Preharvest Putrescine Application Extends the Shelf Life and Maintains the Pear Fruit Quality

Veerpartap Singh	extsuperscript{a}, S.K. Jawandha	extsuperscript{a}, P.P.S. Gill	extsuperscript{a}, and Davinder Singh	extsuperscript{b}

	extsuperscript{a}Department of Fruit Science, Punjab Agricultural University, Ludhiana, India; \textsuperscript{b}Department of Extension Education, Punjab Agricultural University, Ludhiana, India

ABSTRACT
Pear fruits are climacteric in nature and remain biologically active due to continuous respiration, transpiration, and other biochemical processes even after harvest. Under ambient conditions of north-western India, pear fruits have a short shelf life. An experiment was conducted to enhance the shelf life of pear fruits cv. Punjab Beauty using preharvest sprays of putrescine (PUT) @ 1 mM, 2 mM & 3 mM. Mature fruits from PUT treated and control plants were harvested and stored at ambient conditions (32 ± 2 °C, 78 ± 5% RH). Periodical observations for various physicochemical parameters and enzymatic activities were taken on 0, 3, 6, 9, 12 and 15 days after ambient storage. As compared to control, 2 and 3 mM PUT treatments resulted into a reduction in weight loss (WL), spoilage along with retention of higher firmness, soluble solid content (SSC), titratable acidity (TA), and starch content in stored pear fruits. During storage, these treatments had also reduced the fruit softening by reducing the activities of cell wall degrading enzymes like pectin methylsterase (PME) and cellulase. So, it could be inferred that PUT treatment of 2 mM & 3 mM was effective to enhance the shelf life of pear fruits at ambient conditions with acceptable quality.

KEYWORDS
Ambient storage; cellulase; pear; PME; putrescine

Introduction
Pear is a much-appreciated fruit for its luscious taste, a unique fragrance with exceptional flavor, sweetness, and nutritive value. Pear is a table-purpose fruit that has good eating quality with grit cells and crispness. Being a good source of minerals, vitamins, antioxidants, and carbohydrates, such as sucrose, fructose, and sorbitol with low glucose, lipid, and higher dietary fiber content, is considered an important fruit for nutritional diet (Colaric et al., 2007). However, pear has a short post-harvest life at ambient conditions that make the fruits available in the market for a shorter period (Nath et al., 2012). Being perishable in nature, the fruits undergo rapid deterioration of quality under ambient conditions. Generally, pears get mature and harvested in the mid-summer and this period coincides with the high temperature and high relative humidity RH (Nath et al., 2012). Secondly, pear fruit being climacteric in nature remains biologically active and continues respiration, as well as transpiration and other biochemical processes even after harvest that leads to rapid deterioration in quality (Reddy et al., 2017). The climacteric fruits are recognized with a sudden rise in ethylene production that makes them vulnerable to quality losses during storage (Khan and Ali, 2018; Wills et al., 2007). Thus, the development of an adequate postharvest technique is important to sustain fruit quality during storage.

The post-harvest quality of climacteric fruits can be retained to a certain degree with the application of anti-ethylene compounds. Polyamines and ethylene share common biosynthesis precursor S-adenosyl methionine (SAM) and exert an antagonistic effect in fruit ripening. Thus, reduction in
polyamines’ level can be directly correlated to enhanced ethylene production and ripening and vice versa (Valero et al., 2002). Among the various polyamines, putrescine PUT has exhibited great potential for extending the storage life and maintaining the quality of fruits during storage. Putrescine, a natural compound with low molecular weight and aliphatic amine behaves as a competitor to the ethylene precursor, that is, L-ACC (Apelbaum et al., 1981). Pre-storage applications of PUT check the ethylene production (ripening-related event) and extend the postharvest life of various fruits (Khan and Ali, 2018).

Polyamines are involved in many developmental processes and maintain functional qualities by delaying softening and color changes in fruits (Valero et al., 2002). In previous studies, the role of exogenous PUT application to extend the shelf life of pear (Hosseini et al., 2017), mango (Ali et al., 2017; Malik and Singh, 2006) and nectarine (Torrigiani et al., 2004) is well acknowledged. However, to the best of our knowledge, no information is available on the efficacy of preharvest PUT treatment on the quality retention and shelf life extension of subtropical pear fruits stored under ambient conditions that lead to further investigations. Therefore, the current studies were designed with the objective to enhance the shelf life with quality retention of pear fruit cv. Punjab Beauty at the ambient conditions by preharvest foliar application of PUT.

**Materials and Methods**

**Plant Material and Treatments**

Pre-harvest foliar applications of PUT (1 mM, 2 mM & 3 mM) and water (control) were given before 14 days of harvest to 16 uniform and healthy plants of pear cv. Punjab Beauty grafted on *Pyrus pashia* and spaced at 6.5 × 6.5 m in a square system of planting at Fruit Research Farm, Punjab Agricultural University, Ludhiana (30.91° N, 75.85° E & 262 m above mean sea level). Fruits were harvested at a physiological mature phase (135 days following the fruit set) and instantly shifted to the Postharvest Laboratory. Fruits were washed with 100 ppm chlorinated water and then packed in 3-ply layer CFB boxes (5% perforation) with a lining layer of paper and stored at ambient conditions (30 ± 2 °C, 78 ± 5% RH). For each treatment, 144 fruits (6 fruits per replication × 4 replications × 6 storage intervals) were taken and thus a total of 720 fruits were used in 4 treatments during the entire study. The research was performed in the years 2016 & 2017 and laid in a Completely Randomized Design (CRD) with four replications. Periodical observations for physicochemical and enzymatic activities were made on 0 to 15 days of storage at 3 days interval.

**Observations Recorded**

**Weight Loss**

Weight loss in pear fruits was recorded at 3 days periodic interval during ambient storage and cumulative weight loss (WL) of fruits was expressed in percent by applying the formula given below:

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

**Fruit Firmness**

Fruit firmness was calculated by using the stand-mounted penetrometer (Model FT-327, QA Supplies LLC, 1185 Pineridge Road, Norfolk, Virginia 23502 USA) having 8 mm probe of stainless steel from two opposite sides of the fruit following the removal of the peel. Firmness was explicit in the units of Newton (N) force.
**Spoilage**
Fruit spoilage was calculated by counting the spoiled fruit number after every 3 days and expressed in percent.

\[
\text{Spoilage(\%)} = \frac{\text{Number of fruits spoiled} \times 100}{\text{Total number of fruits}}
\]

**Soluble Solids Content**
SSC was calculated by using a digital hand refractometer [PAL-1, ATAGO, Minato-Ku, Tokyo, Japan] and presented in percent units (AOAC, 1990).

**Titratable Acidity**
TA was recorded by adding two drops of phenolphthalein (indicator) to 2 mL of pear juice and titrated with 0.1 N NaOH. The acidity was recorded in percent of malic acid (Ranganna, 2007).

**Starch**
Fruit tissues of 0.2 g were blended with 5 mL diethyl ether solution and three times sugars were omitted with the help of 5 mL of ethanol (80%) at 80°C and residue (starch) remaining was solubilized in 0.5 mL of H$_2$SO$_4$ (0.25 M) for 60 min at 100 °C. The solution was then mixed with 0.5 mL of an anthrone reagent (9, 10-dihydro-9-oxaanthracene) at pH < 7.0 conditions (0.1 g per 100 mL 76% H$_2$SO$_4$) and the mixture was heated for 10 min and then cooled (Stevens and Chapman, 1955). The absorbance was recorded at 620 nm by spectrophotometer (Thermo Scientific Spectronic 20 D), using the distilled water as a blank. A standard curve \( Y = 0.0026X + 0.0123 \) was drawn to determine the concentration of glucose, where \( Y \) is absorbance and \( X \) is the concentration of glucose (\( R^2 = 0.9981 \)). The glucose concentration was multiplied with a factor 0.9 to estimate the starch content.

**Estimation of PME Activity**
Fruit sample of 20 g was homogenized in 80 mL sodium chloride solution (8.7 g NaCl per liter DW) and centrifuged at 448 g force for 30 min at 4 °C after filtered through Whatman no 1 filter paper. PME activity was estimated from the supernatant extract. For PME assay, 1% pectin solution (20 mL) was taken in the beaker and pH was adjusted to 7.0 by using 1 N NaOH. Enzyme supernatant (10 mL) was mixed with 1% neutral pectin solution and again pH was toned to 7.0 with 1 N NaOH. This time is considered as 0 times. Afterward, a water bath (68.5 °C) was given to the enzyme solution for 15 minutes and again pH was neutralized with 0.02 N NaOH. PME activity is expressed as mL of 0.02 N NaOH used (Mahadevan and Sridhar, 1982; Singh et al., 2019).

**Estimation of Cellulase Activity**
Enzyme supernatant for the cellulase activity was extracted as per the method described in PME section. In order to estimate the cellulase activity, Carboxy methylcellulose (CMC) of concentration 0.5% was made in the acidic buffer solution of sodium acetate-acetic acid (0.2 M) at 5.6 pH. Enzyme supernatant (2 mL) was mixed with CMC (4 mL) and buffer (2 mL) and pH was adjusted to 5.6. The solution was poured to the Ostwald Fensk viscometer and then given the water bath (32 ± 1°C). The loss in viscosity was measured at different time intervals and percent reduction in viscosity was expressed as cellulase activity of the substrate (Mahadevan and Sridhar, 1982).

**Statistical Analysis**
The data of both the years were pooled and analysis was performed by one-way analysis of variance (ANOVA) and means were differentiated using LSD test. To analyze the correlation between various qualities attributes that affect the storage life of pear fruits; an association was subjected to compute Pearson’s coefficient of correlations (Table 2). Fruit firmness was correlated with WL, spoilage, PME and cellulase activity. Similarly, starch content was correlated with SSC. Significant combinations of
correlation coefficients (near 1 to −1) associated with various variants were further analyzed to draw the regression equation among two factors shown in Table 3 & Figure 3 (A-E). Statistical differences were calculated significant at \( p \leq 0.05 \) level by using the SAS statistical software (Windows version 9.3). Data in the experiment were presented as mean ± standard errors. Further, Pearson’s correlation analysis was conducted to calculate the nature and significance of the relationship among parameters.

**Results**

**Weight Loss**

Irrespective of treatments applied, the WL in pear fruits increased with the progression of the storage period (Table 1A). However, the rate of WL in pear fruits was rapid up to 9 days of ambient storage and thereafter a steady decrease was noted till the 15 days of storage. Throughout the storage, various PUT treatments significantly lowered the WL in comparison to the control fruits. At the end of storage, the highest WL (6.5%) was recorded in the control fruits, while 3 mM PUT treated fruits exhibited the minimum WL of 5.6%.

**Fruit Firmness**

Pear fruits exhibited substantial reduction in firmness during the ambient storage (Table 1B). However, as compared to control; PUT treatments significantly (\( p \leq 0.05 \)) retarded the rate of softening in pear fruits throughout the ambient storage. On 12th day of storage, PUT 2 and 3 mM treatments were able to maintain the desirable fruit firmness of 33.0 and 35.9 N, whereas, the control fruits exhibited non-desirable fruit firmness of 21.22 N. At the end of studies, fruits treated with 2 & 3 mM PUT registered 42.0% & 45.6% higher firmness, respectively, compared with untreated pears. It was elucidated from the present findings that, fruit firmness was negatively correlated (−0.937, \( R^2 = 0.877 \)) with WL (Table 2, 3 & Figure 3A). The higher WL during fruit storage led to a firmness reduction because of moisture loss in the fruit tissue reduced the turgidity.

**Spoilage**

During ambient storage the pear fruits did not show any spoilage up to sixth day (Table 1C). On ninth day of storage, control fruits recorded 2.1% spoilage, while the PUT treated fruits remained healthy. However, on 15th days of storage, fruits from all the treatments showed symptoms of spoilage

---

**Table 1.** Variation in weight loss (A), firmness (B), and spoilage (C) of pear fruits under ambient conditions in relation to different putrescine treatments.

| Parameters | Putrescine Treatments | Storage period (day) |
|------------|------------------------|----------------------|
|            |                        | 0        | 3        | 6        | 9        | 12       | 15       |
| A.         |                        |          |          |          |          |          |          |
| WL (%)     | 1 mM                   | –        | 2.1 ± 0.05b | 3.7 ± 0.07b | 4.9 ± 0.06b | 5.7 ± 0.04b | 6.2 ± 0.06b |
|            | 2 mM                   | –        | 1.7 ± 0.04c | 3.1 ± 0.04c | 4.3 ± 0.04c | 5.1 ± 0.04c | 5.7 ± 0.07c |
|            | 3 mM                   | –        | 1.6 ± 0.05c | 3.1 ± 0.05c | 4.3 ± 0.05c | 5.0 ± 0.04c | 5.6 ± 0.06c |
|            | Control                | –        | 2.3 ± 0.04a | 4.0 ± 0.05a | 5.2 ± 0.05a | 6.0 ± 0.06a | 6.5 ± 0.07a |
| B.         |                        | 1 mM     | 67.1 ± 0.77ab | 55.3 ± 0.94c | 46.0 ± 1.46b | 38.3 ± 0.96b | 28.6 ± 0.80c | 12.7 ± 0.73b |
| Firmness (Newton) | 2 mM     | 68.2 ± 0.82a | 58.9 ± 1.12b | 51.8 ± 0.95a | 44.1 ± 1.80b | 33.0 ± 0.71b | 17.4 ± 0.68a |
|            | 3 mM                   | 69.3 ± 0.72a | 61.8 ± 0.91a | 55.0 ± 1.92a | 46.7 ± 1.02a | 35.9 ± 0.83a | 18.6 ± 0.74a |
|            | Control                | 65.3 ± 0.90b | 49.7 ± 0.96d | 40.8 ± 1.65c | 34.0 ± 1.11c | 21.2 ± 0.55d | 10.1 ± 0.56c |
| C.         |                        | 1 mM     | –        | –        | –        | 0.0 ± 0.00b | 2.0 ± 0.18b | 3.4 ± 0.23b |
| Spoilage (%) | 2 mM     | –        | –        | –        | 0.0 ± 0.00b | 0.0 ± 0.00c | 2.9 ± 0.17c |
|            | 3 mM                   | –        | –        | –        | 0.0 ± 0.00b | 0.0 ± 0.00c | 2.6 ± 0.21c |
|            | Control                | –        | –        | –        | 2.1 ± 0.16c | 3.4 ± 0.23a | 4.3 ± 0.19c |

Mean values followed by same superscript within a column are significantly at par (\( p \leq 0.05 \)), \( n = 4 \pm S.E. \)
and the minimum spoilage (2.6%) was observed in 3 mM PUT treatment and maximum (4.3%) in the control. Fruit spoilage is negatively correlated to the firmness (−0.811, $R^2 = 0.657$, Table 2, 3 and Figure 3B) as reduction in firmness led to enhanced fruit spoilage.

**Soluble Solids Contents**

The effect of PUT treatments on SSC in pear fruits during ambient storage is presented in Figure 1A. At the time of storage, the highest SSC was found in the untreated fruits and it continued to remain high up to 6 days of storage. During this period PUT treatments (2 & 3 mM) showed a minimum increment in SSC. With the progression of ambient storage, the SSC continued to increase up to 12 days in these treatments, while it declined in untreated fruits after 6 days of storage. At the end of storage, the higher SSC (13.1%) was retained in 2 and 3 mM PUT treatments, while lowest in control (12.8%).

**Titratable Acidity**

Results demonstrated that TA content in pear fruits reduced along with the ambient storage (Figure 1B). But as compared to control, 3 mM PUT treated fruits had the highest TA content during the whole storage period. The cumulative reduction in TA content of fruits during the storage was recorded to be 62.5% in control fruits compared with only 40.5% & 36.8% reduction in 2 and 3 mM PUT treated fruits, respectively.

**Starch**

During ambient storage, starch content in pear fruits decreased considerably irrespective to the treatments; however, the rate of decline was slower in PUT treated fruits (Figure 1C). Throughout the storage studies, pears treated with 2 & 3 mM PUT retained significantly ($p \leq 0.05$) higher starch content than the control. At the end of studies, 2 & 3 mM PUT treated fruits recorded 54.9% & 60.6% higher starch content, respectively, compared with control. Starch content of the pear fruits was negatively correlated (−0.773, $R^2 = 0.597$) with SSC during storage (Table 2, Figure 3C).

| Table 2. Pearson’s correlation coefficients between various attributes of pear fruits. |
|-----------------|--------|--------|-----|--------|-----------|-----------------|
| WL              | WL     | Firmness | Spoilage | SSC   | Starch   | PME activity | Cellulase activity |
| WL              | 1.000  |         |        |       |          |               |                  |
| Firmness        | −0.937** | 1.000  |       |       |          |               |                  |
| Spoilage        | 0.664** | −0.811** | 1.000 |       |          |               |                  |
| SSC             | 0.720** | −0.570** | 0.156* | 1.000 |          |               |                  |
| Starch          | −0.982** | 0.905** | −0.604** | −0.773** | 1.000 |          |                  |
| PME activity    | 0.409** | −0.240** | −0.159* | 0.717** | −0.483** | 1.000 |                  |
| Cellulase activity | 0.746** | −0.579** | 0.156* | 0.834** | −0.794** | 0.725** | 1.000 |

**Significant at** $p \leq 0.01$, **Significant at** $p \leq 0.05$

| Table 3. Regression relationship between various attributes. |
|-----------------|--------|--------|-----|-----------|
| Combination     | Equation                      | $R^2$ |
| **WL**          | Firmness = −8.01*WL + 71.61  | 0.877 |
| **Spoilage**    | Firmness = −10.22*spoilage + 51.74 | 0.657 |
| **SSC**         | Starch = −3.29*SSC + 45.01   | 0.597 |
| *PME activity   | Firmness = 189.58*PME activity$^2$ − 538.46* PME activity + 420.34 | 0.105 |
| *Cellulase activity | Firmness = 9.96*cellulase activity$^2$ − 54.85* cellulase activity + 110.16 | 0.430 |

**Linear Regression relationship, *Quadratic Regression relationship**
During storage, the PME activity in 'Punjab Beauty' pear fruits was significantly influenced by PUT treatments (Figure 2A). PME activity, reached to maximum (1.5 ml of 0.02 N NaOH used) on the sixth day of storage in control fruits, while 3 mM PUT treated fruits registered the highest activity (1.4 ml of 0.02 N NaOH used) on the 12th day of storage and afterward, it declined in all treatments. At 15 days of storage, the highest PME activity was estimated in the fruits treated with 3 mM PUT and lowest in control. Fruit firmness during storage was inversely related to the cell wall degrading enzyme activity of PME (Figure 3E). It was revealed from the Pearson’s correlation coefficient that there was a significant negative correlation between PME & fruit firmness (−0.240, \( R^2 = 0.058 \)) (Table 2, 3 and Figure 3D). During storage an increase in PME activity led to a reduction in fruit firmness.
Cellulase activity of PUT treated as well as control fruits during storage are summarized in Figure 2B. The cellulase activity increased gradually in 2 & 3 mM PUT treated fruits and showed maximum activity (2.8% reduction in viscosity) on 12th day of storage, while in the control, it increased at a rapid rate up to sixth day of storage. At the end of storage, 2 & 3 mM PUT treated fruits registered 15.9% & 19.0% higher activities than in untreated fruits. The study further suggested that PUT has a direct effect on the cellulase activity of pear, which alters the fruit softening process during storage and maintains the quality. Cellulase activity during storage was inversely related to the fruit firmness (Figure 3F). Pearson’s correlation of coefficient revealed a negative correlation between cellulase and firmness (−0.579, R² = 0.335) (Table 2,3 and Figure 3E).

Discussion
The WL in fruits during storage occurs mainly through transpiration, respiration, and other metabolic processes. After harvest, the exchange of water among the inner and outer atmosphere of fruit tissue and cellular breakdown causes weight loss (Ramezanian et al., 2010). PUT treatments modify the tissue permeability to water through stabilization of cell membrane integrity and helps to stabilize the
firmness of fruits and reduces the WL (Martinez et al., 2002; Serrano et al., 2003). The lesser WL in PUT treated pear fruits during ambient storage indicates the turgidity maintenance and freshness of the fruits. PUT applications are reported to decrease the respiration process in fruit by reducing ethylene production since PUT and ethylene contend for the L-amino cyclopropane-L-carboxylic acid precursor (Apelbaum et al., 1981). A similar reduction in WL by PUT applications was reported in pomegranate (Mirdeghhan et al., 2007) and pear fruits (Hosseini et al., 2017; Singh et al., 2019). During ripening, degradation of the cell wall and pectic-substances lead to a loss in fruit firmness (Reddy et al., 2017). In our studies, PUT treatment maintained higher fruit firmness during storage, which might be due to a reduction in the PME activity and poly-galactouronase activity that reduced the cell wall degradation (Valero et al., 2002). Hence, PUT treated fruits exhibited longer storage life compared with control fruits. A similar maintenance of fruit firmness with PUT application has also been reported in pear (Hosseini et al., 2017; Singh et al., 2019) and mango (Ali et al., 2017).

Exogenous putrescine application in “Hayward” kiwifruit reduced the ethylene production and respiration rate, which maintained the firmness and overall fruit quality attributes (Petkou et al., 2004). As compared to control, PUT treatments were effective to reduce the spoilage of fruits during ambient storage, which signifies the anti-pathogenic properties of PUT in pear fruits. Present results are validated by the findings of Khosroshahi et al., (2007) who reported control of fungal infection in PUT treated strawberry fruits during storage.

In present studies, pear fruits exhibited an increase in SSC particularly during the initial storage period and this might be attributed to the reduction in fruit moisture and conversion of starch, protein, pectin, and hemicelluloses into simple sugars by sucrose phosphate synthase (SPS) enzyme’s activity (Hubbard et al., 1991). However, the rate of SSC increment in PUT treated pear was steady which might be due to a reduction in SPS enzymatic activity and sugar synthesis. At later stages of storage, the reduction in SSC might be due to the increase in metabolic activities which utilize the simple soluble sugars as substrate. While, the higher retention of SSC in PUT-applied fruits might be due to less ethylene production and metabolic activities than in control (Razzaq et al., 2014). A similar delayed rise in SSC during storage in PUT treated peaches was also reported by Torrigiani et al. (2004). Titratable acidity is an important quality parameter that is directly related to the content of dominant

Figure 3. Regression relation between firmness and weight loss (A), firmness and spoilage (B), starch and soluble solids content (C), firmness and pectin methylesterase activity (D) & firmness and cellulase activity (E).
organic acids present in the fruit. Organic acids are utilized as an energy source when metabolism increases for respiration and other enzymatic reactions in the fruit ripening phase (Aguayo et al., 2006). Results showed that PUT treatments reduced the TA loss in pear fruits during ambient storage. A comparable maintenance of higher TA in PUT treated fruits over control were also reported in nectarine (Torrigiani et al., 2004) and mango (Razzaq et al., 2014).

There was considerable decrease in starch content in pear fruits during the ambient storage. The reduction in starch content during fruit storage can be explained by breakdown and conversion of starch into free sugars by rapid activation of various enzymes, such as amylase, glycosidase, invertase, phosphorylase, and sucrose synthase (Adao and Gloria, 2005). The starch hydrolysis along with other polysaccharides into soluble sugars and loss of water, also led to an increase in the SSC in the loquat fruits (Akhtar et al., 2010). Similarly, Malik and Singh (2006) postulated that the reduced respiration rate in polyamine treated mango slowed down the breakdown process of starch into sugars.

Pear fruits treated with PUT exhibited the reduction in the cell wall degrading enzymes activity during the ambient storage. During storage, poly-galacturonase catalyzed the PME activity and accelerated the pectin depolymerization through degradation of pectin and led to fruit softening (Roe and Bruemmer, 1981). Polyamines are positively charged aliphatic amines that strengthen the cell walls by cross-linking to the carboxyl (COO⁻) group, which reduced the PME and poly-galactronase enzymatic activity during storage that delayed the cell wall softening (Valero et al., 2002). Similar to our findings, polyamines have been reported to reduce the rate of fruit softening in pear (Hosseini et al., 2017; Singh et al., 2019) and peach (Torrigiani et al., 2012) by down regulation of fruit softening enzymes, such as PG and PME. Polyamine application affects the fruit firmness during storage due to ripening related cellulase enzyme regulated by ethylene (Koehler et al., 1996). A similar reduction in cellulase activity of pear fruits after postharvest dip treatment of PUT was also observed by Singh et al. (2019). The present findings exhibited that 2 & 3 mM PUT treated fruits had lowest enzymatic activity and maintained higher firmness compared with other treatments during the entire storage period (Figure 2A & 2B).

**Conclusion**

Preharvest putrescine applications of 2 and 3 mM can effectively maintain the firmness of pear fruits over control by lowering cell wall degrading enzymatic activities of PME & cellulase during the ambient storage. Furthermore, these treatments also retained the fruit quality by reducing weight loss, spoilage and preserving the SSC, TA and starch content. Therefore, preharvest putrescine application was proved to be an effective measure to retain quality and extend the shelf life of pear fruits under ambient conditions.

**Acknowledgments**

The authors are highly delighted to acknowledge Punjab Agricultural University, Ludhiana, Punjab, India for the necessary research conveniences.

**Disclosure Statement**

No potential conflict of interest was reported by the author(s).

**References**

Adao, R.C., and M.B.A. Gloria. 2005. Bioactive amines and carbohydrates changes during ripening of 'Prata' banana (Musa acuminata × Musa balbisiana). Food Chem 90(4):705–711. doi: 10.1016/j.foodchem.2004.05.020.

Aguayo, E., R. Jansasithorn, and A.A. Kader. 2006. Combined effects of 1-methylcyclopropene, calcium chloride dip, and/or atmospheric modification on quality changes in fresh-cut strawberries. Postharvest Biol. Technol. 40 (3):269–278. doi: 10.1016/j.postharvbio.2006.01.016.
Akhtar, A., N.A. Abbasi, and A. Hussain. 2010. Effect of calcium chloride treatments on quality characteristics of loquat fruits during storage. Pakistan J. Botany 42:181–188.

Ali, M.S., M.A. Elhamahmy, and A.F. El-Shiekh. 2017. Mango trees productivity and quality as affected by Boron and Putrescine. Scientia Hortic. 216:248–255. doi: 10.1016/j.scienta.2017.01.026.

AOAC. 1990. Official and Tentative Methods of Analysis, Association of Official Agric Chemists, 15th Washington, DC, USA: The Journal of American Medical Association. doi: 10.1001/jama.1941.02820120149044

Apelbaum, A., A.C. Burgoon, J.D. Andrew, M. Liberman, R. Ben-Arie, and A.K. Matto. 1981. Polyamines inhibit biosynthesis of ethylene in higher plant tissue and fruit protoplast. Plant Physiol. 68(2):453–456. doi: 10.1104/pp.68.2.453.

Colaric, M., F. Stampar, and M. Hudina. 2007. Content levels of various fruit metabolites in the ‘Conference’ pear response to branch bending. Scientia Hortic. 113:261–266. doi: 10.1016/j.scienta.2007.03.016.

Hosseini, M.S., Z. Fakhar, M. Babalar, and M.A. Askari. 2017. Effect of pre-harvest putrescine treatment on quality and postharvest life of pear cv. Spadana. Adv. In Hortic. Sci. 31:11–17. doi: 10.13128/ahs-20720.

Hubbard, N.L., D.M. Pharr, and S.C. Huber. 1991. Sucrose phosphate synthase and other sucrose metabolizing enzymes in fruits of various species. Physiol. Plant. 82(2):191–196. doi: 10.1111/j.1399-3054.1991.tb00800.x.

Khan, A.S., and S. Ali. 2018. Chapter 9 – Pre-harvest sprays affecting shelf life and storage potential of fruits. Preharvest Modulation of Postharvest Fruit and Vegetable Quality. 209–255. http://dx.doi.org/10.1016/B978-0-12-809807-3.00009-3.

Khosroshahi, M.R.Z., M. Esna-Ashari, and A. Ershadi. 2007. Effect of exogenous putrescine on postharvest life of strawberry (Fragaria ananassa Duch.) fruit cultivar Selva. Sci. Hortic. 114:27–32. doi: 10.1016/j.scienta.2007.05.006.

Koehler, S.M., G.L. Matters, P. Nath, E.C. Kemmerer, and M.L. Tucker. 1996. The gene promoter for a bean abscission cellulase is ethylene-induced in transgenic tomato and shows high sequence conservation with a soybean abscission cellulase. Plant Mol. Biol. 31(3):595–606. doi: 10.1007/BF00042232.

Mahadevan, A., and R. Sridhar. 1982. Methods on physiological plant pathology. Sivagami Pub. Madras.

Malik, A.U., and Z. Singh. 2006. Improved fruit retention, yield and fruit quality in Mango with exogenous application of polyamines. Scientia Hortic 110(2):167–174. doi: 10.1016/j.scienta.2006.06.028.

Martínez, R.D., M. Serrano, A. Carbonell, O.L. Burgos, F. Riquelme, and D. Valero. 2002. Effect of post-harvest putrescine treatment on extending shelf life and reducing mechanical damage in apricot. J. Sci. Food Agric. 67:1706–1712. doi: 10.1016/j.scienta.2006.06.028.

Mirdeghani, S.H., M. Rahemi, S. Castillo, R.D. Martínez, M. Serrano, and D. Valero. 2007. Pre-storage application of polyamines by pressure or immersion improves shelf-life of pomegranate stored at chilling temperature by increasing endogenous polyamine levels. Postharvest Biol. Technol. 44(1):26–33. doi: 10.1016/j.postharvbio.2006.11.010.

Nath, A., C.D. Bidyut, A. Singh, R.K. Patel, D. Paul, L.K. Misra, and H. Ojha. 2012. Extension of shelf life of pear fruits using different packaging materials. J. Food Sci. Technol 49(5):556–563. doi: 10.1007/s13197-011-0305-4.

Petkou, I.T., T.S. Pritsa, and E.M. Sfakiotakis. 2004. Effects of polyamines on ethylene production, respiration and ripening of kiwifruit. J. Hortic. Sci 79:977–980. doi: 10.1080/14620316.2004.11511876.

Ramezanian, A., M. Rahemi, M. Maftoun, K. Bahman, S. Esghighi, M.R. Safizadeh, and V. Tavallali. 2010. The ameliorative effects of spermidine and calcium chloride on chilling injury in pomegranate fruits after long-term storage. Fruits 65(3):169–178. doi: 10.1051/fruits/2010011.

Ranganna, S. 2007. Handbook of analysis and quality control of fruit and vegetable products. Tata McGraw Hill Publishing Co Ltd, New Delhi, 13.

Razzaq, K., A.S. Khan, A.U. Malik, M. Shahid, and S. Ullah. 2014. Role of putrescine in regulating fruit softening and antioxidative enzyme systems in “Samar Bahisht Chaunsia” Mango. Postharvest Biol. Technol. 96:23–32. doi: 10.1016/j.postharvbio.2014.05.003.

Reddy, S.V.R., R.R. Sharma, and S. Barthakur. 2017. Influence of 1-MCP on texture, related enzymes, quality and their relative gene expression in ‘Amrapali’ Mango (Mangifera indica L.) fruits. J. Food Sci. Technol 54(12):4051–4059. doi: 10.1007/s13197-017-2874-2883.

Roe, B., and J.H. Bruemmer. 1981. Changes in pectin substances and enzyme during ripening and storage of ‘Keitt’ mango. J. Food Sci 54(1):186–189. doi: 10.1111/j.1365-2621.1981.tb4560.x.

Serrano, M., D. Martinez-Romero, F. Guilled, and D. Valero. 2003. Effects of exogenous putrescine on improving shelf life of four plum cultivars. Postharvarst Biol. Technol. 30(3):259–271. doi: 10.1016/S0925-5214(03)00113-3.

Singh, V., S.K. Jawandha, P.P.S. Gill, and M.S. Gill. 2019. Suppression of fruit softening and extension of shelf life of pear by putrescine application. Sci. Hortic. 256:108623. doi: 10.1016/j.scienta.2019.108623.

Stevens, F.J., and R.A.G. Chapman. 1955. The determination of starch in meat production with the anthrone reagent. J. AOAC. Inter 32(2):202–210. doi: 10.1093/jaoca/38.2.202.

Torrigiani, P., A.M. Bregoli, V. Ziosi, S. Scaramagli, T. Ciriaci, A. Rasori, S. Biondi, and G. Costa. 2004. Pre-harvest polyamine and aminooxyxyvinylglycine (AVG) applications modulate fruit ripening in stark red gold nectarines (Prunus persica L. Batsch). Postharvest Biol. Technol 33(3):293–308. doi: 10.1016/j.postharvbio.2004.03.008.
Torrigiani, P., D. Bressanin, R.K. Beatriz, A. Tadiello, L. Trainotti, C. Bonghi, V. Ziosi, and G. Costa. 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. Physiolgia Plantarum 146(1):86–98. doi: 10.1111/j.1399-3054.2012.01612.x.

Valero, D., D. Martinez-Romero, and M. Serrano. 2002. The role of polyamines in the improvement of the shelf life of fruit. Trends. Food Sci. Technol 13(6–7):228–234. doi: 10.1016/S0924-2244(02)00134-6.

Wills, R.B.H., W.B. Mc Glasson, D. Graham, and D.C. Joyce. 2007. Postharvest—an introduction to the physiology and handling of fruit, vegetables and ornamentals, CAB International, Nosworthy Way, Wallingford, Oxfordshire, OX10 8DE, UK. pp. 227.