Journal of Postharvest Technology
2023, **11**(2): 45-55
www.jpht.in

RESEARCH ARTICLE

Elite plant metabolites extend the shelf life and quality of banana at room temperature

G. Divyabharathi, K. Rama Krishna*, M. Chithra

Department of Horticulture, School of Life Sciences, Central University of Tamil Nadu, Tiruvarur -610005, TN, India

Received: 03.03.2023 Accepted: 24.04.2023

ABSTRACT

India is the world's largest producer of banana. Even though it has limited export because of its short shelf life and chemical residues. This has led to search of alternate ways, which do not leave any chemical residues harming human health as well as prolong the shelf life of banana. Polyamine-elite plant metabolites, have been attempted to increase the shelf life of fruits. But minuscule research findings on banana shelf life extension are reported. A study was conducted to investigate the efficiency of exogeneous application of polyamines on banana cv. 'Karpooravalli' (ABB). Banana fruit are treated with different concentrations of (10, 20, 30mg), putrescine, spermidine, spermine and stored at ambient conditions (32±1°C and 65±3% RH). The result showed that 20mg putrescine was more efficient than other treatments. Putrescine (20mg) application lowers the physiological loss of weight (10.79%), lowers ripening rate (1.39%), maintain a lower level TSS (16.5°B), reduced spoilage with higher consumer acceptance and extend the shelf life for seven days. Spermidine 20mg was found as the second-best treatment which showed 6 days of extension of shelf life. Untreated fruit exhibits higher physiological weight loss, TSS, spoilage, ripening rate with a shelf life of only 4 days. Finally, the results proven that polyamine application lowers loss of weight and delay the ripening rate thereby increasing shelf life.

Keywords: Putrescine, spermidine, spermine, organoleptic, room temperature, postharvest

Citation: Divyabharathi, G., Krishna, K. R., Chithra, M. 2023. Elite plant metabolites extend the shelf life and quality of banana at room temperature. *Journal of Postharvest Technology*, **11** (2): 45-55.

INTRODUCTION

Banana (Musa spp.) is a very popular and important tropical fruit, especially in commercial trade, due to its nutrient content and availability in all seasons. It is native to tropical areas of the world and accounts for 18% of the total fruit production of the world (FAO, 2021). In India, it occupies an area of 0.88 Mha with an annual production of 31.78 MT and which makes banana first place in production among the tropical fruit crops (Department of Agriculture, Cooperation & Farmers Welfare, 2020). But India's contribution to the global trade is insignificant and only 0.21 MT of the banana produced were exported (FAO, 2020). Among the banana producing states, Andhra Pradesh (16.27% share), occupies the first position, followed by Gujarat, Maharashtra and Tamil Nadu (NHB, 2018). It is the cheapest among the fruits grown and also highly perishable one. The Postharvest loss in banana is estimated to be more than 6.60% (Jha et al., 2015). The shelf life of ripened banana is for only 2-3 days under normal environmental conditions. The problem in export is rapid ripening which leads to short shelf life. During fruit ripening, starch is

* *For correspondence*: K. R. Krishna (Email: ramakrishna.karri001@gmail.com)

ISSN: 2348-4330

converted to sugars, peel colour changes, and flavour develop by losing its astringency (Pathak et al., 2003). These physiological changes limit handling and transportation. The ripening can be delayed using special chemicals and storage at low temperatures. Sometimes, storage at temperatures below the recommended results in chilling injury, whereas the use of chemicals leads to several health hazards (Facundo et al., 2015; Jiang et al., 2004). So, there is a need for bio-based molecules. Fruit quality deterioration is linked to a decrease in polyamine concentration in ripening fruits and increased ethylene production. (Lee et al., 1997). Research evidence showed that exogenous application of polyamine delays the ripening process.

Polyamines are low-molecular-weight biological molecule having aliphatic nitrogen groups found in plants, animals, and microbes. Polyamines are naturally occurring chemical that aids in the development process and stops ethylene biosynthesis enzyme activities. They exert a competition during its synthesis for a common precursor S-adenosyl methionine (Nabeesam et al., 2008). The major polyamines found in every plant cell are spermidine (N-3-aminopropyl-1, 4 diaminobutane), spermine (N-3-aminopropyl)-1, 4-diaminobutane] and putrescine (1, 4-diaminobutane). Polyamines operate as anti-senescent agents, slowing respiration, delaying ethylene synthesis, preserving fruit firmness, increasing mechanical resistance, and lowering chilling injury symptoms. (Valero et al., 2002). The effect of polyamines on shelf life of banana cv. 'Karpooravalli' for the domestic market and its influence on quality are lacking. Therefore, the present study is envisaged to investigate the effects of postharvest treatment with polyamines such as putrescine, spermine and spermidine on maintaining quality and extending the postharvest life of banana cv. 'Karpooravalli'.

MATERIALS AND METHODS

Harvesting and pre-treatment

Banana cv. 'Karpooravalli'(ABB) fruits at optimum maturity (disappearance of angles and shedding of floral remnants) were harvested from the farm nearby fields of Thiruvarur, Tamil Nadu region. The harvesting was done manually in the morning hours (6 to 7 am). Maturity was decided based on the characteristics of the. The fruits were collected and transported to the laboratory (Department of Horticulture, CUTN, Thiruvarur). Fruits of uniform size, shape and maturity were selected for experimental work, scratch and decayed fruits were manually removed to maintain uniformity. Further fruits were washed in clean water for the purpose of removing dirt and air-dried under the fan and these fruits were used for further experimental work. Polyamines were procured from HiMedia® Laboratories, private limited and three different concentrations of putrescine, spermidine and spermine were prepared.

Preparation of putrescine, spermidine and spermine treatments

10 mg of putrescine, spermidine and spermine were weighed and dissolved in distilled water and made to a volume of one litre, each. Similarly, 20 and 30 mg putrescine, spermidine and spermine was dissolved in distilled water and made to a volume of one litre.

Treatment and storage

Fruits of each replication were dipped in polyamines solutions for 5 minutes each. Then the treated fruits along with one set of control were stored at ambient room temperature (32±1°C and 65 ± 3 % RH). Whereas T0 (Untreated fruits), T1, T2, T3 (10 mg, 20 mg, 30 mg putrescine, respectively), T4, T5, T6 (10 mg, 20 mg. 30, mg spermidine, respectively), T7, T8, T9 (10 mg, 20 mg, 30 mg spermine, respectively) were treatments given. Physicochemical and physiological parameters were recorded at regular intervals from the day of treatment until the end of the shelf life of the fruit.

Physiological loss in weight (%)

To determine the physiological loss of weight, the banana hands in each treatment were weighed at the beginning of storage, and recorded as initial weight. Then, weights were measured on a daily basis during storage, and the cumulative loss in weight of fruits was calculated and expressed as percent physiological loss in weight. The commercial PLW % breakpoint was considered as 10%, after which it is assumed that the fruits have no commercial value.

Total soluble solids (°Brix)

The juice was extracted by squeezing the homogenized pulp of the banana using a muslin cloth to measure total soluble solids. Total soluble solids were determined by using a hand refractometer (ATC Model, Japan) and expressed as °Brix.

Ripening rate

The colour of the peel is used as an indicator of ripening. Each stage of ripening (visually) was given a score (Unripe (UR)=1, Quarter ripe (QR)=2, Semi ripe (SR)=3, ¾ ripe (3/4R)=4, Full Red (FR)=5) and the ripening co-efficient was calculated using the formulae below:

$$\text{Co-efficient of ripening} = \frac{\sum \text{(No. of fruits at a particular ripening stage x its score)}}{\text{Total number of fruits}}$$

Sensory evaluation

The sensory evaluation of the banana fruit was carried out by semi-trained and trained panellists. The sensory characteristics like skin colour, appearance, aroma, firmness and overall acceptability of flesh were evaluated on a 9 point Hedonic scale (1 = extremely dislike and 9 = extremely like) (Stone et al., 2012).

Spoilage (%)

Observations are recorded periodically where spoiled fruits were counted and the total number of the spoiled fruits was determined by adding all diseased/decayed fruits from successive storage intervals. The spoilage percent was determined by dividing the number of spoiled fruits by the total number of fruits initially stored and multiplying the result by 100.

Shelf life

The shelf life of the fruits was estimated by the days taken for the fruits to be kept under storage till the edible last stage. The mean was recorded and expressed as days. The readings of shelf life were recorded until 50 percent of the fruits were edible.

Statistical analysis

The experiment consisted of 10 treatments stored at ambient conditions. The fruits were replicated thrice, and each replication had 10 fruits. The observations were recorded at regular intervals. Statistical analysis of data was carried out using SPSS statistics 17.0 software package (SPSS Inc. US). Differences between means were evaluated using Duncan's multiple range test at $p \leq 0.05$. Analysis of variance (ANOVA) was used to determine the significance of differences among the treatments.

RESULTS AND DISCUSSION

Physiological loss in weight (PLW %)

The physiological loss in weight (PLW) on the seventh day of storage at ambient condition, banana fruits treated with putrescine 20 mg (T2) (10.79%) exhibited a lower physiological loss percentage followed by fruits treated with spermidine 20 mg (T5) (12.64%). But the control lost its commercial weight (breakpoint 10%) on the fourth day. The exogenous application of polyamine decreased weight loss in comparison to control. The metabolic process such as transpiration and respiration are the two major issues for weight loss during postharvest storage of the fruits. The cellular breakdown and the stomata on the peel of the banana hasten the transpiration process. The consolidation and maintenance of both cell integrity and tissue permeability is the cause of the minimal weight loss in putrescine and spermidine-treated fruits. Polyamines form a bond with cell membranes and help to keep wax in the cuticle layer (Mirdehghan et al., 2007) which would have played a major role in the controlled exchange of water through the skin. Furthermore, reduced respiration rates in polyamine treated fruits may contribute to a slower weight loss rate (Valero et al., 1998). These results are in agreement with the findings of in mango cv. 'Langra' (Jawandha et al., 2012), in pomegranate cv. 'Mridula' (Barman et al., 2011), in strawberry (Khosroshahi et al., 2007), and plum fruit (Serrano et al., 2003).

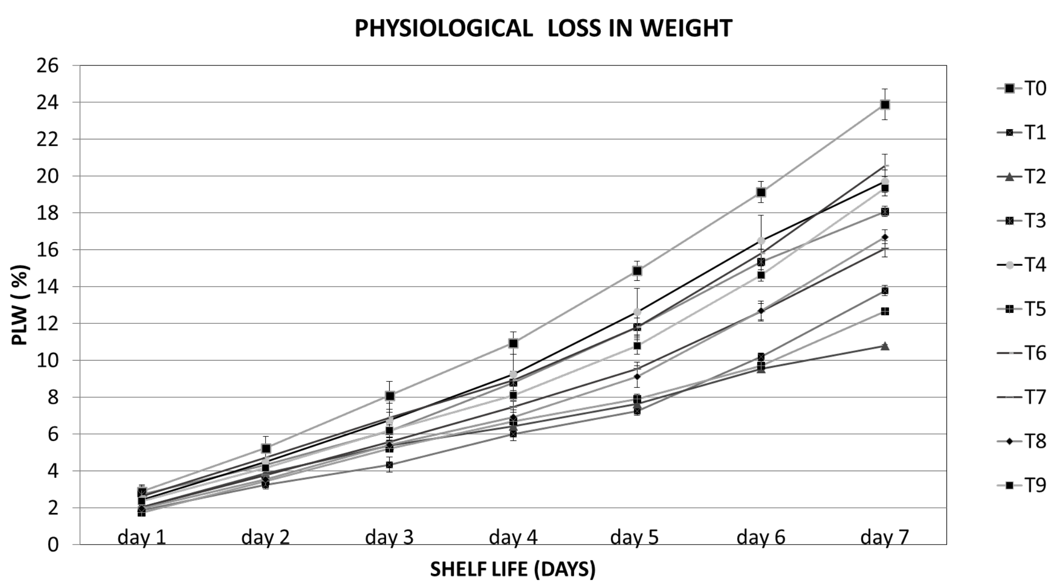

Fig. 1: Physiological loss in weight of the banana fruits treated with different polyamines. The error bar on the treatment legends indicates standard deviation (p ≤ 0.05) according to Duncan's multiple range test.

Total soluble solids (°Brix)

The total soluble solids increased during their storage period. At sixth day of storage at ambient conditions, the highest TSS was shown by control (11.08°B) and spermine 30mg treated fruits (T9) (10.63°B) whereas the lowest TSS was observed in putrescine 20mg (T2) (8.05°B) treated fruits. Similarly, on eight-day, maximum TSS was more pronounced in control (26.5°B) and minimum TSS was observed in putrescine 20mg (T2) (16.5°B) and spermidine 20mg (T5) (17.86°B) treated fruits (Table 1). This could be owing to the retarded ripening process and slow metabolic transformation of soluble components, as well as other factors like slow conversion of starch resulting in the slow build-up of sugars (Seymour et al., 1993). In control (T0), there was an increased conversion of polysaccharides into simple sugars, resulting in increased TSS (Marriot and Palmer, 1980). In this investigation, polyamine treated fruit showed low TSS. The delayed variations in TSS in polyamine treated fruits could be due to a slower conversion of starch to sugar, a delay in ethylene production, and as a result a slower ripening process. These results are supported with the findings in grapes cv. 'Flames seedless' (Champa et al., 2014), mango cv. 'Langra' (Jawandha et al., 2012), pomegranate (Mirdehghan et al., 2007).

Table.1: Effect of polyamine coatings on TSS (°B) content of banana at room temperature

Treatments	At harvest	Days after harvest			
		2	4	6	8
Control (T0)	3.4	5.05^{c} ± 0.05	8.05^{f} ± 0.06	11.08^{g} ± 0.07	26.50^{g} ± 0.50
Putrescine 10 mg (T1)	3.4	4.05^{a} ± 0.05	6.05^{c} ± 0.05	9.40^{c} ± 0.10	20.50^{c} ± 0.50
Putrescine 20 mg (T2)	3.4	4.15^{ab} ± 0.13	5.51^{a} ± 0.07	8.05^{a} ± 0.05	16.50^{a} ± 0.50
Putrescine 30mg (T3)	3.4	4.28^{b} ± 0.07	5.85^{b} ± 0.05	8.55^{b} ± 0.05	18.50^{b} ± 0.50
Spermidine 10 mg (T4)	3.4	4.15^{ab} ± 0.15	6.56^{d} ± 0.05	10.25^{e} ± 0.25	22.50^{d} ± 0.50
Spermidine 20 mg (T5)	3.4	4.11^{ab} ± 0.10	6.13^{c} ± 0.04	9.56^{c} ± 0.05	17.86^{b} ± 0.23
Spermidine 30 mg (T6)	3.4	4.06^{a} ± 0.05	6.82^{e} ± 0.02	9.83^{d} ± 0.03	23.50^{e} ± 0.50
Spermine 10mg (T7)	3.4	4.15^{ab} ± 0.13	6.75^{e} ± 0.05	10.18^{e} ± 0.17	24.76^{f} ± 0.25
Spermine 20mg (T8)	3.4	4.03^{a} ± 0.05	6.55^{d} ± 0.86	10.24^{e} ± 0.06	24.96^{f} ± 0.83
Spermine 30mg (T9)	3.4	4.10^{ab} ± 0.10	6.64^{d} ± 0.04	10.63^{f} ± 0.04	25.33^{f} ± 0.57

Means followed by the same letter along the column are not significantly different (p ≤ 0.05) according to Duncan's Multiple Comparison test.

Ripening rate

The ripening rate of banana fruits was expressed as co-efficient of ripening with a score of 1 to 5, where 1 indicates mature green stage and 5 indicates full ripe stage. The ripening rate of the banana fruits stored at ambient temperature increased from the day of harvest till the end of their shelf life, irrespective of the pre-treatment given (Figure 2). On the seventh day of storage at ambient condition, the co-efficient of ripening rate is lower in T2 (2.09%) and T5 (2.07%) treated fruits, while in control (4.83%) and other treatments the co-efficient of ripening rate was high (Figure 2). Ethylene plays an important role in the senescence process, which is characterised by a general deterioration of cellular structures, the cessation of photosynthesis, and extensive loss of chlorophyll and proteins (Pandey et al., 2000). Since the biosynthesis of ethylene and polyamine share the same precursor S- adenosyl methionine and are known to have opposing effects on fruit ripening. The putrescine and spermidine have been proved to exert opposite effects with concern to ripening (Valero et al,. 2002). The effect of polyamines on delayed ripening is reported on climacteric fruits like Banana and papaya (Barbang et al., 2000); mango (Malik et al., 2006); kiwifruit (Jammel and Ram, 2012) and in apricot (Davarynejad et al., 2013).

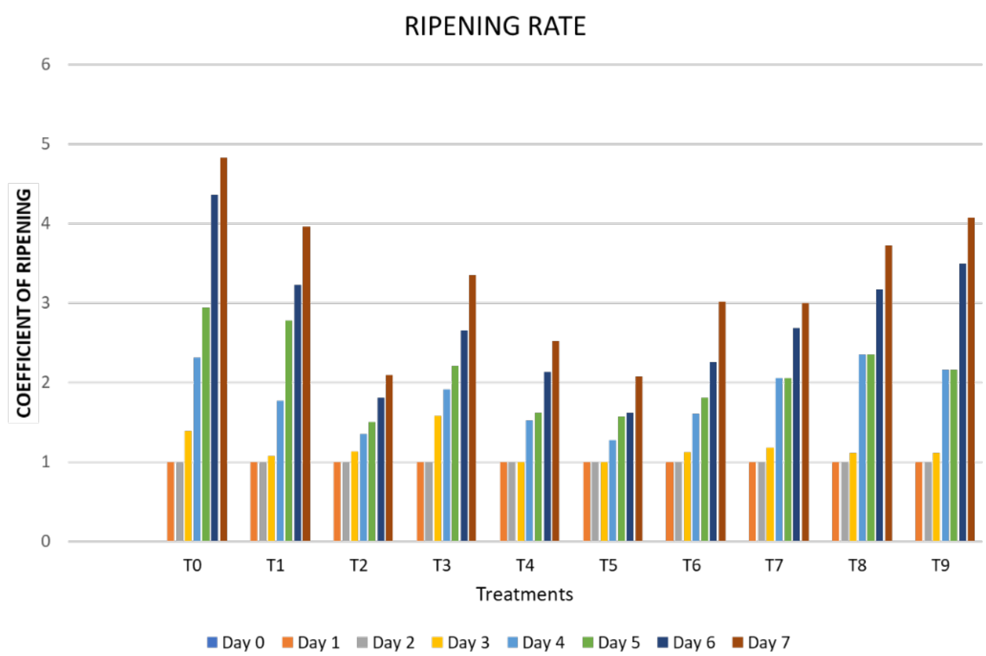

Fig. 2: Ripening rate of the banana fruits treated with polyamines stored at ambient conditions.

Sensory evaluation

The sensory evaluation results of treated and untreated fruits are presented in (Figure 3). T2, T5 treated fruits attained maximum overall acceptance score by the panellists in all parameters followed by T4 treatment. Whereas, untreated fruits have shown the least score at the end of the storage period. In several banana cultivars, colour variations throughout ripening have been utilized as a rough indicator of the stage of maturity (Thompson, 1996). The maximum score for skin colour was recorded in T2 and T4 treated fruits. The control had lower values for firmness. Due to the poor texture of the fruit during ripening, it has poor quality and is more susceptible to mechanical damage during handling and transportation. Exogenous polyamine application resulted in decreased ethylene and respiration rates, which slowed the ripening and senescence process, resulting in improved organoleptic quality, particularly in terms of flavour, firmness, and colour. Because of the delayed ripening, the aroma and the appearance of putrescine and spermidine treated fruits is preserved, whereas it is diminished in untreated fruits.. Similar results have been found in grapes (Champa et al., 2014); mango (Jawandha et al., 2012) where higher sensory scores are obtained by treating with polyamines.

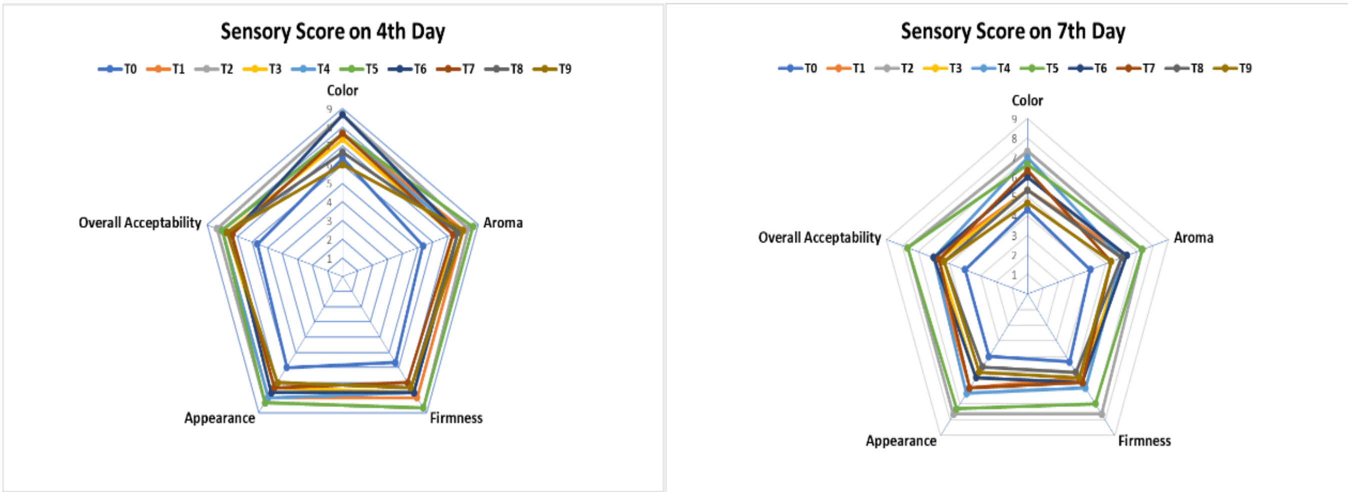

Fig. 3: Sensory evaluation scores of the banana fruits treated with polyamines on 4th day and 7th day of storage at ambient temperature.

Spoilage %

On 7th day of storage, the majority of fruits of T0 (75%) got spoiled followed by T1 (57.14%). The spoilage percentage observed in T5 (7.69%) and T2 (9.09) is very low compared to other treatments like T1 (57.14), T8 (36.36), T3 (33.33) (Figure 4). Exogeneous application of polyamine lowers ethylene production and respiration rate there by more cell wall integrity, reduced ripening which might have resulted in less spoilage. Exogenous Application of putrescine improved the storability and quality of the fruit (Archana and Suresh, 2019). Polyamines have been used as an anti-senescent agent and also induces mechanical resistance and reduce spoilage (Valero et al., 1998).

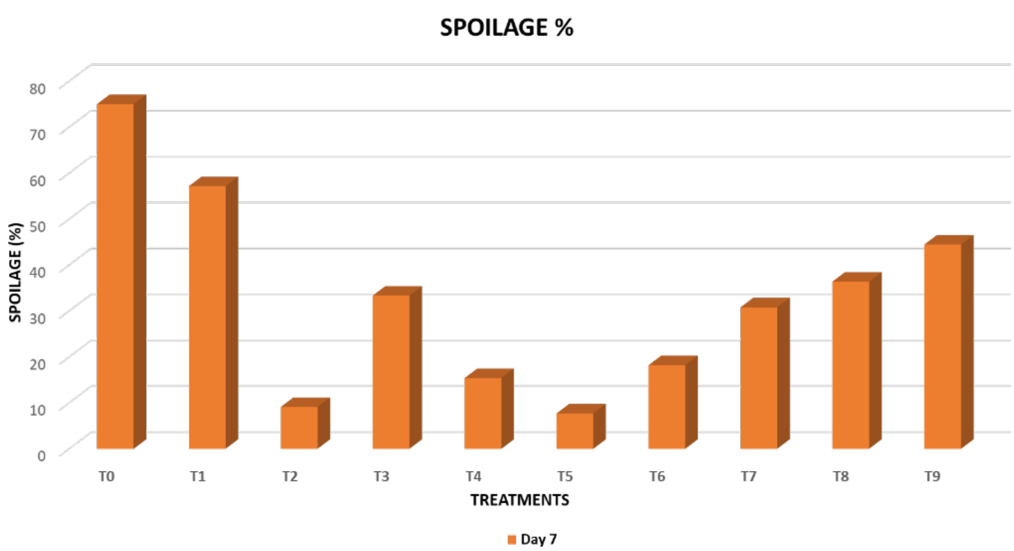

Fig. 4: Spoilage percentage of the banana fruits treated with polyamines as edible coatings on 7th day of storage

Shelf life

On the basis of physiological loss of weight value, 10% is considered as the breakpoint. Results concluded that the T2 treatment had a shelf life of up to seven days. Treatments like T5 and T1 had a shelf life up to six days, T7 and T8 had 5 days of shelf life, whereas, T9, T4, T6 and control had 4 days of shelf life (Figure 5). Bananas with the longest shelf life are those that have been allowed to ripen slowly. Fruit ripening is linked to the same enzymatic processes that induce fruit softening. Ethylene is a hormone that promotes senesce and ripening. The slowdown of ethylene production by exogeneous application of polyamines in fruits increase their shelf life because ethylene and polyamines have the common precursor, S- adenosyl methionine (SAM) and competition for utilization by polyamines prevented ethylene biosynthesis (Pandey et al., 2000). These findings are proved in fruits such as pomegranate (Mirdehghan et al., 2007) and mango (Jawanda et al., 2012).

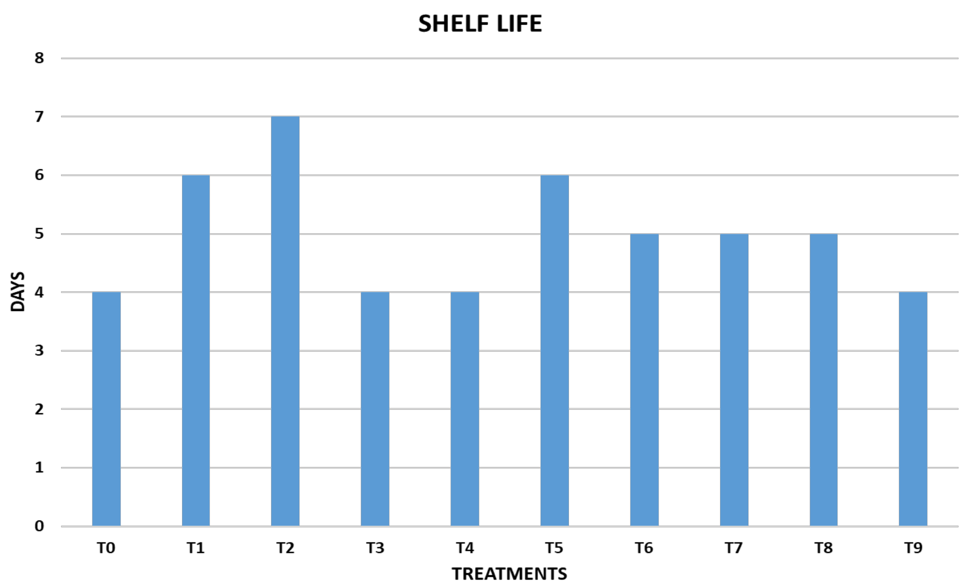

Fig. 5: Shelf life of the banana fruits treated with polyamines stored at ambient condition.

The lower doses of polyamines such as putrescine and spermidine have retained higher quality and longer shelf life than control. However, the higher concentration of polyamines had no/deleterious effect on the quality of fruit. Similar type of observation was recorded when higher concentrations of polyamines were used in fruits such as kiwi (Petkov et al., 2004), grapes (Champa et al., 2014), peach (Martinez-Romero et al., 2000), plum (Serrano et al., 2003), pomegranate (Mirdehghnan et al., 2007) which are in accordance to the results obtained. Even though the reasons behind the negative effects of polyamines at higher concentration remains elusive, these may be postulated to the results of Bregoli et al., (2002) where results reveled early ethylene emission in peach when a higher concentration of polyamines used. This might be interpreted to the stress response due to high amine concentration, as the polyamines are also involved in stress regulation mechanisms (Liv et al., 2015; Gill and Tuteia, 2010). These may have in turn, triggered the ethylene autocatalyzing process. Similar results of high ethylene emission were observed in kiwi fruit when high concentrations of polyamines were used (Petkov, 2004).

CONCLUSION

Polyamines are naturally occurring chemical that aids in the development process and stops ethylene biosynthesis enzyme activities. Polyamines, being environment-friendly organic compounds will promote sustainability by mitigating post-harvest losses. The outcome from our results showed that fruits treated with putrescine 20mg and spermidine 20mg had a positive effect on fruits. Putrescine 20 mg treated fruits lower physiological loss in weight, maintained TSS, lower ripening rate, more shelf life and also had scored maximum value in an organoleptic evaluation followed by spermidine 20mg treated fruits. Postharvest application of polyamines could be a simple and effective technique to control postharvest loss with improvement in shelf life and quality of banana.

REFERENCES

Archana, T. J., and Suresh, G. J. 2019. Putrescine and spermine affects the postharvest storage potential of banana cv. Grand Naine. International Journal Current Microbiology and Applied Sciences, 8 (1): 3127-3137.

Barbang, B. S., Susanto, S., and Novita, T. 2000, November. Studies on the physiology of polyamines and ethylene during ripening of banana and papaya fruits. In International Symposium on Tropical and Subtropical Fruits, 575 (pp. 651-657).

Barman, K., Asrey, R., and Pal, R. K. 2011. Putrescine and carnauba wax pretreatments alleviate chilling injury, enhance shelf life and preserve pomegranate fruit quality during cold storage. Scientia Horticulturae, 130 (4):795-800.

Bregoli, A. M., Scaramagli, S., Costa, G., Sabatini, E., Ziosi, V., Biondi, S., and Torrigiani, P. 2002. Peach (Prunus persica) fruit ripening: amino ethoxy vinylglycine (AVG) and exogenous polyamines affect ethylene emission and flesh firmness. Physiologia Plantarum, 114(3):472-481.

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 Biology and Technology, 91:57-63.

Davarynejad, G., zarei, M., Ardakani, E., & nasrabadi, M. E. 2013. Influence of putrescine application on storability, postharvest quality and antioxidant activity of two Iranian apricot (Prunus armeniaca L.) cultivars. Notulae Scientia Biologicae, 5(2):212-219.

Department of Agriculture, Cooperation & Farmers Welfare. 2020. Pocket book of agricultural statistics 2020. https://eands.dacnet.nic.in/PDF/Pocket%202020-%20Final%20web%20file.pdf

Facundo, H. V. D. V., Gurak, P. D., Mercadante, A. Z., Lajolo, F. M., and Cordenunsi, B. R. 2015. Storage at low temperature differentially affects the colour and carotenoid composition of two cultivars of banana. Food Chemistry, 170:102-109.

FAO. 2021. World Food and Agriculture - Statistical Yearbook 2021. Rome. https://www.fao.org/3/cb4477en/cb4477en.pdf

FAO. 2020. Banana market review, Preliminary results 2020. https://www.fao.org/3/cb5150en/cb5150en.pdf

Gill, S. S., and Tuteja, N. 2010. Polyamines and abiotic stress tolerance in plants. Plant signaling and behavior, 5(1), 26-33.

Jameel, J. and Ram, R.S., 2012. Effect of postharvest treatments with polyamines on physiological and biochemical attributes of kiwifruit (Actinidia deliciosa) cv. Allison. Fruits, 67:13-22.

Jawandha, S. K., Gill, M. S., Gill, P. P, and Singh, N., 2012. Effect of postharvest of putrescine on storage of mango cv. Langra. African Journal of Agriiculture Research., 7 (48): 6432-6436.

Jha, S. N., Vishwakarma, R. K., Ahmad, T., Rai, A. and Dixit, A. K. (2015). Report on assessment of quantitative harvest and post-harvest losses of major crops and commodities in India. ICAR-All India Coordinated Research Project on Post-Harvest Technology, ICAR-CIPHET, P.O-PAU-Ludhiana- 141004.

Jiang, Y. M., Joyce, D. C., Jiang, W. B., and Lu, W. J. 2004. Effects of chilling temperatures on ethylene binding by banana fruit. Plant Growth Regulation, 43: 109-115.

Khosroshahi, M. R. Z., Esna-Ashari, M., and Ershadi, A. 2007. Effect of exogenous putrescine on post-harvest life of strawberry (Fragaria ananassa Duch.) fruit, cultivar Selva. Scientia Horticulturae, 114 (1):27-32.

Lee, M. M., Lee, S. H., and Park, K. Y. 1997. Effects of spermine on ethylene biosynthesis in cut carnation (Dianthus caryophyllus L) flowers during senescence. Journal of plant physiology, 151 (1):68-73.

Liu, J. H., Wang, W., Wu, H., Gong, X., and Moriguchi, T. 2015. Polyamines function in stress tolerance: from synthesis to regulation. Frontiers in Plant Science, 6, 827.

Malik, A. U., and Singh, Z. 2006. Improved fruit retention, yield and fruit quality in mango with exogenous application of polyamines. Scientia Horticulturae, 110 (2): 167-174.

Martinez-Romero, D., Valero, D., Serrano, M., Burlo, M., Carbonell, A., Burgos, L.,Requelme, F. 2000. Exogenous polyamine and gibberellic acid effects on peach (Prunus Persica L.) storability improvement. Journal of Food Science, 65, 288–294.

Marriott, J., and Palmer, J. K. 1980. Bananas—physiology and biochemistry of storage and ripening for optimum quality. Critical Reviews in Food Science and Nutrition, 13 (1):41-88.

Mirdehghan, S. H., Rahemi, M., Castillo, S., Martínez-Romero, D., Serrano, M., and Valero, D. 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 Biology and Technology, 44 (1): 26-33.

Nambeesan, S., Handa, A. K., and Mattoo, A. K. 2008. Polyamines and regulation of ripening and senescence. Postharvest Biology and Technology of Fruits, vegetables and flowers, 319-340.

NHB. 2018. Banana production in India. https://agriexchange.apeda.gov.in/India%20Production/India_Productions.aspx?cat=fruit&hscode=1042

Pandey, S., Ranade, S. A., Nagar, P. K., and Kumar, N. 2000. Role of polyamines and ethylene as modulators of plant senescence. Journal of Biosciences, 25 (3): 291-299.

Pathak, N., Asif, M. H., Dhawan, P., Srivastava, M. K., and Nath, P. 2003. Expression and activities of ethylene biosynthesis enzymes during ripening of banana fruits and effect of 1-MCP treatment. Plant Growth Regulation, 40 (1):11-19.

Petkou, I. T., Pritsa, T. S., and Sfakiotakis, E. M. 2004. Effects of polyamines on ethylene production, respiration and ripening of kiwifruit. The Journal of Horticultural Science and Biotechnology, 79(6), 977-980.

Serrano, M., Martinez-Romero, D., Guillen, F., and Valero, D. 2003. Effects of exogenous putrescine on improving shelf life of four plum cultivars. Postharvest Biology and Technology, 30 (3):259-271.

Seymour, G. B., Taylor, J. E., and Tucker, G. A. (Eds.). 1993. Biochemistry of fruit ripening. Springer Science and Business Media.

Smith, N. 1989. Textural and biochemical changes during ripening of bananas (Doctoral dissertation, University of Nottingham).

Thompson, A. K., 1996, Fruit ripening conditions. In: postharvest technology of fruits and vegetables. Blackwell Science Ltd., pp. 186.

Valero, D., Martínez-Romero, D., Serrano, M., and Riquelme, F. 1998. Influence of postharvest treatment with putrescine and calcium on endogenous polyamines, firmness, and abscisic acid in lemon (Citrus lemon L. Burm cv. Verna). Journal of Agricultural and Food Chemistry, 46 (6):2102-2109.

Valero, D., Martínez-Romero, D., and Serrano, M. 2002. The role of polyamines in the improvement of the shelf life of fruit. Trends in Food Science & Technology, 13 (6-7): 228-234..