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Effect of postharvest treatments on shelf life and quality attributes of banana cv. Nendran (*Musa* AAB) under ambient storage conditions

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Abstract
India is the largest producer of banana (*Musa* spp.), the world's favourite but highly perishable fruit. Nendran, a French plantain, is the most important banana cultivar in Kerala. An experiment was conducted to study the effect of various post-harvest treatments *viz., Pseudomonas fluorescens* (1%), hot water at 50 °C, *Trichoderma viride* (1%), chitosan (0.5%), a combination of chitosan (0.5%) and gum arabic (5%), salicylic acid (200 ppm), boric acid (1%), calcium chloride (1%), *Bacillus subtilis* (1%) on the shelf life of Nendran banana open stored at 30-34 °C and 65-76% relative humidity. The experimental results revealed that *Trichoderma* and hot water treated fruits recorded minimum weight loss, lower decay, and maximum marketability with an additional shelf life of three days. But hot water treatment proved to be better for fruit quality attributes compared to *Trichoderma* and hence can be used as an eco-friendly postharvest treatment in banana cv. Nendran for storage under ambient conditions.

Keywords: Nendran banana, trichoderma, hot water treatment, shelf life, marketability

1. Introduction

India is the largest producer of bananas with an annual production of 33061.79 MT (GoI 2021) [32] accounting for about a quarter of worldwide banana production. Nendran, a French plantain cultivar belonging to *Musa* AAB group is the most important banana variety in Kerala with an area of 57694 ha and production of 544188 MT (GoK, 2022) [1], owing to its unique taste and great suitability for crispy chips. Being a climacteric fruit, post-harvest loss in banana is huge and it is about 21.67% (Saha *et. al.,* 2021) [29]. Post-harvest treatments are hence required to extend the shelf life and reduce the postharvest losses in the crop.

Anti-fungal properties of microbes, hot water treatment, biopolymers, growth regulators and inorganic salts are reported to be effective in postharvest disease management. Application of microbial antagonist could suppress growth of postharvest pathogens (Babychan *et. al.,* 2017) [5]. *Trichoderma*, an eco-friendly alternative to chemical treatments could extend shelf life of fruits (Gonzalez-Estrada *et. al.,* 2018) [13]. *Trichoderma* sp. along with 8% wax coating has reported extending shelf life and fruit quality in banana variety Rasthali (Devi *et. al.,* 2021) [7]. Non-pathogenic PGPB can be used to induce disease resistance and US FDA has recommended *Bacillus subtilis,* a PGPB, as a natural plant protection product. Ghazanfar *et al.,* (2016) [11] reported that *Pseudomonas fluorescens* provided good control against the important postharvest pathogens of tomato i.e., *Geotrichum candidum* (78.1%) and *Rhizopus oryzae* (82.2%). Hot water dip at mild temperatures above 40 °C delayed degreening and suppressed the growth of microbes. (Dissanayake, 2019) [8]. A decrease in disease incidence and improvement in fruit quality was observed when a combination of hot water (50 °C for 5 minutes) treatment and garlic extract (1:1) was given (Das *et. al*., 2021) [6].

Boric acid, an inorganic salt with antifungal properties, was effective in postharvest disease management and anthracnose in banana caused by *Colletotrichum musae* was suppressed by boric acid at 5% and 10% concentrations (Jagana *et al*., 2018) [9]. Calcium chloride affects cell wall composition of fruits, alters the enzymes associated with ripening process and thus delays ripening. Post-harvest spray of calcium chloride was found effective in extending shelf life of banana (Minh, 2022) [25]. Use of plant growth regulator, salicylic acid along with wax coating increased shelf life, fruit quality and decreased PLW and disease incidence in Cavendish banana (Mandal *et. al.,* 2019) [22]. Chitosan could extend shelf-life and increase fruit quality in banana at 1% or lower concentrations (Hosseini *et. al.*, 2018 [15], Sikder *et al.,* 2019) [31]. Synthetic chemicals alternated with gum arabic was used for extending shelf life and quality of banana (Alali *et. al*., 2018) [2] and when used in combination they gave protection against anthracnose disease (Maqbool *et al*., 2010) [23]. Hence, the present study was conducted to evaluate different postharvest treatments for extending shelf life of banana cv. Nendran.

2. Materials and Methods
Evaluation of different post-harvest treatments to extend the shelf life of banana cv. Nendran was conducted at Pineapple Research Station, Vazhakulam, Kerala.

2.1 Experiment Details
The experimental design was completely randomized design (CRD) with 3 replications. Nendran bunches, from farmer's field located at Koothattukulam, at fully mature stage were collected, dehanded, washed and sanitized with 100 ppm sodium hypochlorite for 10 minutes followed by washing in running tap water. The fingers were then subjected to the following postharvest treatments to assess their effectiveness to extend shelf life.

1. *Pseudomonas fluorescens* (1%)
2. Hot water treatment at 50 ℃ for 5 minutes
3. *Trichoderma viride* (1%)
4. Chitosan (0.5%)
5. Chitosan (0.5%) and GA (5%)
6. Salicylic acid (200 ppm)
7. Boric acid (1%)
8. Calcium chloride (1%)
9. *Bacillus subtilis* (1%)
10. Control

Commercial talc-based formulation of *T. viride* purchased from Kerala Agricultural University, Thrissur was used for the experiment. Chitosan solution was prepared in 1% acetic acid whereas all other treatment solutions were prepared with distilled water. The fingers were dipped in the treatment solution for 10 minutes and the excess solutions was allowed to drain off and fingers were air dried prior to storage. Electric water bath (Rotek) maintained at 50 ℃ for 5 minutes was used for hot water treatment.

2.2 Observations on physico-chemical charcters

Physiological loss in weight (PLW), ripening score, number of days to ripen based on peel colour, decay percentage and marketable fruit percentage up to 15 days after storage (DAS) were recorded. The PLW was calculated for each interval and converted into a percentage of initial weight using Eq. (1). Ripening score was noted visually from the chart (Fig.1). Decay percentage was calculated using Eq. (2) Decay score was derived from the decay percentage using the score card given in Table 1. The shelf life was calculated by counting the days required to attain the last stage of ripening, but up to the stage when fruit remained still acceptable for consumption or marketing as described by Liamngee *et al*. (2018) [19] and expressed in number of days.

Chemical parameters *viz*. pH, TSS, acidity and Brix/acid ratio were analysed in every two days from 5 DAS up to 13 DAS. Total soluble solids was measured using hand refractometer (ERMA) of range 0-32°Brix and pH measured using Elico digital pH meter. Titrable acidity of the fruits was determined by titrometric method as described by Ranganna (1997) [28]. Mean average length, diameter and firmness of the fingers, and the temperature and relative humidity of storage environment were also recorded. Fruit firmness was checked using digital penetrometer (G-Tech GY-4) with a probe radius 4 mm.

2.3 Statistical analysis
The experiment was arranged in completely randomized design (CRD), with 10 treatments each having 3 replicates. Each replicate was comprised of 8 uniform sized fruits of banana cv. Nendran. Data were subjected to analysis of variance (ANOVA) using statistical software GRAPES1.0.0 (KAU, 2022) [14] and the critical difference ($p \leq 0.05$) was used to compare the means (Gomez and Gomez 1984) [12].

3. Result and Discussion
The present study was undertaken to find a suitable postharvest treatment for extending the shelf life of banana cv. Nendran by replacing fungicide treatment. Average length, diameter and firmness of the banana fingers taken for storage studies was 20.45 cm, 12.48 cm and 95.78 kg cm^{-2} respectively. Relative humidity and temperature of the storage environment during the study was 30-34 ℃ and 65-76 per cent respectively.

The physiological loss in weight (PLW) continuously increased during the entire period of storage irrespective of the treatments (Table 2). Significant difference in PLW between the treatments was observed on 10, 11 and 12 DAS with the minimum values in T3 (16.913) followed by T2 (17.630) on 12 DAS. PLW represents the weight loss due to reduction in moisture and substrates during ripening and affects the saleable weight which is economically important. *Trichoderma* (22.77%) and hot water (24.03%) treated fruits recorded minimum PLW after 15 days of storage also. The weight loss of bananas during storage occurred due to the loss of water from the fruits, microbial decay and storage environment like temperature and humidity.

Hot water (T2) and *Trichoderma* (T3) treated fruits ripened only after 11 days of storage whereas control fruits (T10) and T5 ripened on 8 DAS (Fig 2). Perusal of the ripening score (Table 3) showed that T5 even though ripened along with control fruits, it remained acceptable for another 5 days perhaps due to the protective biopolymer coating given over the fruit surface. The ripening score differed significantly only on 6, 7 and 8 DAS and least score for ripening on 8 DAS was recorded in T3 (4.1).

Decay started in the fruits from 8 DAS (Table 4) and decay score was recorded until untreated fruits (T10) decayed completely (15 DAS). Minimum decay score after 15 days of storage was observed in fruits treated with *Trichoderma* (2.7) followed by hot water (3.1) and *Bacillus subtilis* (3.2). Postharvest rots in banana, could be controlled by immersing the fruit in hot water, the combinations of 50 ℃ for 6 and 12 min, 53 ℃ for 9 min and 56 ℃ for 3 min, enabled appropriate decay control for preservation of postharvest quality (Nolasco *et al.* 2008) [26]. According Alvindia (2012) [4], hot water treatment was effective for fungal pathogen control in banana, because fungal spores and latent infections were present either on the surface or in the first few cell layers under the peel of the fruit (Lurie 1998) [21].

Trichoderma, the fast-growing antagonistic fungus, might have inhibited the spore germination of pathogens by direct parasitism and the production of metabolites. Alvindia and Acda (2012) [3] reported that postharvest treatment of banana involving combination of hot water treatment and *Trichoderma harzianum* DGA01 resulted in fruit with excellent appearance, lesser loss in weight, firmer texture and low disease severity even at conditions favourable for decay causing pathogens. They have detected in vitro production of chitinase and pectinase by *Trichoderma* which are reported for their antifungal properties, and opined that the effects of these metabolites on the quality of banana fruit, especially on the edible portion, have to be investigated. These enzymes produced by *Trichoderma* could degrade and disassemble the cellulose and hemicellulose of the cell such as chitin and pectin, which play important roles in hardness and fruit ripening (Lohani *et al.* 2004 [20]; San˜udo-Barajas *et al*. 2009 [30]).

Marketable percentage of fruits on 15DAS was highest in T3(54.86%) followed by T2(50.35%) against 16.67% in control (Fig. 3). This may be due to lower weight loss and decay observed with hot water and *Trichoderma* treatment. Postharvest treatment with hot water was reported effective in banana (Marreo *et al.* 1997), [24] papaya (Kodikara *et al.* 1996) [18] and mango (Feng *et al*. 1991) [10].

Chemical parameters *viz.*, TSS, titrable acidity, pH and Brix:acid ratio did not show significant variation due to different postharvest treatments. The total soluble solids content of fruits increased with the advancement of the storage period which may be due to hydrolysis of insoluble polysaccharide into simple sugars. The lower value for TSS content observed in T5 (Fig. 4), might be due to reduced respiration rate and delayed ripening. Fruit acidity gradually declined as the storage period increased (Fig. 5). With the increase in storage duration, acidity was decreased but the use of postharvest treatments like hot water, wax and fungicide application reduced the postharvest decrease in acidity as compared to control group because these treatments decreased the postharvest metabolic activities (Rab *et al.*, 2011) [27]. High respiration consequent to high temperature and low humidity under ambient storage may have augmented the degradation of organic acids into sugars resulting in decreased acidity. Similarly, pH of fruits also increased with storage period (Fig. 6).

Values for Brix:acid ratio increased with advancement of storage period (Fig 7). The ratio of Brix to acidity in the edible portion of fruits is frequently used as an index of flavor, as it measures the balance between sweetness and tartness. Among the superior postharvest treatments (T2 and T3) Brix acid ratio was higher in T2, reflecting superior fruit quality. Higher acidity and lower Brix/acid ratio at the end of storage study was observed in calcium chloride treated (T8) fruits. Titratable acidity and Brix/acid ratio are the best parameters to evaluate the maturity and quality of fruits (Johnson, 2000) [17]. For most fruits, a higher Brix-acid ratio is interpreted to mean better eating quality. Hence it can be inferred that hot water treatment was the superior postharvest treatment to offer an additional shelf life of three days with good fruit quality.

Table 1: Decay score card for banana

Percentage of decay/ blackening	Decay Score
0-25%	1
25-50%	2
50-75%	3
75-100%	4

Table 2: Physiological loss in weight of banana cv. Nendran stored with different postharvest treatments

Treatment	1 DAS*	2 DAS*	3 DAS*	5 DAS*	6 DAS*	7 DAS*	8 DAS*	9 DAS*	10 DAS	11 DAS	12 DAS	13 DAS*	14 DAS*	15 DAS*
T1	1.553	3.457	4.420	6.960	8.300	9.483	11.873	12.053	14.310 ^{de}	15.503 ^{de}	18.230 ^{de}	19.36	20.88	23.01
T2	1.343	2.987	4.050	5.880	7.483	9.590	9.607	11.783	13.307 ^{f}	14.533 ^{f}	17.630 ^{f}	19.26	21.73	24.03
T3	1.523	3.013	4.353	6.563	8.403	8.687	10.433	11.493	12.830 ^{f}	14.400 ^{f}	16.913 ^{f}	17.88	20.27	22.77
T4	1.290	3.083	4.563	7.023	8.823	10.387	11.190	12.990	14.447 ^{cd}	16.150 ^{cd}	17.833 ^{cd}	19.56	20.93	24.35
T5	1.153	2.930	4.563	8.023	9.450	11.173	12.517	14.033	15.603 ^{b}	17.517 ^{b}	19.187 ^{b}	21.18	23.29	25.71
T6	1.557	3.727	5.180	7.290	9.753	10.933	12.093	13.427	15.373 ^{b}	16.987 ^{b}	18.897 ^{b}	20.42	22.79	25.15
T7	1.340	3.043	4.007	6.537	8.297	9.813	10.620	11.793	13.647 ^{ef}	15.440 ^{ef}	16.480 ^{ef}	19.18	21.09	23.76
T8	1.910	3.597	5.050	8.167	10.197	11.490	13.110	14.647	16.413 ^{a}	18.110 ^{a}	19.703 ^{a}	21.58	24.05	25.37
T9	1.490	3.433	4.930	7.547	9.417	10.187	12.310	12.863	14.483 ^{bc}	16.973 ^{bc}	19.003 ^{bc}	20.84	23.17	25.09
T10	1.533	3.460	4.830	7.380	9.503	10.823	11.823	13.463	15.053 ^{bc}	16.697 ^{bc}	18.740 ^{bc}	19.21	20.84	22.72

*non-significant at 5% level

Table 3: Ripening score of banana under different post-harvest treatments

Treatments	3 DAS*	5 DAS*	6 DAS	7 DAS	8 DAS	9 DAS*	10 DAS*	11 DAS*	12 DAS*	13 DAS*	14 DAS*	15 DAS*
T1	2.79	3.57	3.77	4.72	5.28	6.11	6.39	6.52	6.86	7.00	7.00	7.00
T2	2.69	3.51	3.72	4.60	5.16	5.38	5.82	6.13	6.47	6.55	6.57	6.85
T3	2.69	3.19	3.35	3.66	4.10	4.72	5.44	5.75	6.57	6.74	7.00	7.00
T4	2.25	3.60	4.10	4.91	5.94	6.38	6.57	6.72	6.82	6.83	7.00	7.00
T5	2.72	4.35	5.22	5.69	6.75	6.75	7.00	7.00	7.00	7.00	7.00	7.00
T6	2.35	3.04	3.25	4.10	4.81	5.34	6.21	6.56	6.88	6.95	7.00	7.00
T7	2.38	2.91	3.19	3.81	4.47	4.91	6.13	6.44	6.88	7.00	7.00	7.00
T8	2.66	2.81	3.50	4.63	5.79	6.25	6.75	6.76	6.82	7.00	7.00	7.00
T9	2.69	3.41	3.63	4.28	5.04	5.53	6.44	6.57	6.65	6.80	6.83	6.92
T10	2.44	4.06	4.19	5.39	6.15	6.57	6.88	7.00	7.00	7.00	7.00	7.00
CD (0.05)			0.758	0.853	1.262							

*non-significant at 5% level

Table 4: Decay score of banana cv. Nendran stored with different postharvest treatments

Treatment	9 DAS*	10 DAS*	11 DAS	12 DAS	13 DAS	14 DAS*	15 DAS*
T1	0.20	0.20	0.70	1.40	2.30	3.00	3.40
T2	0.30	0.40	1.20	1.50	2.10	2.60	3.10
T3	0.00	0.00	0.00	0.90	1.50	2.30	2.70
T4	0.20	0.50	0.70	2.30	2.90	3.20	3.60
T5	1.00	1.40	1.80	2.40	3.00	3.70	3.90
T6	0.10	0.10	0.20	1.30	2.10	3.00	3.40
T7	0.10	0.30	0.40	1.50	2.40	3.00	3.50
T8	0.20	0.50	0.60	2.10	2.80	3.30	3.70
T9	0.10	0.20	0.30	1.30	2.20	2.90	3.20
T10	0.20	0.50	2.00	2.30	2.90	3.50	3.90
CD (0.05)	NS	NS	0.490	0.459	0.383	NS	0.212

*non-significant at 5% level

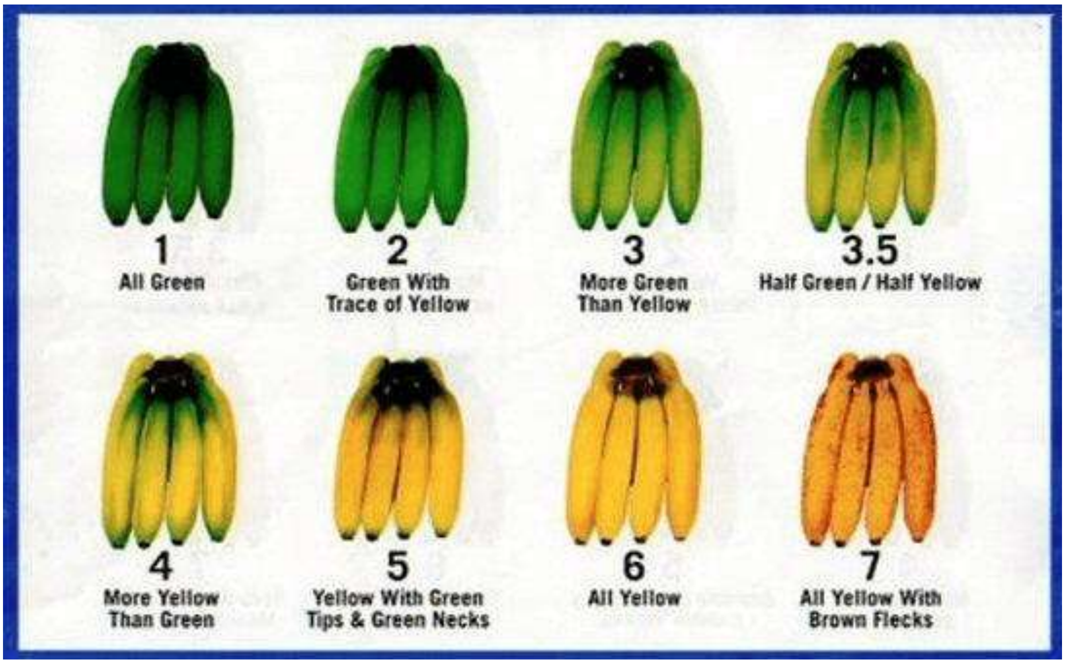

Fig 1: Ripening score of banana

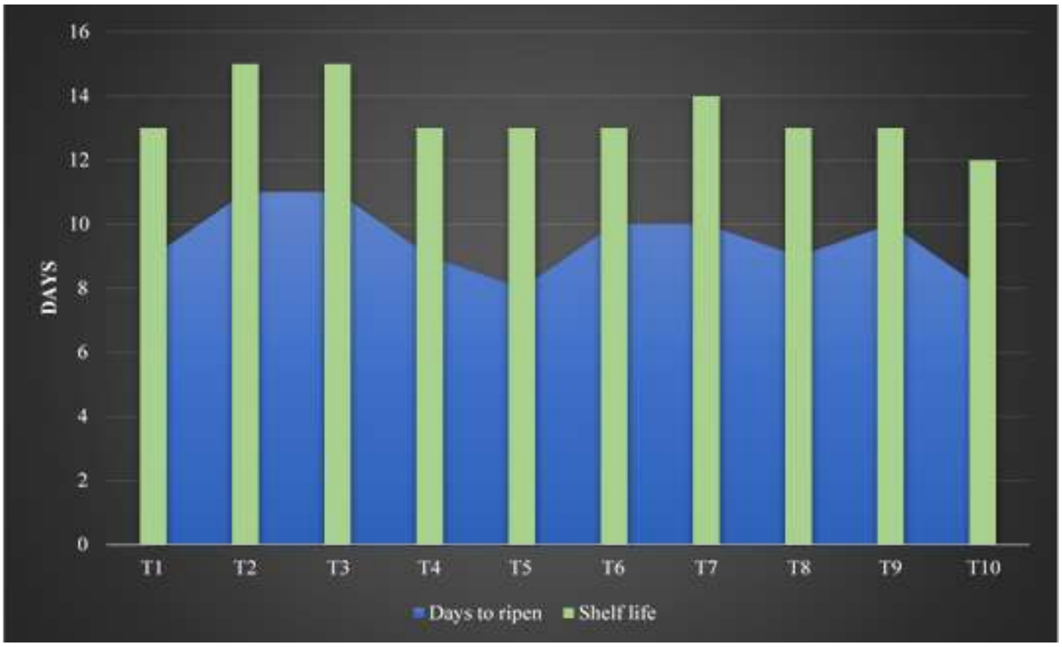

Fig 2: Shelf life and days to ripen banana cv. Nendran stored with different postharvest treatments

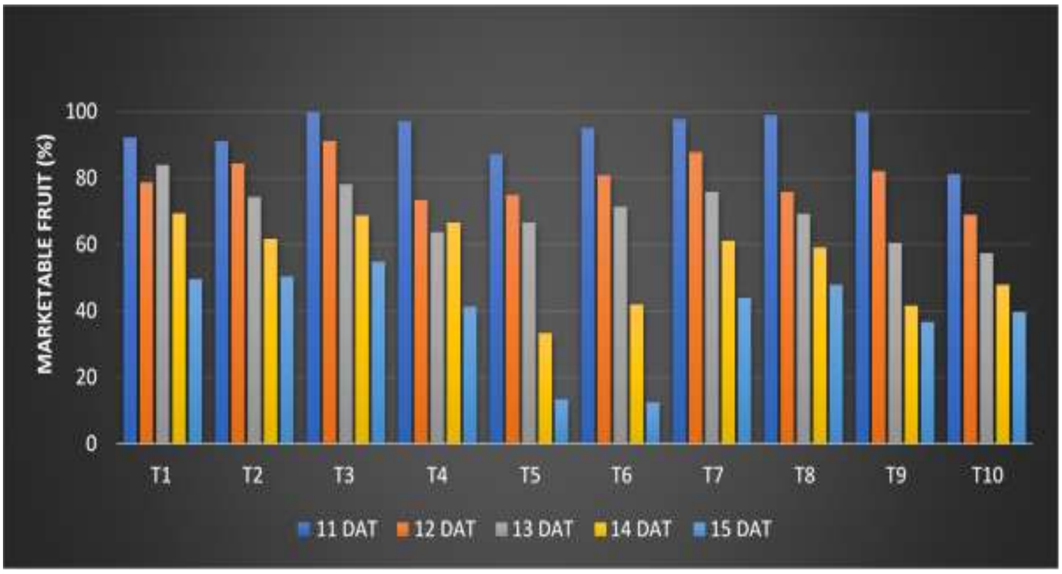

Fig 3: Marketability percentage of banana cv. Nendran stored with different postharvest treatments

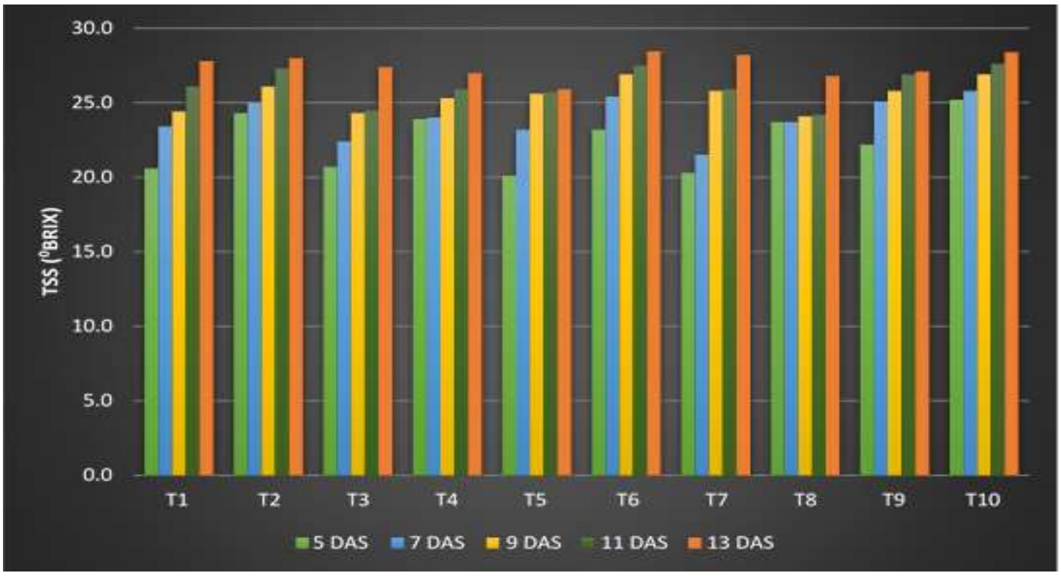

Fig 4: TSS of banana cv. Nendran stored with different postharvest treatments

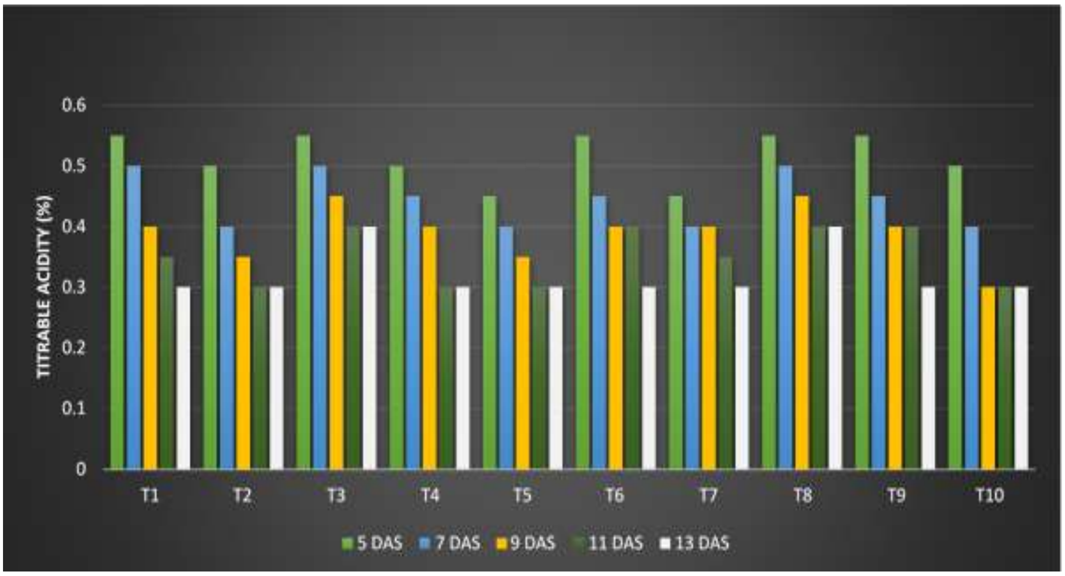

Fig 5: Titrable acidity of banana cv. Nendran stored with different postharvest treatments

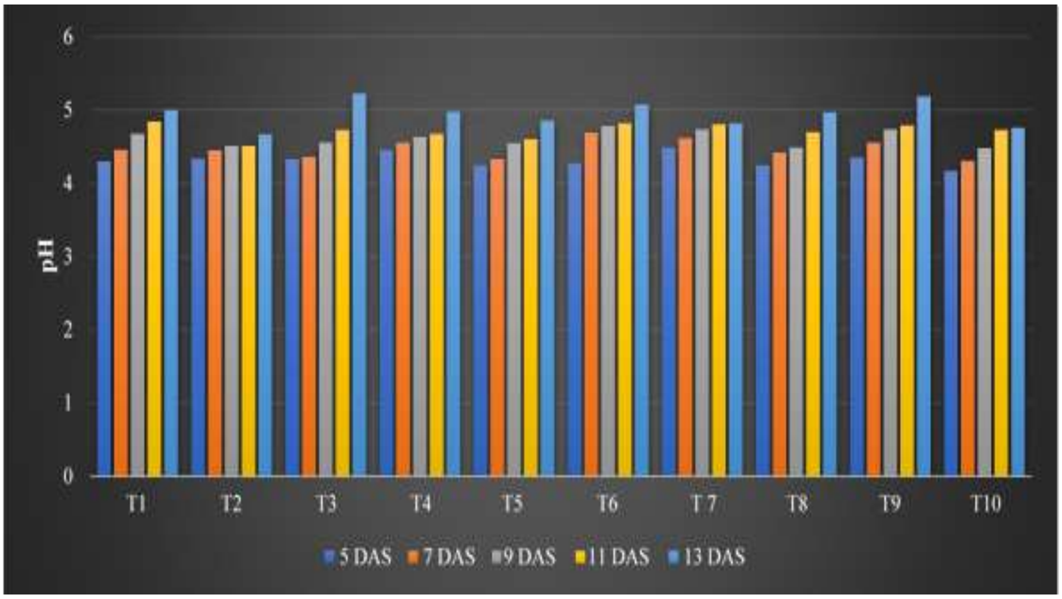

Fig 6: pH of banana cv. Nendran stored with different postharvest treatments

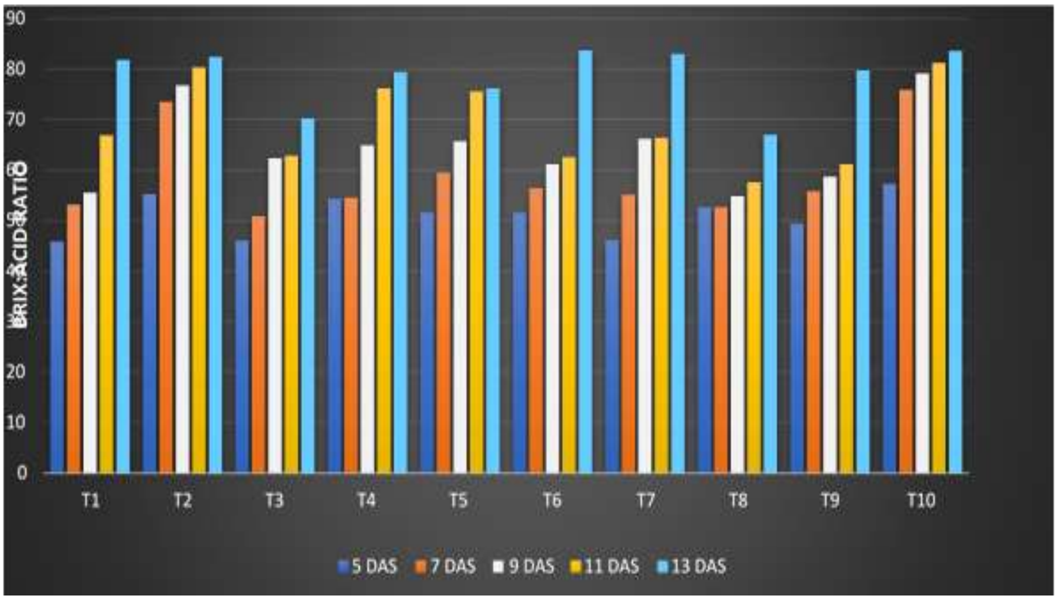

Fig 7: Brix:acid ratio of banana cv. Nendran stored with different postharvest treatments

Equations used in the text

PLW= (Initial weight - Final weight) / (Initial weight) X 100 (1)

Decay (%) = (Number of decayed fruits at specific storage period / Initial number of stored fruits) X 100 (2)

Marketable fruit (%) = (Number of sound fruit at specific storage period / initial number of stored fruits) X 100 (3)

4. Conclusion

Postharvest treatment with hot water 50 °C for 5 minutes and postharvest dip in fungal antagonist *Trichoderma viride* (1%) significantly reduced the weight loss, ripening score and fruit decay and enhanced shelf life and marketability in banana cv. Nendran in open storage conditions. But the quality of the ripe fruit was superior with hot water treatment, making it the best postharvest treatment for enhancing the shelf life of banana cv. Nendran under ambient conditions.

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