Plant Archives Vol. 25, No. 1, 2025 pp. 1201-1210 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.1.180

POSTHARVEST SPERMIDINE TREATMENTS RETAIN HIGHER QUALITY AND EXTEND THE SHELF LIFE OF POINTED GOURD (*TRICHOSANTHES DIOICA* ROXB.) DURING COLD STORAGE

Devesh Kumar[1], Sajeel Ahamad[1]*, Arjun Singh[2], Mohd Faruk[2] and Anurag Saurabh[1]

[1]Division of Food Science and Postharvest Technology, ICAR-Indian Agricultural Research Institute, New Delhi-110 012, India.
[2]Division of Vegetable Science, ICAR-Indian Agricultural Research Institute, New Delhi - 110 012, India.
*Corresponding author E-mail : sajeelahamad04@gmail.com

(Date of Receiving-10-02-2025; Date of Acceptance-12-04-2025)

ABSTRACT

Postharvest deterioration significantly limits the shelf life and commercial potential of pointed gourd (*Trichosanthes dioica* Roxb.). This study investigates the effect of exogenous spermidine (SPD) treatment on the maintenance of postharvest quality attributes during cold storage. Fruits treated with SPD at concentration of 3.0 mM/L and fruits were stored at 10±1°C and 85–90% relative humidity exhibited significantly lower physiological weight loss (PLW) and better firmness retention compared to untreated controls. Additionally, SPD application effectively delayed seed hardening and preserved green pigmentation, as evidenced by higher chromaticity values and reduced lightness in colorimetric analysis. Biochemical evaluations revealed that SPD treatment enhanced total phenolic content and antioxidant activity, while mitigating chlorophyll degradation. Moreover, SPD-treated fruits showed a marked reduction in malondialdehyde (MDA) accumulation, indicating decreased lipid peroxidation and oxidative damage. Elevated proline content further suggested enhanced stress resilience under cold storage conditions. Collectively, these findings highlight the potential of spermidine as a promising postharvest treatment to extend shelf life and maintain the nutritional and physiological quality of pointed gourd during storage.

Key words : Firmness, Antioxidant activity, Lipid peroxidation, Proline, Shelf-life.

Introduction

Pointed gourd (*Trichosanthes dioica* Roxb.), a prominent cucurbitaceous vegetable, is indigenous to the Indian subcontinent and is widely cultivated in tropical and subtropical regions of India, Bangladesh, Nepal, Myanmar, Sri Lanka, and China. India leads global production, yielding approximately 310 thousand million tonnes of fruit annually from an area of 20,000 hectares (Yadav *et al.,* 2022). The fruit is classified as a pepo, with its edible portion comprising the pericarp and a small part of the mesocarp. Rich in nutrients and bioactive compounds, pointed gourd is often hailed as the "King of Gourds." Pointed gourd is a rich source of dietary fiber, vitamins A and C, and essential minerals such as calcium and iron. It also contains antioxidants that help boost immunity and promote overall health (Khandaker *et al*., 2018). The fruit contains various phytochemicals, including triterpenes, sterols, saponins, glycosides, tannins and peptides. In traditional Ayurvedic medicine, pointed gourd is valued for its digestive, antipyretic, anthelmintic, diuretic, appetizing, anti-rheumatic and expectorant properties (Sharma and Pant, 1998). Additionally, in India's tribal regions, the fruit is traditionally used to treat chickenpox scars (West Bengal) and various ailments such as skin diseases, laxative needs, fever, liver and spleen enlargement, boils and spermatorrhea (Odisha) (Sharmila *et al*., 2003).

Pointed gourd fruit has a very short shelf life of only 2–3 days under ambient conditions, resulting in significant postharvest losses each year due to its high production volume. After harvest, the fruit experiences rapid moisture loss, leading to shriveling, loss of turgidity and texture deterioration, which severely impacts its marketability. Additionally, chlorophyll degradation (yellowing) and seed hardening occur quickly, further reducing the fruit's consumer appeal. To mask yellowing, avoid wrinkling and enhancing marketing period, traders use synthetic color and obnoxious chemical which are highly undesirable from human health and environment safety point of view. To address these postharvest storage problems, researchers have tested several approaches to regulate senescence in fruit and vegetable for minimizing postharvest losses, storage disorders and extending shelf-life.

Polyamines (PAs) are low molecular weight, open-chained hydrocarbon nitrogenous bases that contain at least two amino groups (Gundogdu *et al*., 2023). These compounds, along with their biosynthetic enzymes, are involved in a wide range of metabolic processes in both plants and animals, including cell division, organogenesis, and stress protection (Kaur *et al*., 2013). Exogenous application of spermidine (SPD) helps prevent or delay the onset of senescence symptoms, likely because senescence is believed to initiate with a decline in the activity of the enzyme arginine decarboxylase (Sharma *et al*., 2017). Spermidine increase the more longevity of fruits in storage and decrease damage of storage. It is believed that exogenous polyamines increase postharvest life and quality improvement of fruits due to maintenance of firmness, water loss and delay changes of color (Raeisi *et al*., 2013). Spermidine is the most effective superoxide radical scavenger, and is considered to be helpful in ethylene synthesis and evolution (Jhalegar *et al*., 2012).

However, limited information is available on the use of SPD to extend the shelf life and preserve the quality of harvested pointed gourd. Therefore, this study explored the effectiveness of postharvest SPD dips in enhancing the shelf life and maintaining quality during cold storage.

Materials and Methods

Plant materials, treatments and storage conditions

The fruit of pointed gourd at healthy immature stage were taken from known source at Azadpur Vegetable Mandi, New Delhi (Asia largest fruits and vegetable mandi). Fruits were immediately brought to the postharvest laboratory. Uniform size 180 fruits were divided into four groups, each with in triplicate, containing 45 fruits per treatment. The fruits were washed and dipped in various SPD concentrations (1.5, 3.0 and 4.5 mM/L) for 20 min, while a control group was dipped in distilled water for the same duration. After air-dried, the fruits were stored at 10±1°C and 85–90% relative humidity. On the basis of PLW, fruit firmness and visual inspection it showed that the 3.0 mM/L putrescine treatment had the most favorable effects on color retention and shelf-life extension. Therefore, this concentration was selected for further investigation in the extended experiment. Samples were analyzed at 5-days intervals over 20 days for various physical and biochemical parameters.

Physical parameters

Physiological loss in weight (PLW) : The PLW was evaluated and reported as a percentage (%) by compared the beginning and final weight of pointed gourd at 5-day intervals.

Fruit firmness and seed firmness : A firmness analyzer (TA +Di, Stable Micro Systems, UK) with a 2 mm probe measured pointed gourd fruits hardness (Dhami *et al*., 2023). The hardness was measured at the top, middle, and bottom of each fruit at 10 mm depth for each replication. The strongest force was recorded in Newtons (N) at the peak.

Color parameter : A colorimeter (Miniscan XE PLUS) was used to assess the color of the pointed gourd fruit (upper, middle and bottom portions). The Hunter color scale was used to record the color parameters; the green-red and blue-yellow axes are represented by a* and b*, respectively, and lightness-darkness is indicated by L* (Ahamad *et al*., 2024b).

Physiological parameters

Respiration rate : The respiration of pointed gourd fruit was measured using static headspace technique as outlined by Menaka *et al.* (2024). A gas analyzer (Checkmate 9900 model, PBI Dansensor, Denmark) was used to measure the carbon dioxide (CO_2) levels of fruits that had been sealed in an airtight container for four hours. The CO_2 concentrations were given as mL CO_2 kg^{-1} h^{-1}.

Biochemical parameters

Total phenolic content : The total phenolic content (TPC) of pointed gourd was determined using the Folin-Ciocalteu reagent (Ahamad *et al*., 2024c). The results of TPC were expressed as mg GAE 100 g^{-1} FW.

Total chlorophyll content : The total chlorophyll content of pointed gourd fruit was determined using the dimethyl sulphoxide (DMSO) method (Prajapati *et al*., 2024). The values were expressed as mg 100 g^{-1} FW.

Total antioxidant activity : The antioxidant (AOX) activity of pointed gourd was assessed using the CUPRAC method, as described by Apak *et al.* (2004). Results were expressed in terms of µ mol Trolox equivalents (TE)/g FW.

pH : The pH was assessed following the method of Ahamad *et al.* (2024c) with slight modifications. Juice was extracted from the pointed gourd, and the pH of the solution was measured using a digital pH meter (Model HI991001, Germany).

Defence-related compounds

Malondialdehyde (MDA) : The MDA level of fruit was evaluated using the colorimetric procedure of thiobarbituric acid (TBA) and absorbance was measured at 532 nm and 600 nm. The findings were given as µM g^{-1} FW (Ahamad *et al.,* 2024a).

Proline content : Proline content was measured by mixing 0.5 g of pointed gourdes with 10 mL of 3% sulphosalicylic acid, centrifuging, and heating 2 mL of the supernatant with ninhydrin, glacial acetic acid, and phosphoric acid at 95°C for 1 hour. After cooling, toluene was added and the proline concentration was determined by measuring absorbance at 520 nm, using a standard curve, and expressed as µM g^{-1} FW (Vinod *et al*., 2024).

Results and Discussion

Physiological loss in weight (PLW)

Physiological loss in weight (PLW) is a critical indicator of fruit quality and shelf life in pointed gourd. The effect of spermidine treatment on PLW is illustrated in Fig. 1a. Throughout the storage period, weight loss increased progressively in both treated and untreated fruits. However, spermidine-treated fruits consistently exhibited lower PLW compared to the control. By the 20th day of storage, the treated fruits recorded the lowest PLW at 7.62% under low-temperature conditions, whereas the control fruits showed a significantly higher PLW of 10.33%. These results suggest that spermidine application effectively reduces moisture loss, thereby enhancing the storage potential and maintaining the quality of pointed gourd.

PLW is a critical postharvest quality attribute that directly influences the shelf life of pointed gourd. Typically, weight loss occurs due to moisture loss through transpiration and respiration, leading to visible fruit shrinkage. Additionally, PLW can increase as a result of carbon loss during each respiration cycle (Kablan *et al*., 2008). In our study, PLW (%) was found to increase progressively with the duration of storage. However, treatment with SPD significantly reduced PLW compared to the control by the 20th day of storage. This indicates that SPD plays a crucial role in minimizing weight loss, likely due to its anti-senescent properties and its ability to stabilize cell integrity and regulate tissue permeability. Similar reductions in weight loss following SPD treatment

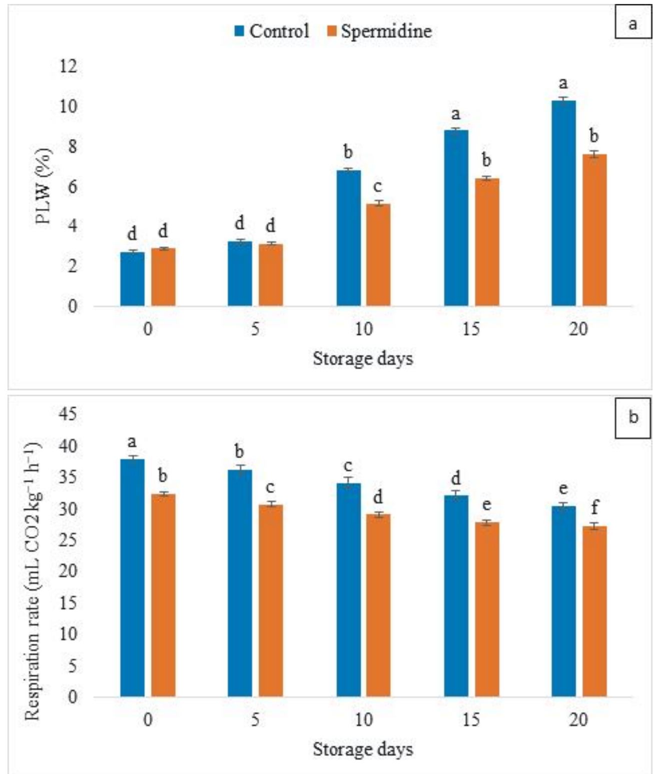

Fig. 1 : Effect of spermidine treatment on PLW (a) and respiration rate (b) of pointed gourd during storage. Error bar specify standard deviation and alphabetic letters specify significant difference ($p < 0.05$).

have also been reported in green bell peppers and green chilies (Patel *et al.*, 2019). Furthermore, SPD's role in stabilizing cell structure and permeability was observed in mango cultivar Kensington Pride (Malik and Singh, 2005).

Fruit firmness

Pectin plays a crucial role in maintaining fruit firmness, which is an important quality parameter in pointed gourd. During the storage period, a gradual decline in firmness was observed in both treated and control fruits (Fig. 2a). However, by the end of storage, spermidine-treated fruits retained significantly higher firmness (20.92 N) compared to the control fruits (14.96 N). This indicates that spermidine treatment helps slow down the degradation of pectin and delays softening, thereby preserving the textural quality of pointed gourd during storage.

Pectin substance plays an important role in providing fruit firmness, which is most important parameter of fruit quality. Enzymes such as polygalacturonase (PG), pectin methyl esterase (PME) and cellulose participate in cell wall degradation of fruit. In our study, the higher fruit firmness was found to decrease with increase in storage period. SPD treatments enhance tissue firmness by

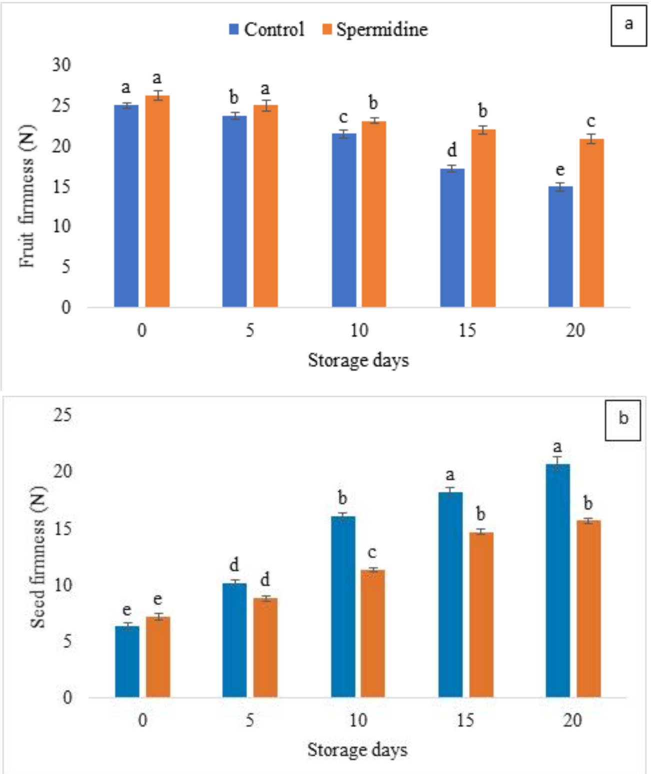

Fig. 2 : Effect of spermidine treatment on fruit firmness and seed firmness of pointed gourd during storage. Error bar specify standard deviation and alphabetic letters specify significant difference ($p < 0.05$).

linking with carboxyl groups ($-COO^-$) of pectic compounds, stabilizing cell walls by inhibit cell wall-degrading enzymes like pectin methylesterase, pectinesterase, and polygalacturonase, thereby reducing fruit softening during storage (Raeisi *et al.*, 2013; Valero *et al.*, 2002). SPD also inhibit softening mechanism by blocking softening enzymes action and modifying cell wall (Champa *et al.*, 2014).

Seed firmness : The effect of spermidine treatment on seed firmness of pointed gourd is shown in Fig. 2b. Regardless of treatment, seed firmness increased progressively as storage duration advanced. However, spermidine-treated fruits consistently exhibited lower seed firmness compared to the control, indicating delayed seed hardening. On the 20th day of storage, seed firmness in SPD-treated fruits was recorded at 15.67 N, while control fruits showed significantly higher firmness at 20.75 N. This suggests that spermidine treatment helps in maintaining seed tenderness, thereby contributing to better overall fruit quality during extended storage.

Seed hardness is a negatively correlated quality parameter that directly affects consumer acceptability and cooking quality of fruits. In the present study, fruits treated with SPD exhibited significantly lower seed hardness compared to untreated fruits by the end of the storage period. This trend suggests that SPD treatment may have contributed to maintaining seed tenderness, possibly by delaying the lignification process, which is often associated with increased seed hardness during storage. These findings are supported by Koley *et al.* (2009), who reported that polyamine applications can suppress lignin biosynthesis, thereby preserving textural quality.

Table 1 : Effect of spermidine treatment on quality and shelf life of pointed gourd during cold storage.

Storage days	Control	Spermidine @ 3 mM/L	Mean
Antioxidant activity (µmol TE/g)			
0	3.76 ± 0.05a	3.15 ± 0.04b	3.45 ± 0.05a
5	2.76 ± 0.04c	2.88 ± 0.04c	2.82 ± 0.04b
10	2.36 ± 0.03d	2.53 ± 0.03d	2.45 ± 0.03c
15	1.88 ± 0.03e	2.31 ± 0.03e	2.09 ± 0.03d
20	1.50 ± 0.02f	1.79 ± 0.02f	1.65 ± 0.02e
Mean	2.45 ± 0.03b	2.53 ± 0.03a	
Total phenol content (mg GAE 100 g^{-1})			
0	171.85 ± 1.98b	193.54 ± 2.11a	182.69 ± 2.05a
5	151.04 ± 1.86d	183.75 ± 2.04b	167.40 ± 1.95b
10	142.74 ± 1.78e	164.80 ± 1.97c	153.77 ± 1.88c
15	130.25 ± 1.69f	137.76 ± 1.75e	134.01 ± 1.72d
20	116.84 ± 1.61g	128.30 ± 1.68f	122.57 ± 1.64e
Mean	142.55 ± 1.78b	161.63 ± 1.91a	
Total chlorophyll (mg 100 g^{-1})			
0	3.95 ± 0.05a	4.51 ± 0.06a	4.23 ± 0.05a
5	3.54 ± 0.04b	3.99 ± 0.05b	3.76 ± 0.04b
10	3.28 ± 0.04c	3.32 ± 0.04c	3.30 ± 0.04c
15	2.84 ± 0.03d	3.18 ± 0.04d	3.01 ± 0.04d
20	2.37 ± 0.03e	2.58 ± 0.03e	2.47 ± 0.03e
Mean	3.20 ± 0.04b	3.52 ± 0.04a	
pH			
0	6.60 ± 0.05a	6.72 ± 0.04a	6.66 ± 0.05a
5	6.53 ± 0.04a	6.66 ± 0.05a	6.60 ± 0.05a
10	6.40 ± 0.04b	6.61 ± 0.04a	6.50 ± 0.04b
15	6.30 ± 0.03c	6.58 ± 0.04b	6.44 ± 0.04c
20	6.25 ± 0.03c	6.50 ± 0.03b	6.37 ± 0.03d
Mean	6.41 ± 0.04b	6.61 ± 0.04a	

The results are presented as the mean of three replicate ± standard deviation. Different letters in the same column and row specify significant difference ($p < 0.05$).

Colour

The color of pointed gourd is a key quality attribute that significantly influences consumer preference, and it tends to deteriorate as storage duration increases (Table

2 and Fig. 4). Among the color parameters, the L* value represents the lightness of the fruit was notably higher in SPD-treated fruits (32.93) compared to control fruits (25.55), indicating that SPD treatment helped retain brightness during storage. The a* value, which when negative indicates green coloration, was more pronounced in SPD-treated fruits (-2.55) than in the control (-2.87), suggesting better preservation of green color. Meanwhile, the b* value, which reflects the yellow component of color, was higher in control fruits (15.29) than in SPD-treated fruits (11.48) on the 20th day of storage. This reduction in yellowness in SPD-treated fruits suggests a delay in ripening and senescence, contributing to better visual quality and extended shelf life.

Color is one such factor which lays down the foundation for maturity index in pointed gourd. Usually, fruits turn yellow due to degradation of photosynthetic pigments such as chlorophyll in response to increased storage duration (Abbasi *et al.*, 2019). In our study, SPD @ 3.0 mM/L has exerted positive effect on fruit color of pointed gourd. The slower changes in the brightness (L*) of the surface of pointed gourd fruit after SPD application could be ascribed to the delay in senescence and reduced degradation of chlorophyll with respect to extended storage day. Application of SPD has also been successfully utilized for optimum color development on the fruit surface in peach and apricot (Kaur *et al.*, 2013; Martínez-Romero *et al.*, 2001) and also reduced hydrolytic activities acting on chloroplast thylakoid membranes (Lester, 2000). Besides, application of polyamines could reduce the loss of chlorophyll in thylakoid membranes by stabilizing photosystem complexes (Beigbeder *et al.*, 1995).

Respiration Rate

The effect of spermidine treatment on the respiration rate of pointed gourd is presented in Fig. 1b. Throughout the storage period, the respiration rate showed a gradual increase in both treated and untreated fruits. However, spermidine-treated fruits consistently exhibited a lower respiration rate compared to the control. On the 20th day of storage, the respiration rate in SPD-treated fruits was recorded at 27.20 mL CO_2 kg^{-1} h^{-1}, which was notably lower than that of the control fruits, which reached 30.40 mL CO_2 kg^{-1} h^{-1}. This reduction suggests that spermidine treatment effectively slows down the metabolic activity, thereby contributing to prolonged shelf life and better postharvest quality.

Respiration plays a vital role in physiological processes till the fruit inters in senescence stage. In this study, pointed gourd fruits treated with SPD exhibited significantly lower respiration rates compared to the control, particularly toward the end of the storage period. This apprehends that SPD may control chemical metabolism rates such as hydrolysis of sucrose into reducing sugars (Champa *et al.*, 2014). Polyamines suppress the consumption of organic acids in metabolism and delayed the senescence (Barman *et al.*, 2014; Torrigiani *et al.*, 2004). Furthermore, the suppression of respiration in SPD-treated strawberry fruits slowed the metabolic activities, leads to delayed ripening and extended shelf life (Orman *et al.*, 2024). Polyamine treated kiwi fruits attributed to the anti-senescence help preserve cellular structures and delay the degradation of membrane lipids, resulting in slower metabolic activity (Jhalegar *et al.*, 2012).

Total Phenolic

The effect of spermidine treatment on the total phenolic content of pointed gourd is presented in Table 1. Throughout the storage period, a continuous decline in total phenolic content was observed in both treated and untreated fruits. However, by the end of 20 days of storage, SPD-treated fruits retained a significantly higher total phenolic content (128.30 mg GAE/100 g) compared to untreated fruits (116.84 mg GAE/100 g). This indicates that spermidine treatment effectively slows down the degradation of phenolic compounds, thereby helping to preserve the antioxidant potential and overall quality of pointed gourd during storage.

Total phenolic compounds are key plant constituents known for their redox properties, which contribute significantly to antioxidant activity and stress resistance in fruits and vegetables (Soobrattee *et al.*, 2005). In the present study, polyamine-treated fruits exhibited a slower degradation of phenolic compounds compared to the control. This suggests that polyamines may play a role in delaying the activity of polyphenol oxidase enzymes, potentially due to the reduction in respiratory activity during storage (Jhalegar *et al.*, 2012). The retention of phenolic compounds is further supported by the presence of diverse antioxidants and phytochemical constituents that collectively contribute to the antioxidant defense system (Tavarini *et al.*, 2008). Consistent with these findings, Mirdehghan *et al.* (2007) also reported that polyamine application helped preserve the functional quality of pomegranate arils by maintaining their phenolic content and delaying senescence during storage.

Total chlorophyll

The total chlorophyll content of pointed gourd a steady decline was observed in both treated and untreated fruits during storage (Table 1 and Fig. 4). However, the reduction was more rapid in control fruits, while spermidine-treated fruits exhibited a slower and more gradual decline. By the 20th day of storage, SPD-treated fruits retained the highest chlorophyll content (2.58 mg 100 g^{-1}), compared to 2.37 mg 100 g^{-1} in control fruits. This suggests that spermidine treatment helps delay chlorophyll degradation, thereby maintaining the green color and visual quality of pointed gourd during storage.

Chlorophyll degradation in green vegetables and fruits typically occurs due to the activity of the chlorophyllase enzyme, which leads to the loss of green pigmentation during storage. In the present study, total chlorophyll content gradually declined over the storage period in all treatments. However, fruits treated with SPD showed significantly slower chlorophyll degradation. SPD treatments were effective in maintaining higher enzymatic antioxidant activities and preserving bioactive compounds, thereby contributing to delayed deterioration and better retention of chlorophyll during storage (Sharma *et al*., 2022). It is also proposed that SPD plays a crucial role in maintaining higher chlorophyll content by reducing malondialdehyde (MDA) accumulation and minimizing electrolyte leakage, both of which are indicators of oxidative stress and membrane damage (Zheng *et al*., 2019).

Total Antioxidant activity

The effect of spermidine treatment on the total antioxidant content of pointed gourd is presented in Table 1. Regardless of treatment, total antioxidant content declined steadily throughout the storage period. However, spermidine-treated fruits showed significantly better retention of antioxidant capacity compared to the control. On the 20th day of storage, SPD-treated fruits recorded a higher antioxidant content (1.79 µ mol Trolox/g) than control fruits (1.50 µ mol Trolox/g), indicating that spermidine effectively helps preserve antioxidant properties during postharvest storage.

Antioxidant activity reflects the presence and effectiveness of various secondary metabolites and serves as a reliable indicator of the nutritional value of fruits after storage (Hanif *et al*., 2020). In the present study, total antioxidant activity decreased progressively with the advancement of storage duration; however, fruits treated with SPD exhibited significantly higher retention of antioxidant capacity. Exogenous application of SPD effectively mitigated the rise in ROS by promoting the synthesis of secondary metabolites, thereby enhancing the antioxidant defense system (Collado-González *et al*., 2021). The elevated levels of bioactive compounds in polyamine-treated fruits may be attributed to the intrinsic antioxidant properties of polyamines. In addition to scavenging ROS, polyamines suppress respiration and chlorophyll degradation, which collectively reduce cell wall breakdown and the subsequent generation of oxidative stress (Jalali *et al*., 2023). The positively charged nature of polyamines also allows them to directly neutralize free radicals, thereby contributing to the production and stabilization of antioxidant compounds (Mirdehghan *et al*., 2007; Razzaq *et al*., 2014).

pH

The pH plays a crucial role in regulating biochemical reactions and preserving the physicochemical qualities of fruits. The effect of SPD treatment on the pH of stored pointed gourd is shown in Table 1. Throughout the storage period, a gradual decline in pH was observed. However, by the end of 20 days, fruits treated with SPD retained a higher pH value (6.50) compared to the control (6.25).

The pH of fruit tissue is an important biochemical indicator reflecting acidity and metabolic activity during postharvest storage and is widely used to evaluate fruit quality in pointed gourd. In this study, pH levels gradually increased in both treated and control fruits over the storage period; however, the increase was significantly lower in SPD-treated fruits, suggesting its role in slowing postharvest metabolic changes. The rise in pH may result from enzymatic sugar conversion and associated biochemical activities (Kuchi *et al*., 2016). Additionally, a thin film formed by SPD may reduce respiration and delay ethylene production, thereby influencing organic acid metabolism (Davarynejad *et al*., 2013). Lower ethylene and respiration rates could slow the breakdown of organic acids, maintaining a lower pH (Khosroshahi and Ashari, 2007). Orman *et al.* (2024) similarly found that SPD-treated nectarine fruits exhibited slower pH increase, attributed to reduced degradation of organic acids, thus preserving internal quality and stability.

MDA content

Both the SPD treated and untreated pointed gourd displayed a progressive rise in MDA content during storage, which showed significant ($P<0.05$) difference (Fig. 3a). Nevertheless, the fruits treated with SPD consistently showed reduced MDA content compared to the without treated fruits throughout the storage duration. Specifically, on the 20^{th} day of storage, untreated fruits showed the maximum amount of MDA accumulation (6.13 µM g^{-1} FW), whereas pointed gourd fruits treated with SPD showed reduced MDA accumulation (4.24 µM g^{-1} FW).

MDA a byproduct of oxidative damage induced by

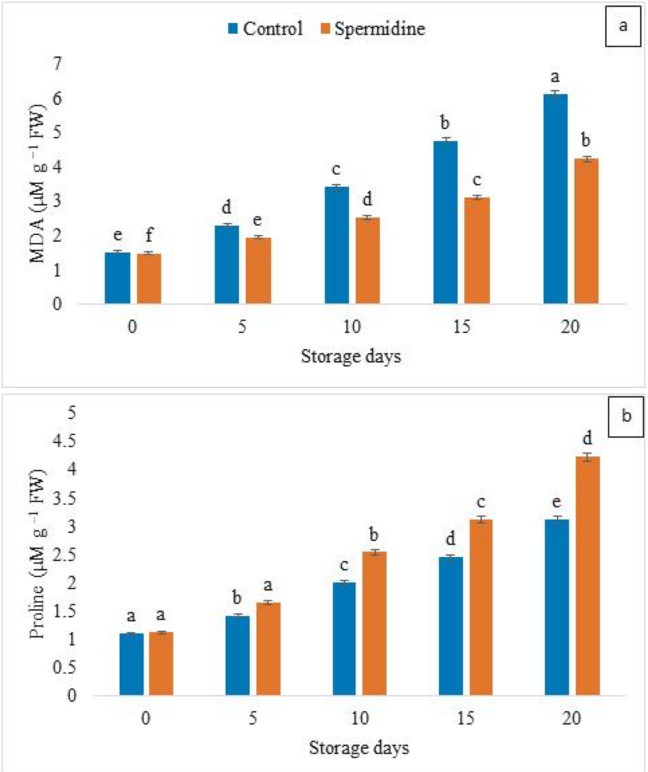

Fig. 3 : Effect of spermidine treatment on MDA and proline content of pointed gourd during storage. Error bar specify standard deviation and alphabetic letters specify significant difference ($p < 0.05$).

ROS, is widely recognized as a biochemical marker for membrane lipid peroxidation and overall oxidative stress (Ahamad *et al*., 2024b). Polyamines have been shown to suppress MDA accumulation by enhancing the activity of antioxidant enzymes and elevating levels of endogenous antioxidants, thereby protecting cellular membranes from oxidative damage and preserving the fresh appearance of fruits (Jia *et al*., 2018). SPD act as an effective free radical scavenger, contributing to a significant reduction in MDA content by delaying the accumulation of lipid peroxidation products, as demonstrated in tomato fruits (Orabi *et al*., 2020). Consistently, Sharma *et al*. (2022)

Table 2 : Effect of spermidine treatment on quality and shelf life of pointed gourd during cold storage.

Storage days	Control	Spermidine @ 3 mM/L	Mean
L*			
0	39.97 ± 0.12a	39.87 ± 0.11a	39.92 ± 0.11a
5	36.58 ± 0.11b	39.35 ± 0.12a	37.97 ± 0.12b
10	33.31 ± 0.10c	39.73 ± 0.11a	36.52 ± 0.11c
15	28.88 ± 0.09d	35.50 ± 0.10b	32.19 ± 0.10d
20	25.55 ± 0.08e	32.93 ± 0.09c	29.24 ± 0.09e
Mean	32.86 ± 0.10b	37.48 ± 0.11a	
a*			
0	-5.30 ± 0.05b	-5.97 ± 0.06a	-5.64 ± 0.05a
5	-4.81 ± 0.04c	-5.39 ± 0.05b	-5.10 ± 0.05b
10	-4.27 ± 0.04d	-4.95 ± 0.04c	-4.61 ± 0.04c
15	-3.54 ± 0.03e	-3.64 ± 0.03d	-3.59 ± 0.03d
20	-2.87 ± 0.03f	-2.55 ± 0.03e	-2.71 ± 0.03e
Mean	-4.16 ± 0.04b	-4.50 ± 0.04a	
b*			
0	22.70 ± 0.12a	21.45 ± 0.11b	22.07 ± 0.12a
5	21.57 ± 0.11b	18.16 ± 0.10c	19.87 ± 0.11b
10	22.37 ± 0.11a	15.71 ± 0.09d	19.04 ± 0.10c
15	17.47 ± 0.10c	13.94 ± 0.09e	15.71 ± 0.10d
20	15.29 ± 0.09d	11.48 ± 0.08f	13.39 ± 0.09e
Mean	19.88 ± 0.11a	16.15 ± 0.09b	

The results are presented as the mean of three replicate ± standard deviation. Different letters in the same column and row specify significant difference ($p < 0.05$).

reported that polyamine treatment delayed MDA accumulation in bell pepper, which was attributed to a more robust antioxidant defense system and the retention of higher levels of bioactive compounds that actively scavenged ROS, ultimately reducing oxidative damage.

Proline content

The proline content in pointed gourd steadily increased during storage in treated fruit as well as control fruit.

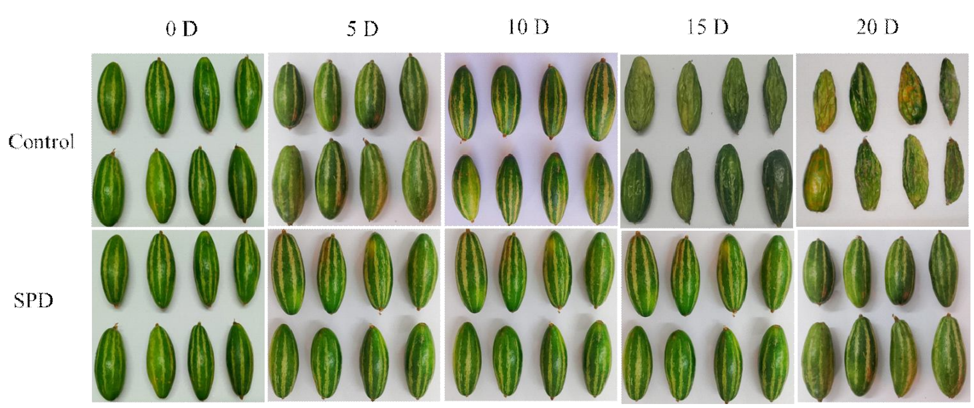

Fig. 4 : Effect spermidine treatment on visual quality of pointed gourd fruits during storage.

Remarkably, fruits treated with SPD consistently showed higher proline levels compared to control fruits. By the end of storage, pointed gourd fruits treated with SPD exhibited the highest proline content (4.23 µM g^{-1} FW), while untreated fruits exhibited the lowest proline content (3.12 µM g^{-1} FW) (Fig. 3b). These results suggest that proline not only acts as an osmoprotectant but also plays a key role in maintaining postharvest quality and delaying ripening in climacteric and non-climacteric fruits.

Elevated proline levels were found to be effective in maintaining the green coloration of pointed gourd during storage. In this study, treatments that resulted in higher proline accumulation contributed significantly to the preservation of green pigmentation, indicating a delay in chlorophyll degradation (Malekzadeh *et al.*, 2023). This observation is supported by similar findings in bell pepper, where polyamine treatment helped retain higher proline content and delayed senescence (Patel *et al.*, 2019). Likewise, SPD application in tomato was reported to increase proline levels, which was associated with elevated concentrations of bioactive compounds and improved stress resistance (Orabi *et al.*, 2020).

Conclusion

The present study demonstrates that exogenous spermidine (SPD) treatment is an effective strategy for maintaining postharvest quality and extending the shelf life of pointed gourd during cold storage. SPD-treated fruits exhibited reduced physiological weight loss, delayed firmness loss and slower seed hardening, contributing to better physical appearance and texture. The treatment also preserved green pigmentation and enhanced biochemical parameters such as antioxidant activity and total phenolic content, while reducing malondialdehyde (MDA) levels and increasing proline accumulation indicators of lower oxidative damage and improved stress tolerance. These results underscore the potential of SPD as a sustainable and practical approach for postharvest management of pointed gourd, supporting its commercial viability by reducing spoilage and preserving nutritional quality during storage.

Acknowledgement

The authors gratefully acknowledge the ICAR-Indian Agricultural Research Institute, New Delhi, for providing the necessary resources and support to conduct this research in a timely manner.

References

Abbasi, N.A., Ali I., Hafiz I.A., Alenazi M.M. and Shafiq M. (2019). Effects of putrescine application on peach fruit during storage. *Sustainability*, **11(7)**, 2013.

Ahamad, S., Asrey R., Singh A.K., Sethi S., Joshi A., Vinod B.R. and Choupdar G.K. (2024a). Melatonin treatment enhances bioactive compound retention, antioxidant activity and shelf-life of bell pepper (*Capsicum annuum* L.) during cold storage. *Int. J. Food Sci. Technol.*, **59(10)**, 7918-7931.

Ahamad, S., Asrey R., Vinod B.R., Meena N.K., Menaka M., Prajapati U. and Saurabh V. (2024b). Maintaining postharvest quality and enhancing shelf-life of bell pepper (*Capsicum annuum* L.) using brassinosteroids: A novel approach. *S. Afr. J. Bot.*, **169**, 402-412.

Ahamad, S., Sagar V.R., Asrey R., Islam S., Tomar B.S., Vinod B.R. and Kumar A. (2024c). Nutritional retention and browning minimization in dehydrated onion slices through potassium metabisulphite and sodium chloride pre-treatments. *Int. J. Food Sci. Technol.*, **59(8)**, 5794-5805.

Apak, R., Güçlü K., Ozyürek M. and Karademir S.E. (2004). Novel total antioxidant capacity index for dietary polyphenols and vitamins C and E, using their cupric ion reducing capability in the presence of neocuproine: CUPRAC method. *J. Agric. Food Chem.,* **52**, 7970–7981.

Barman, K., Asrey R., Pal R.K., Kaur C. and Jha S.K. (2014). Influence of putrescine and carnauba wax on functional and sensory quality of pomegranate (*Punica granatum* L.) fruits during storage. *J. Food Sci. Technol.*, **51(1)**, 111-117.

Beigbeder, A., Vavadakis M., Navakoudis E. and Kotzabasis K. (1995). Influence of polyamine inhibitors on light-independent and light-dependent chlorophyll biosynthesis and on the photosynthetic rate. *J. Photochem. Photobiol. Biol*., **28(3)**, 235-242.

Champa, W.H., Gill M.I.S., Mahajan B.V.C. and Arora N.K. (2014). Postharvest treatment of polyamines maintains quality and extends shelf-life of table grapes (*Vitis vinifera* L.) cv. Flame Seedless. *Postharvest Biol. Technol.*, **91**, 57-63.

Collado-González, J., Piñero M.C., Otálora G., López-Marín J. and del Amor F.M. (2021). Exogenous spermidine modifies nutritional and bioactive constituents of cauliflower (*Brassica oleracea* var. *botrytis* L.) florets under heat stress. *Sci. Hortic.*, **277**, 109818.

Davarynejad, G., Zarei M., Ardakani E. and Nasrabadi M.E. (2013). Influence of putrescine application on storability, postharvest quality and antioxidant activity of two Iranian apricot (*Prunus armeniaca* L.) cultivars. *Not. Sci. Biol.*, **5(2)**, 212-219.

Dhami, K.S., Asrey R., Vinod B.R. and Meena N.K. (2023). Postharvest methyl jasmonate alleviates chilling injury and maintains quality of 'Kinnow' (*Citrus Nobilis* Lour x *C. deliciosa* Tenora) fruits under differential storage temperature. *Erwerbs-Obstbau*, **65(5)**, 1667–1674.

Gundogdu, M., Güler E., Aðlar E., Arslan T., Kan T. and Çelik K. (2023). Use of spermidine to preserve organic acids, polyphenols, and quality of cold stored plum fruits. *J. Food Compos. Anal.*, **121**, 105411.

Hanif, A., Ahmad S., Jaskani M.J. and Ahmad R. (2020). Papaya treatment with putrescine maintained the overall quality and promoted the antioxidative enzyme activities of the stored fruit. *Sci. Hortic.*, **268**, 109367.

Jalali, P., Zakerin A.R., Aboutalebi-Jahromi A.H. and Sadeghi H. (2023). Improving postharvest life, quality and bioactive compounds of strawberry fruits using spermine and spermidine. *Braz. J. Biol.*, **83**, e273886.

Jhalegar, M.J., Sharma R.R., Pal R.K. and Rana V. (2012). Effect of postharvest treatments with polyamines on physiological and biochemical attributes of kiwifruit (*Actinidia deliciosa*) cv. Allison. *Fruits*, **67(1)**, 13-22.

Jia, B., Zheng Q., Zuo J., Gao L., Wang Q., Guan W. and Shi J. (2018). Application of postharvest putrescine treatment to maintain the quality and increase the activity of antioxidative enzyme of cucumber. *Sci. Hortic.*, **239**, 210-215.

Kablan, T., Koffi N.R., Marina K. and Oule M.K. (2008). The effects of different storage temperatures on the quality of bell pepper (*Capsicum annuum* L.). *Agric. J.*, **3(2)**, 157-162.

Kaur, B., Jawandha S.K., Singh H. and Thakur A. (2013). Effect of putrescine and calcium on colour changes of stored peach fruits. *Int. J. Agric. Environ. Biotechnol.*, **6(2)**, 301.

Khandaker, M., Akter S. and Imam M.Z. (2018). *Trichosanthes dioica* Roxb.: A vegetable with diverse pharmacological properties. *Food Sci. Hum. Wellness*, **7(1)**, 34-48.

Koley, T.K., Asrey R. and Samuel D.V.K. (2009). Effect of sanitizers and storage environment on shelf-life and quality of pointed gourd (*Trichosanthes dioica*). *Indian J. Agric. Sci.*, **79(3)**, 170.

Kuchi, V.S. and Singh H. (2016). Modified atmospheric packaging studies of pointed gourd: treatment with disinfectant and polyethylene film maintains quality. *Int. J. Agric. Sci. Res.*, **6**, 425-432

Lester, G.E. (2000). Polyamines and their cellular anti-senescence properties in honey dew muskmelon fruit. *Plant Sci.*, **160(1)**, 105-112.

Malekzadeh, P., Hatamnia A.A. and Tiznado-Hernández M.E. (2023). Arginine catabolism induced by exogenous arginine treatment reduces the loss of green color rate in broccoli florets. *Physiol. Mol. Plant Pathol.*, **124**, 101973.

Malik, A.U. and Zora S. (2005). Pre-storage application of polyamines improves shelf-life and fruit quality of mango. *J. Hortic. Sci. Biotechnol*., **80(3)**, 363-369.

Martínez-Romero, D., Valero D., Riquelme F., Zuzunaga M., Serrano M., Burló F. and Carbonell-Barrachina A. (2001). Infiltration of putrescine into apricots helps handling and storage. *Acta Hortic.*, **553**, 189–192

Menaka, M., Asrey R., Meena N.K., Vargheese E., Sethi S., Ahamad S. and Goswami A.K. (2024). Effect of melatonin on biochemical changes, antioxidant system and oxidative membrane damage of Indian guava (cv. Barafkhana) during cold storage. *S. Afr. J. Bot.*, **169**, 95-108.

Mirdehghan, S.H., Rahemi M., Serrano M., Guillén F., Martínez-Romero D. and Valero D. (2007). The application of polyamines by pressure or immersion as a tool to maintain functional properties in stored pomegranate arils. *J. Agric. Food Chem.*, **55(3)**, 755-760.

Orabi, S.A., Salman S.R., Sharara F.A. and Abou-Hussein S.D. (2020). Protective role of spermidine on two tomato cultivars against cold-induced lipid peroxidation by enhancing capacity of anti-oxidative system. *Middle East J*., **9(4)**, 848-856.

Orman, E., Yavic A., Gundogdu M., Aglar E., Celik K. and Kan T. (2024). Polyamines in cold storage: impact of postharvest spermidine on strawberry quality. *J. Food Meas. Charact.*, **18(11)**, 9618-9630.

Patel, N., Gantait S. and Panigrahi J. (2019). Extension of postharvest shelf-life in green bell pepper (*Capsicum annuum* L.) using exogenous application of polyamines (spermidine and putrescine). *Food Chem.*, **275**, 681-687.

Prajapati, U., Asrey R., Sinha S.K., Joshi A., Varghese E. and Meena N.K. (2024). Salicylic acid and putrescine treatments reduce yellowing, decay and retain postharvest quality of bitter gourd (*Momordica charantia* L.) during cold storage. *S. Afr. J. Bot.*, **164**, 111-120.

Raeisi, M., Samani R.B. and Honarvar M. (2013). Application of exogenous spermidine treatment for reducing of chilling on fruit quality and quantity of Valencia orange var. olinda. *Int. J. Farm Allied Sci*., **2**, 1292-1297.

Razzaq, K., Khan A.S., Malik A.U., Shahid M. and Ullah S. (2014). Role of putrescine in regulating fruit softening and antioxidative enzyme systems in 'Samar Bahisht Chaunsa'mango. *Postharvest Biol. Technol.*, **96**, 23-32.

Sharma, G. and Pant M.C. (1988). Effects of feeding *Trichosanthes dioica* (parval) whole fruits on blood glucose, serum triglyceride, phospholipid, cholesterol and high-density lipoprotein-cholesterol levels in the normal albino rabbits. *Curr. Sci.*, **57(19)**, 1085-1087.

Sharma, S., Krishna H., Barman K., Kole B., Singh S.K. and Behera T.K. (2022). Synergistic effect of polyamine treatment and chitosan coating on postharvest senescence and enzyme activity of bell pepper (*Capsicum annuum* L.) fruit. *S. Afr. J. Bot.*, **151**, 175-184.

Sharma, S., Pareek S., Sagar N.A., Valero D. and Serrano M. (2017). Modulatory effects of exogenously applied polyamines on postharvest physiology, antioxidant system and shelf life of fruits: a review. *Int. J. Mol. Sci.*, **18(8)**, 1789.

Sharma, S., Singh A.K., Singh S.K., Barman K. and Kumar S. (2018). Polyamines for preserving postharvest quality. In: *Emerg. Postharvest Treat. Fruits Veg.* (pp. 381-404). Apple Academic Press.

Sharmila, B.G., Kumar G. and Rajasekara P.M. (2007). Cholesterol lowering activity of the aqueous fruit extract of *Trichosanthes dioica* Roxb. in normal and streptozotocin diabetic rats. *J. Clin. Diagn. Res.*, **1(6)**, 561-569.

Soobrattee, M.A., Neergheen V.S., Luximon-Ramma A., Aruoma O.I. and Bahorun T. (2005). Phenolics as potential antioxidant therapeutic agents: mechanism and actions. *Mutat. Res. Fundam. Mol. Mech. Mutagen.*, **579(1-2)**, 200-213.

Tavarini, S., Degl'Innocenti E., Remorini D., Massai R. and Guidi L. (2008). Antioxidant capacity, ascorbic acid, total phenols and carotenoids changes during harvest and after storage of Hayward kiwifruit. *Food Chem.*, **107(1)**, 282-288.

Torrigiani, P., Bregoli A.M., Ziosi V., Scaramagli S., Ciriaci T., Rasori A. and Costa G. (2004). Pre-harvest polyamine and aminoethoxyvinylglycine (AVG) applications modulate fruit ripening in Stark Red Gold nectarines (*Prunus persica* L. Batsch). *Postharvest Biol. Technol*., **33(3)**, 293-308.

Valero, D., Pérez Vicente A., Martínez Romero D., Castillo S., Guillen F. and Serrano M. (2002). Plum storability improved after calcium and heat postharvest treatments: role of polyamines. *J. Food Sci*., **67(7)**, 2571-2575.

Vinod, B.R., Asrey R., Menaka M., Ahamad S., Meena N.K., Bhan C. and Avinash G. (2024). Synergistic effect of aqueous ozone and guar gum coating on the quality and shelf life of stored papaya fruit. *J. Food Meas. Charact.*, **18(6)**, 4000-4011.

Yadav, N., Singh A.K., Pal A.K., Sharma S. and Barman K. (2022). Postharvest application of 6-benzylaminopurine preserves quality and delays senescence of pointed gourd (*Trichosanthes dioica* Roxb.) fruit. *Natl. Acad. Sci. Lett.*, 1-5.

Zheng, Q., Zuo J., Gu S., Gao L., Hu W., Wang Q. and Jiang A. (2019). Putrescine treatment reduces yellowing during senescence of broccoli (*Brassica oleracea* L. var. italica). *Postharvest Biol. Technol.*, **152**, 29-35.

Zokaee Khosroshahi, M.R. and Esna-Ashari M. (2008). Effect of putrescine application on post-harvest life and physiology of strawberry, apricot, peach and sweet cherry fruits. *Isfahan Univ. Technol. J. Crop Prod. Process*, **12(45)**, 219-230.