., & Khan, N. A. (2024). The ethylene biosynthetic enzymes, 1-aminocyclopropane-1-carboxylate (ACC) synthase (ACS) and ACC oxidase (ACO): the less explored players in abiotic stress tolerance. *Biomolecules*, *14*(1), 90. https://doi.org/10.3390/biom14010090
20. Kramchote, S., Khaliq, G., & Ali, S. (2025). Postharvest Physiological Disorders of Mango. In Postharvest Physiological Disorders of Fruits (pp. 3–40). Apple Academic Press.
21. Lekshmi, S. G., Sethi, S., Paul, V., Sindhu, P. M., & Nayak, S. L. (2025). Physiology and Ripening of Fruits and Vegetables. In *Fruits and Vegetables Technologies: Postharvest Processing and Packaging* (pp. 31–55). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-96-8433-5_2
22. Maldonado-Celis, M. E., Yahia, E. M., Bedoya, R., Landázuri, P., Loango, N., Aguillón,J., … Guerrero Ospina, J. C. (2019). Chemical composition of mango (Mangifera indica L.) fruit: Nutritional and phytochemical compounds. Frontiers in plant science, 10,1073. https://doi.org/10.3389/fpls.2019.01073
23. Maldonado-Celis, M. E., Yahia, E. M., Bedoya, R., Landázuri, P., Loango, N., Aguillón,J., … Guerrero Ospina, J. C. (2019). Chemical composition of mango (Mangifera indica L.) fruit: Nutritional and phytochemical compounds. *Frontiers in plant science*, *10*, 1073. https://doi.org/10.3389/fpls.2019.01073
24. Malik, A. U., & Zora, S. (2005). Pre-storage application of polyamines improves shelf-life and fruit quality of mango. *The Journal of Horticultural Science and Biotechnology*, *80*(3), 363–369. https://doi.org/10.1080/14620316.2005.11511945
25. Martinez-Romero, D.; Serrano, M.; Carbonell, A.; Burgos, L.; Riquelme, F.; Valero, D. Effects of postharvest putrescine treatment on extending shelf life and reducing mechanical damage in apricot. J. Food Sci. 2002, 67, 1706–1712. https://doi.org/10.1111/j.1365-2621.2002.tb08710.x
26. Mirdehghan, S. H.; Rahemi, M.; Castillo, S.; Martínez-Romero, D.; Serrano, M.; Valero, D. Pre-storage application of polyamines by pressure or immersion improves shelf-life of pomegranate stored at chilling temperature by increasing endogenous polyamine levels. *Postharvest Biology and Techno.* 2007, *44*, 26–33, DOI: 10.1016/j.postharvbio.2006.11.010
27. Mirdehghan, S.H.; Rahemi, M.; Castillo, S.; Martínez-Romero, D.; Serrano, M.; Valero, D. Pre-storage application of polyamines by pressure or imMersion improves shelf-life of pomegranate stored at chilling temperature by increasing endogenous polyamine levels. Postharv. Biol. Technol. 2007, 44, 26–33. https://doi.org/10.1016/j.postharvbio.2006.11.010

28. Modesti, M., Zampella, L., & Petriccione, M. (2019). Chitosan mono-and bilayer edible coatings for preserving postharvest quality of fresh fruit. In *Polymers for Agri-Food Applications* (pp. 465–486). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-19416-1_23
29. Mortazavi, S.M.H., Siruie, B., Moalemi, N. And Eshghi, S., 2012. The effects of polyamines and UV-C irradiation on postharvest quality of strawberry fruit. In: *VII International Strawberry Symposium*, 2012, Beijing, China. Belgium: International Society for Horticultural Science, pp. 749–754. 10.17660/ActaHortic.2014.1049.117
30. Nambeesan, S., Handa, A. K., & Mattoo, A. K. (2008). Polyamines and regulation of ripening and senescence. *Postharvest biology and technology of fruits, vegetables and flowers*, 319–340.
31. Negi, P. S., & Handa, A. K. (2008). Structural deterioration of the produce: the breakdown of cell wall components. *Postharvest biology and technology of fruits, vegetables, and flowers*, *978*, 0–8138.
32. Nilprapruck, P., Meetum, P., &Chanthasa, C. (2016). Influence of exogenous spermidine on to peel color change and browning symptom of Musa (AAA group) cv. Kluai Hom Thong at low temperature storage. *Science, Engineering and Health Studies*, 38–42. https://doi.org/10.14456/sustj.2016.5
33. Noori, A. K., Akberpour, F. V., Alizadeh, M., & Abadi, M. H. (2024). Investigating the effect of postharvest application of putrescine and spermidine on preserving quantitative and qualitative properties of grape cv. Shahroudi. *Journal of Research in Applied Science and Biotechnology*, *3*, 32–38. https://doi.org/10.55544/jrasb.3.2.9
34. Orman, E. (2023). Effect of postharvest spermidine treatments on quality and biochemical properties of nectarine fruits. *Turkish Journal of Agriculture and Forestry*, *47*(2), 186–195. https://doi.org/10.55730/1300-011X.3077
35. Panse, V. G., &Sukhatme, P. V. (1967). Statistical methods for agricultural workers ICAR Publication. *New Delhi*, *259*.
36. Prakash, D., Upadhyay, G., Pushpangadan, P., & Gupta, C. (2011). Antioxidant and free radical scavenging activities of some fruits. Journal of complementary & integrative medicine, 8(1).
37. QI, Y., ZHANG, G., WANG, F., & YANG, Q. (2025). Effects of Spermidine and Its Inhibitors on the Storage Quality and Reactive Oxygen Species Metabolism of Sweet Cherry Fruits during Refrigerated Storage. *Food Science*, *46*(5), 292–300. https://doi.org/10.7506/spkx1002-6630-20240815-117
38. Rajan, S. (2021). Mango: The king of fruits. In The Mango Genome (pp. 1–11). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-47829-2_1
39. Razzaq, K., Khan, A. S., Malik, A. U., Shahid, M., & Ullah, S. (2014). Role of putrescine in regulating fruit softening and antioxidative enzyme systems in 'Samar Bahisht Chaunsa'mango. Postharvest Biology and Technology, 96, 23–32. https://doi.org/10.1016/j.postharvbio.2014.05.003
40. Sabir, F., A. Sabir, S. Ozcelik, and A. Kucukbasmaci. 2019. "Maintenance of Postharvest Quality of Blackberry (*Rubus fructicosus* L.) Fruits Through Salicylic Acid and CaCl2 İmMersions." *Acta ScientiarumPolonorumHortorum Cultus* 18, no. 4: 121–128.
41. Sharma, S., Pareek, S., Sagar, N. A., Valero, D., & Serrano, M. (2017). Modulatory effects of exogenously applied polyamines on postharvest physiology, antioxidant system and shelf life of

fruits: a review. *International journal of molecular Sciences*, *18*(8), 1789. https://doi.org/10.3390/ijms18081789

42. Shokrollah Fam S, Hajilou J, Zare Nahandi F (2015) The effects of type of polyamines on storage of plum fruit cultivar 'Shablon'. Iran Hortic Sci 64(6):456–463. https://ijhs.ut.ac.ir/article_56912_7311.html
43. Singh, S. K., Dayal, V., & Singh, A. organic cultivation of Mango (Mangifera indica l.). *SubTropicalFruiTplanTS*, 355.
44. Thakur, J. P., Gothwal, P. P., & Singh, I. (2017). Post-harvest treatments for extension of mango fruit var. Dashehari (Mangifera indica L.). Int. J. Food Sci. Nutr, 2(4), 156–162.
45. Torrigiani, P., Bressanin, D., Beatriz Ruiz, K., Tadiello, A., Trainotti, L., Bonghi, C., Ziosi, V. and Costa, G. (2012), Spermidine application to young developing peach fruits leads to a slowing down of ripening by impairing ripening-related ethylene and auxin metabolism and signaling. Physiologia Plantarum, 146: 86–98. https://doi.org/10.1111/j.1399-3054.2012.01612.x
46. Wu, Z., Zhang, X., He, B., Diao, L., Sheng, S., Wang, J., … Wan, J. (2007). A chlorophyll-deficient rice mutant with impaired chlorophyllide esterification in chlorophyll biosynthesis.*Plant physiology*, *145*(1), 29–40. https://doi.org/10.1104/pp.107.100321
47. Xing, Y., Zhang, H., Liu, C., Liu, C., & Zhou, Y. (2025). Spermidine Revives Aged Sorghum Seed Germination by Boosting Antioxidant Defense. *Antioxidants*, *14*(3), 349. https://doi.org/10.3390/antiox14030349
48. Yang, C., Xu, Y., Xie, X., Wu, Y., Gao, Z., Li, K., … Liu, M. (2025). Post-harvest physiology of vegetable crops and its regulation. In Growth Regulation and Quality Improvement of Vegetable Crops: Physiological and Molecular Features (pp. 495–557).Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-96-0169-1
49. Yeshiwas, Y., Tadele, E., Mohammed, A., & Hu, X. (2026). Impacts of climate change on horticultural systems with focus on socio-economic implications, production and postharvest challenges, and adaptive pathways. *Discover Environment*, *4*(1), 55.
50. Yuan, F., Wang, C., Yi, P., Li, L., Wu, G., Huang, F., … Gan, T. (2023). The effects of combined 1-methylcyclopropene and melatonin treatment on the quality characteristics and active oxygen metabolism of mango fruit during storage. *Foods*, *12*(10), 1979. https://doi.org/10.3390/foods12101979
51. Zahedi, S. M., Hosseini, M. S., Karimi, M., & Ebrahimzadeh, A. (2019). Effects of postharvest polyamine application and edible coating on maintaining quality of mango (Mangifera indica L.) cv. Langra during cold storage. *Food Science & Nutrition*, *7*(2), 433–441. https://doi.org/10.1002/fsn3.802
52. Zhang, M., Liu, M., Pan, S., Pan, C., Li, Y. And Tian, J., 2018. Perillaldehyde controls postharvest black rot caused by Ceratocystis fimbriata in sweet potatoes. Frontiers in Microbiology, vol. 9, pp. 1102. https://doi.org/10.3389/fmicb.2018.01102

53. Zhang, X., Zhang, W., Liu, Y., Yang, W., Cao, J., Guo, M., & Chen, G. (2025). Spermidine treatment delays postharvest senescence of prune (Prunus domestica L.) fruit by regulating reactive oxygen species and membrane lipid metabolism. *Postharvest Biology and Technology*, *228*, 113670. https://doi.org/10.1016/j.postharvbio.2025.113670.
54. Zhou, W., Y. Niu, X. Ding, S. Zhao, Y. Li, G. Fan and K. Liao, 2020. Analysis of carotenoid content and diversity in apricots (Prunus armeniaca L.) grown in China. Food Chem., 330: 127223. https://doi.org/10.1016/j.foodchem.2020.127223

Figures

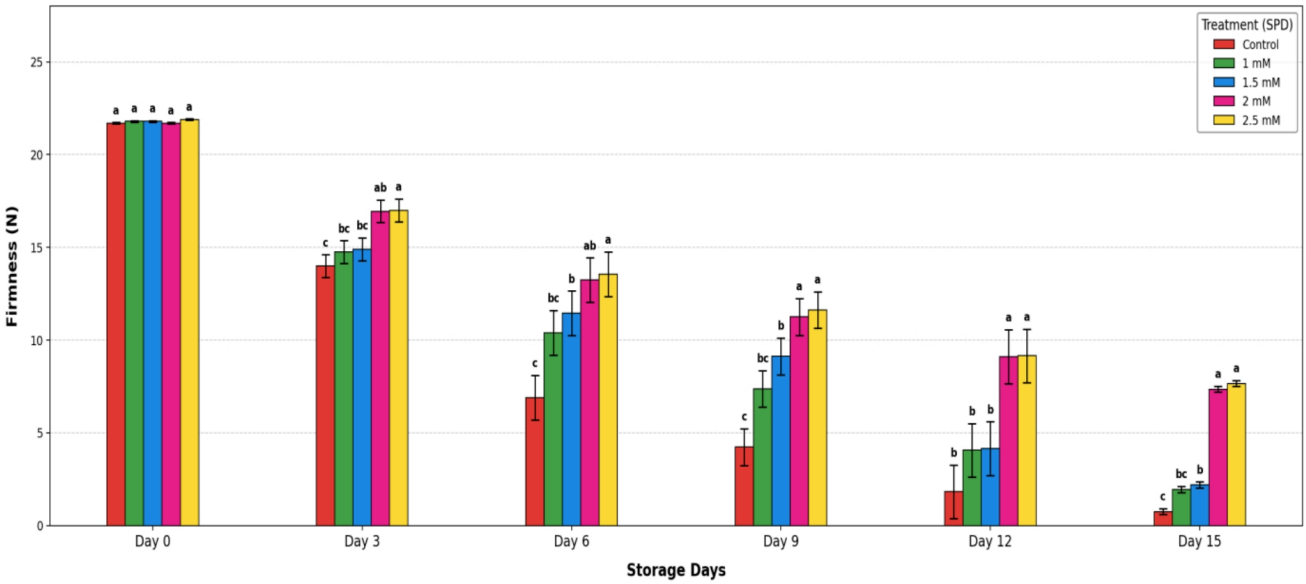


Figure 1

Fig. 3.1:The effect of storage period and Spd treatment on fruit firmness (N). Error bars represent ± SEM. Bars labelled with the same letter are statistically similar (DMRT, p ≤ 0.05).

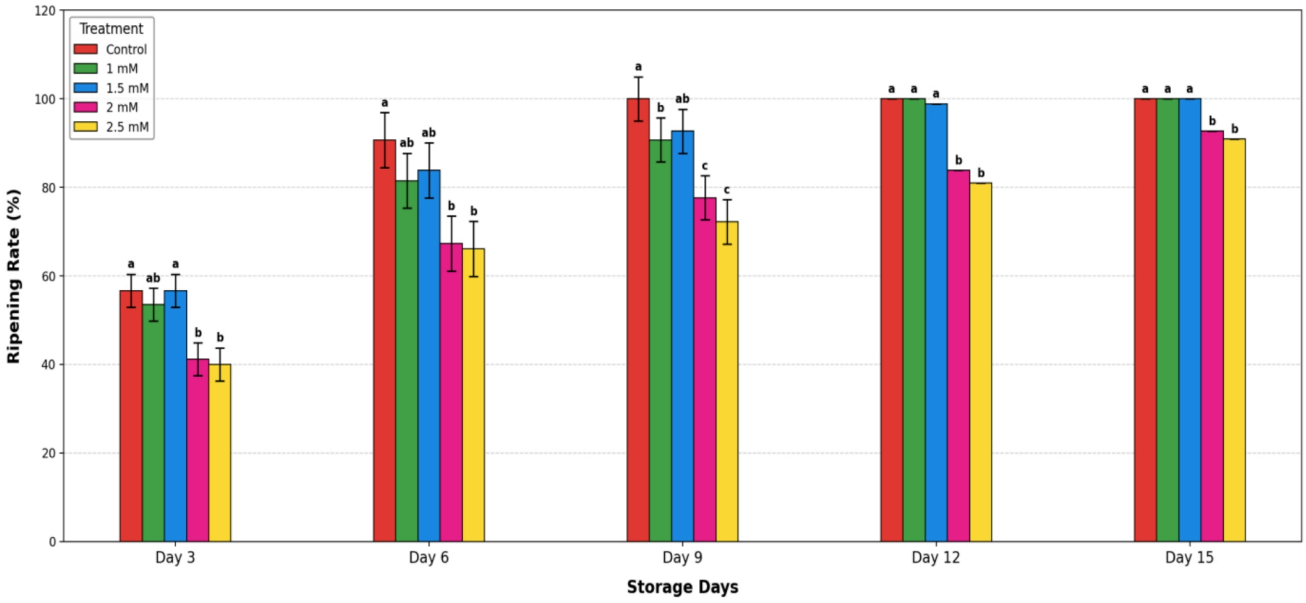


Figure 2

Fig. 3.2: The effect of storage period and Spd treatment on Ripening rate (%). Error bars represent ± SEM. Bars labelled with the same letter are statistically similar (DMRT, p ≤ 0.05).

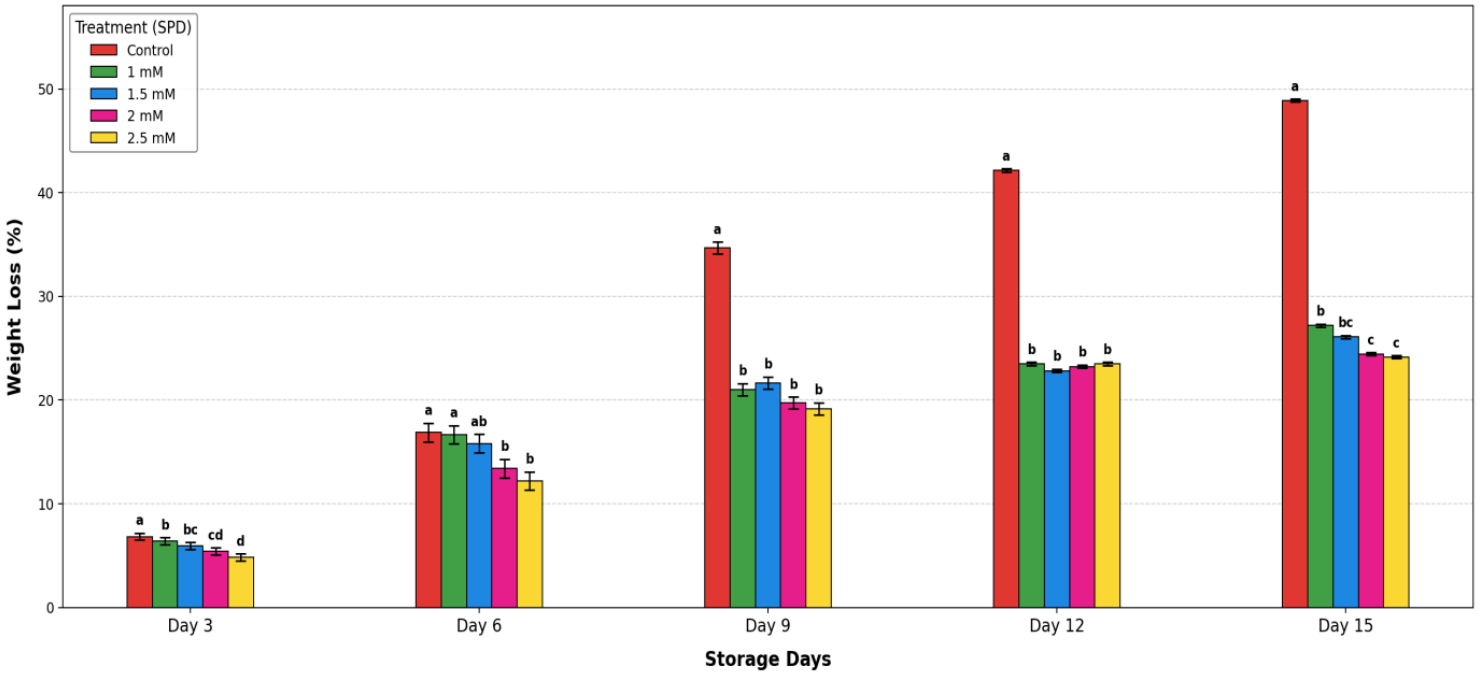


Figure 3

Figure 3.3: The effect of storage period and Spd treatment on Weight loss (%). Error bars represent ± SEM. Bars labelled with the same letter are statistically similar (DMRT, p ≤ 0.05).

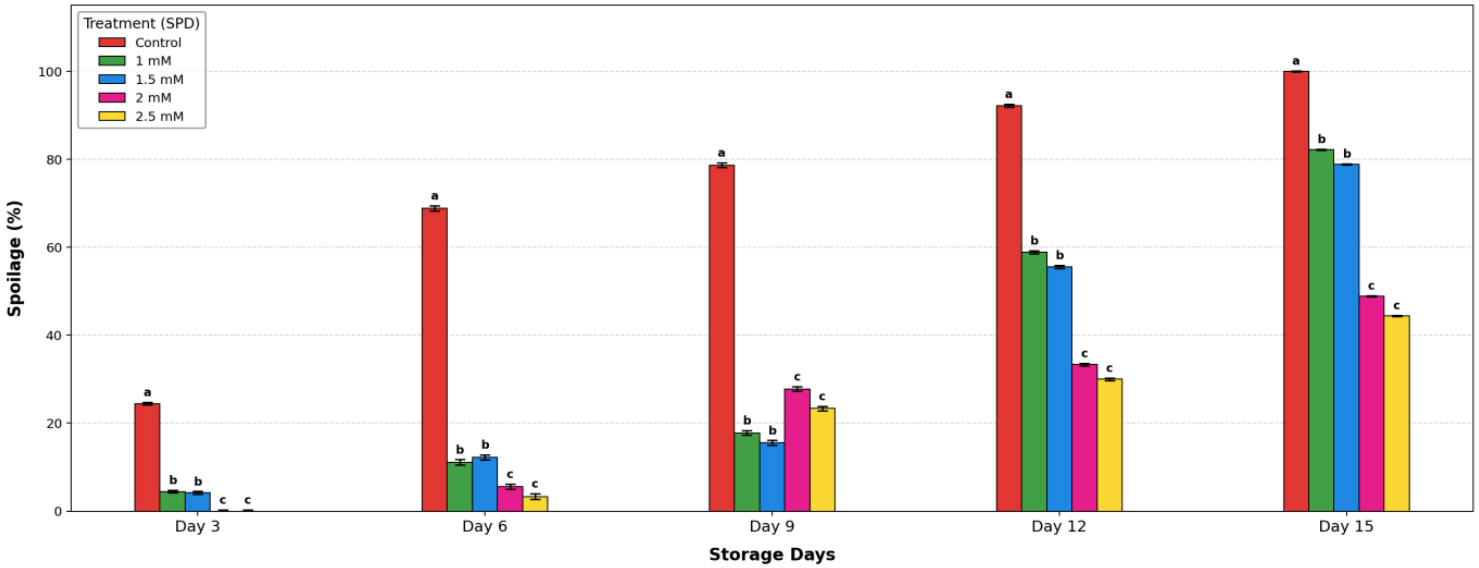


Figure 4

Fig. 3.4: The effect of storage period and Spd treatment on Spoilage (%). Error bars represent ± SEM. Bars labelled with the same letter are statistically similar (DMRT, p ≤ 0.05).