



Innovative Post-harvest Treatments to Enhance the Shelf-life and Quality of *Carica papaya*

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ABSTRACT

Background: Post-harvest losses in *Carica papaya* are attributed to multiple factors, including suboptimal harvesting practices, improper handling, inadequate storage conditions, inefficient packaging and transportation and the incidence of post-harvest pathogens. The implementation of effective post-harvest management strategies is essential to mitigate these losses, thereby enhancing fruit quality, ensuring nutritional availability and improving economic returns for producers.

Methods: The research was undertaken at the Department of Post-harvest Technology to investigate the post-harvest interventions to enhance the shelf life and quality of papaya. The harvested red lady papaya fruits went through various postharvest treatments: T₁-Hexanol (1%), T₂- Hexanol (2%), T₃- Chitosan (1%), T₄- Chitosan (2%), T₅- Salicylic acid (1 mm), T₆- Salicylic acid (2 mm), T₇- Potassium schoenite (1%), T₈- Potassium schoenite (2%), T₉- Control. They were stored in corrugated fibreboard boxes with 5 per cent ventilation at room temperature and periodically analyzed for physiological and biochemical parameters until the end of shelf life.

Result: In the study, post-harvest application of 2 mm salicylic acid significantly modulated the physiological and biochemical responses of *Carica papaya* (L.), reducing weight loss and respiration rate while enhancing TSS, reducing, non-reducing sugar content and ascorbic acid levels. Despite temporal variation across storage intervals, this treatment consistently delayed ripening and extending the shelf life to approximately 15.98 days and preserving overall fruit quality of papaya fruits.

Key words: Papaya, Post-harvest treatments, Quality, Shelf life.

INTRODUCTION

Carica papaya is globally valued for its nutritional composition, notably its high levels of ascorbic acid (60.9 mg), vitamin A (0.047 mg) and calcium (20 mg) per 100 g of fruit pulp (Pinnamaneni, 2017). As a climacteric fruit, papaya exhibits rapid postharvest ripening driven by ethylene, leading to a short shelf life and significant postharvest losses, especially during storage and transportation. The primary postharvest issues include microbial spoilage, mechanical injuries and firmness degradation, all of which hinder extended marketability and long-distance distribution. Ripening and senescence are accompanied by extensive metabolic alterations that influence sugar and organic acid levels, polyphenolic profiles, antioxidant activity, volatile compounds, structural polysaccharides and softening-related enzymes (Vinod *et al.*, 2023). Approximately 7.36% of papaya production is lost during pre-and post-harvest operations, encompassing cultivation, storage and transport (Bhanushree *et al.*, 2018).

The papaya industry faces significant post-harvest losses attributed to mechanical injuries during harvesting, inadequate handling, overripe and desiccated fruits, post-harvest diseases (such as anthracnose, stem end rots and rhizopus rot), pest infestations, chilling injuries from improper storage temperatures, physiological disorders and insufficient post-harvest infrastructure (Patil *et al.*, 2018). Among them, anthracnose caused by *Colletotrichum gloeosporioides* is the most common disease affecting mature fruits in India's papaya-producing regions. There are a variety of physical therapies that have been reported to

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be successful in preserving postharvest quality retention, disease control and shelf-life extension in a wide variety of fruits and vegetables. In addition to being risk-free, these methods do not leave any chemical residues behind and they enable the fruit to keep its quality throughout the duration of its shelf life and cold storage. According to Fallik and Ilić (2021), it has been demonstrated that physical

treatments have an impact on several aspects of post-harvest quality, including ripening processes, respiration, ethylene evolution and both external and internal quality enhancement. Adding postharvest treatments to fruits allows for an extension of their shelf life without causing any degradation in their quality. Within the same species, various cultivars react differently to post-harvest chemical treatments, which are used to delay the ripening process and increase the shelf life of the product. According to Baenas *et al.* (2014), the use of chemical elicitors has been shown to promote defensive reactions and physiological adaptations in plants. Various pre and postharvest studies have demonstrated the beneficial effects of chitosan application on the quality and shelf life of multiple fruit crops (Ahmed *et al.*, 2021). Salicylic acid is involved in the control of many physiological functions in plants, including transpiration, ion absorption, stomatal closure, suppression of ethylene production and stress tolerance (Singh *et al.*, 2026). The application of SA in pre/post-harvest treatment of fruits and vegetables can significantly improve quality, extend shelf life and inhibit deterioration (Ahmed *et al.*, 2021). Chitosan serves as a natural coating and recent studies indicate that fruits treated with chitosan exhibit a lower deterioration index compared to untreated controls, without significantly impacting their physicochemical properties (Sebastian *et al.*, 2025). According to Singh *et al.* (2018), chitosan demonstrates significant antimicrobial activity against various pathogenic and spoilage microorganisms, encompassing both fungi and bacteria. Therefore, the major purpose of this study is to preserve postharvest quality and increase the shelf life of papaya fruit using different post-harvest treatments.

MATERIALS AND METHODS

Sample collection and experiment set up

Healthy and disease-free mature papaya (Red Lady) were harvested and collected from a local farmers field of Chengalpattu district (12°22'01.8"N 79°42'59.8"E) to post-harvest management laboratory at SRM College of Agricultural Sciences during 2024-2025. All trials employed uniformly sized ripe fruits that were 70-80 per cent free of bruises and blemishes. After washing with distilled water and drying under air, treatments were applied on samples and stored at room temperature (RT) (25±1°C) and 85-90 per cent relative humidity (RH).

The fruits were dipped in the following chemicals: T₁ - Hexanol (1 per cent), T₂ - Hexanol (2%), T₃ - Chitosan (1%), T₄ - Chitosan (2%), T₅ - Salicylic acid (1 mM), T₆ - Salicylic acid (2 mM), T₇ - Potassium schoenite (1%), T₈ - Potassium schoenite (2%), T₉ - Control. The trial was set up in a totally randomized manner, with nine treatments in three replications. Observations on changes in physiological quality, chemical quality, microbiological quality and sensory quality were taken at three-day intervals until the end of shelf life.

Physiological loss in weight (PLW)

Physiological loss in fruit weight was determined by noting the weight of the sample at 3 days intervals and deducted from the initial weight recorded at the time of storage. PLW was calculated using the formula mentioned below and expressed as a percentage (Koraddi and Devendrappa, 2011).

Physiological loss in weight (per cent) =

$$\frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Respiration rate (mL CO₂ kg⁻¹ h⁻¹)

The pretreated papaya fruits after weighing precisely were placed in a closed plastic container (5 L capacity by volume) for estimation of respiration rate. Immediately after one hour, CO₂ concentration was recorded using checkpoint portable gas analyser (GA-200) by penetrating needle through a silicon rubber septum fixed to lid and expressed in mL CO₂ kg⁻¹ h⁻¹ (Bhande *et al.*, 2008).

Total soluble solids (TSS)

A hand refractometer (0-32°B) was used to measure the total soluble solids (TSS). The juice extracted from the randomly selected fruit was put on the prism of the hand refractometer and the value reflected was noted Ranganna (1997).

Ascorbic acid content (mg 100-g)

The ascorbic acid was estimated by the titration method using 2, 6-dichlorophenol indophenols dye as per the method reported by Ranganna (1997).

Total sugar (%) and reducing sugar (%)

Total sugar (%) and reducing sugar (%) of a treated fruit were determined as per the procedure of Ranganna (1997) and expressed in percentage.

Carotenoids (mg 100 g⁻¹)

Carotenoids of a treated fruit were determined as per the procedure of Saini *et al.* (2001) and expressed in mg 100 g⁻¹ of sample.

Shelf life (days)

The shelf-life of fruit was based on the development of discolouration *i.e.*, blackened skin, off-flavor, fungal attack and skin shriveling. The stage at which more than 50 per cent of the stored fruits became unsuitable for consumption was considered as the end of shelf-life.

Statistical analysis

The data underwent statistical analysis (Panse and Sukhatme 1985) using the AGRES software. A randomised block design was utilised to assess the effects of treatments on the mango trees. Mean comparisons were conducted after computing analysis of variance (ANOVA), standard deviation SE(d) and least significant difference (LSD) values, with the critical difference set at a significance level of five per cent.

RESULTS AND DISCUSSION

Variations in the physicochemical characteristics of papaya can offer valuable insights into its storability, considering factors such as weight loss, nutritional content, antioxidant activity and disease occurrence during storage. This knowledge can contribute to effective postharvest management strategies for papaya. Weight loss is a critical parameter in quality control; when weight loss escalates, firmness diminishes and instances of wilting, shrivelling, or browning intensify. The reduction of moisture primarily results from water diffusion through the peel surface, which can influence fruit weight loss *via* respiration and transpiration processes (Valero *et al.*, 2006). The present investigation exhibited that application of salicylic acid (2 mM), reduced the physiological loss in weight throughout the storage period. With the extension of the storage duration, PLW significantly escalated across all treatments. However, in contrast to the control group, the treated fruits exhibited a slower rate of rise shown in Table 1. The augmented weight loss of untreated fruits may result from an enhanced metabolic rate owing to respiration and transpiration, whereas postharvest treatments inhibit these physiological processes. The results

align with the findings of Promyou and Supapvanich (2014) regarding papaya cv. Kaek Dam. The diminished weight loss of papaya cv. Red Lady during storage and ripening may be attributed to stomatal closure, resulting in a reduced transpiration rate (Lata *et al.*, 2018; Mandal *et al.*, 2017). Comparable findings were reported by Devarakonda *et al.* (2020) in papaya cultivar Red Lady. This aligns with the findings of the current investigation on the papaya cultivar Red Lady.

The typical climacteric behaviour is demonstrated by papaya, which has a peak in respiration rate that coincides with the ripening process. According to Lu *et al.* (2011), respiration is a catabolic process that converts complex chemicals that have been stored, such as starch, pectin, organic acids and sugars, into simple molecules that are soluble. This process contributes to economic loss and increases the rate of senescence at the same time. Therefore, it is vital to manage the rate of respiration using postharvest treatments in order to delay the ripening process and increase the storage life of papaya fruits.

The respiratory process, ripening and senescence processes were all significantly reduced by the treatments,

Table 1: Effect of postharvest treatments on physiological loss in weight during storage.

Treatments	Physiological loss of weight (%)				
	3 rd day	6 th day	9 th day	12 th day	15 th day
T ₁ - Hexanol 1%	2.54	4.74	8.56	15.99	17.68
T ₂ - Hexanol 2%	2.25	4.32	8.24	15.32	17.33
T ₃ - Chitosan 1%	1.89	3.95	7.85	14.01	17.21
T ₄ - Chitosan 2%	1.64	3.37	7.35	13.68	16.88
T ₅ - Salicylic acid 1 mM	1.31	2.95	6.98	13.05	15.11
T ₆ - Salicylic acid 2 mM	1.13	2.64	6.42	12.65	14.78
T ₇ - Potassium schoenite 1%	2.97	5.67	9.55	16.88	18.55
T ₈ - Potassium schoenite 2%	2.74	5.12	9.24	16.35	18.23
T ₉ - Control	3.65	6.58	19.21	35.35	49.44
SE(d)	0.13	0.27	0.57	1.07	1.30
CD (5%)	0.27	0.55	1.18	2.19	2.67

*Significant at P 0.05; NS- Non significant at P>0.05.

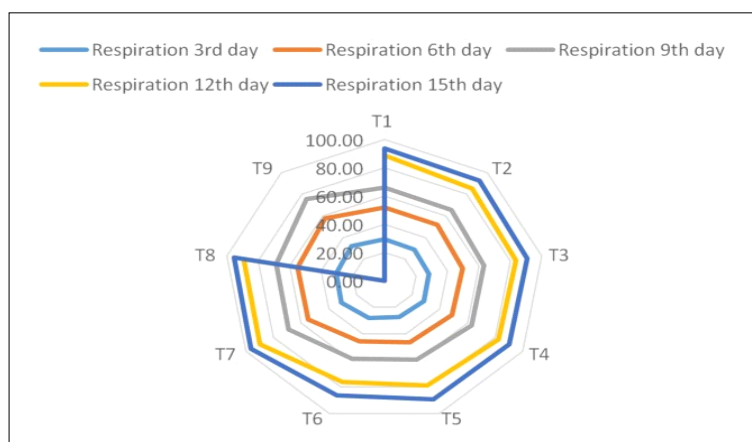


Fig 1: Effect of postharvest interentions on respiration rate.

with SA at a concentration of 2 mM being the most effective was shown in (Fig 1). A similar reduction in respiration rate was seen by Srivastava and Dwivedi (2000) in banana cv. Harichal, Aghdam *et al.* (2009) in kiwifruit and Jaishankar and Kukanoor (2016) in sapota cv. Kalipatti. By inhibiting the activity of enzymes that produce ethylene, such as (1-aminocyclopropane-1-carboxylate) ACC synthase and oxidase, salicylic acid was able to reduce the pace of respiration and the amount of ethylene that was produced (Asghari and Aghdam, 2010).

TSS signifies that fruits are either maturing or at an advanced storage stage. TSS levels exhibited a modest rise during the early phase, attributable to the conversion of organic acids into sugars *via* pectin degradation and the transformation of carbohydrates into simple sugars throughout storage, driven by the metabolic activities of the tissues (Rapisarda *et al.*, 2008). In the current study, papaya fruits treated with 2 mM salicylic acid exhibited a reduced rate of change in total soluble solids during storage compared to the control group (Fig 2). The control fruits had the highest total soluble solids (TSS) during storage, indicating rapid ripening. The treatment with salicylic acid maximised total soluble solids by inhibiting sucrose-

phosphate synthase and decreasing the ethylene production rate (Aghdam *et al.*, 2011). Khademi and Ershadi (2013) said that SA might impede the increase in TSS by diminishing the respiration rate and suppressing ethylene production, consequently decreasing the total soluble solids content in fruits. Promyou and Supapvanich (2014) indicated that SA treatment of papaya (cv. Kaek Dam) reduced the rise in total soluble solids and total sugars, hence decelerating the ripening phase. Mandal *et al.* (2017) in papaya cv. Red Lady, Supapvanich and Promyou (2017) in papaya cv. Devarakonda *et al.* (2020) in papaya cv. Red Lady all corroborated similar results of lower TSS with SA treatment.

Sugars can affect the production of specialised 'sensory' chemicals in fruits (Yu *et al.*, 2022). The increase in reducing sugar may be ascribed to the enzymatic transformation of starch into reducing sugar, as well as the conversion of some non-reducing sugars into reducing sugars *via* the process of inversion (Gol and Ramana Rao 2011). In the current investigation, papaya fruits treated with salicylic acid at a dose of 2 mM exhibited the lowest total sugar and reducing sugar content in comparison to other treatments (Fig 3 and 4). During storage, the hydrolysis of

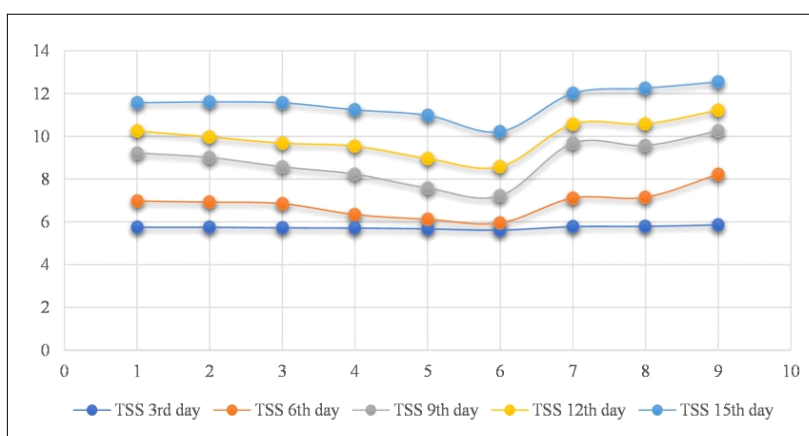


Fig 2: Effect of postharvest interentions on TSS content.

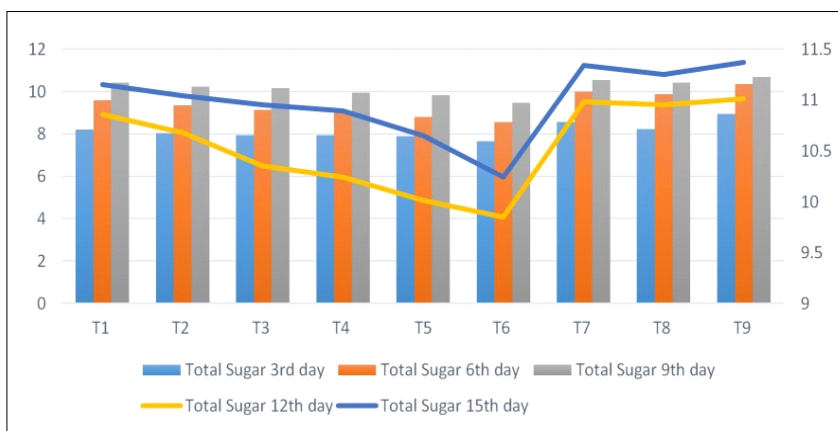


Fig 3: Effect of postharvest interentions on total sugar content.

complex metabolites into simple molecules or the degradation of starch into soluble sugars by amylase led to the buildup of glucose and fructose. This may explain the increase in total sugars during storage (Jaishankar and Kukanoor, 2016). Yadav *et al.* (2001) proposed that the administration of salicylic acid (SA) inhibits amylase activity, hence impeding the conversion of complex starch molecules into soluble sugars, which leads to a gradual rise in total sugars. Similar findings were noted in strawberry (Salari *et al.*, 2013) and peach (Khademi and Ershadi, 2013), where a delayed increase in total sugars was reported following SA treatment. Supapvanich and Promyou (2013) observed a decreased accumulation of total sugars in papaya treated with SA. This was corroborated by the findings of Shivendra and Singh (2015) in mango, as well as Lata (2017) and Devarakonda *et al.* (2020) in papaya cv. Red Lady.

Ascorbic acid, one of the secondary metabolites, influences fruit ripening and stress tolerance and is crucial for regulating quality during postharvest storage (Zheng *et al.*, 2022). The ascorbic acid concentration markedly diminished with the prolongation of the storage time across all treatments and the control group. The decline in ascorbic acid levels over time is due to respiration, which alters the internal O_2 and CO_2 composition of the tissue and the oxidation

of ascorbic acid to dehydro-ascorbic acid facilitated by the enzyme ascorbic acid oxidase (Hesami *et al.*, 2021). The Ascorbic acid content influences the nutritional quality of fruits and diminishes during ripening, likely due to the oxidative catabolic activity of enzymes affecting ascorbic acid (Singh and Rao, 2005). In Red Lady papaya, ascorbic acid diminished with the progression of the storage time, regardless of the treatments used. The postharvest application of SA was determined to be the most efficient in reducing the oxidation of ascorbic acid, hence preserving a higher ascorbic acid content compared to the control in this investigation. The postharvest application of 2 mM salicylic acid on Red Lady papaya resulted in the highest retention of ascorbic acid while the untreated control papaya exhibited the lowest ascorbic acid content during storage (Table 2). The treatment with salicylic acid markedly diminished the oxidation of ascorbic acid by inhibiting the activity of enzymes such as catalase, peroxidase, ascorbic acid oxidase and polyphenol oxidase, resulting in a gradual decrease in acidity and ascorbic acid during storage, as reported by Bal and Celik (2010). The SA treatment of papaya positively influenced the reduction of respiration rate and ethylene production, while maximising the retention of ascorbic acid content. This is corroborated by the research

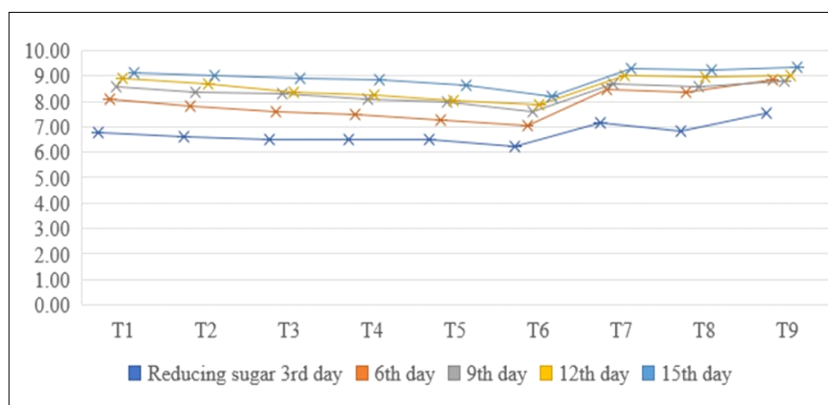


Fig 4: Effect of postharvest interentions on reducing sugar content.

Table 2: Effect of postharvest treatments on Ascorbic acid content during storage.

Treatments	Ascorbic acid				
	3 rd day	6 th day	9 th day	12 th day	15 th day
T ₁	40.85	38.47	34.12	28.49	22.88
T ₂	41.02	39.04	34.35	29.03	23.14
T ₃	41.33	39.23	35.66	29.40	23.42
T ₄	41.57	39.54	35.84	29.90	23.65
T ₅	42.01	40.13	36.22	29.76	24.33
T ₆	42.65	40.86	37.65	30.60	25.42
T ₇	40.77	38.21	33.15	27.57	22.32
T ₈	40.78	38.24	33.21	27.89	22.41
T ₉	40.23	36.01	32.54	26.97	20.32
SE(d)	1.45	1.32	1.15	0.96	0.75
CD (5%)	NS	NS	2.36	1.97	1.55

*Significant at P 0.05; NS- Non significant at P>0.05.

Table 3: Effect of postharvest treatments on shelf life (days).

Treatments	Shelf life
T ₁ - Hexanol 1%	11.05
T ₂ - Hexanol 2%	11.25
T ₃ - Chitosan 1%	13.11
T ₄ - Chitosan 2%	13.25
T ₅ - Salicylic acid 1 mM	15.04
T ₆ - Salicylic acid 2 mM	15.98
T ₇ - Potassium schoenite 1%	9.89
T ₈ - Potassium schoenite 2%	10.65
T ₉ - Control	7.05
SE(d)	0.93
CD (5%)	1.92

*Significant at P 0.05; NS- Non significant at P>0.05.

of Asghari (2006) and Coltro *et al.* (2014) in strawberries, Aghdam *et al.* (2011) in kiwifruit, Jaishankar and Kukanoor (2016) in sapota, Lata (2017) in papaya cv. Red Lady and Supapvanich and Promyou (2017) in papaya cv. Holland.

The optimal parameter, shelf life, denotes the duration from harvesting to the final edible and marketable stage (Rashid *et al.*, 2019). The postharvest treatments of papaya cv. Red Lady fruits decreased the pace of physiological activity and biochemical alterations, hence extending shelf life. The postharvest administration of salicylic acid at a dose of 2 mM substantially resulted in the maximum shelf life of 15.98 days compared to the control group (Table 3). The application of salicylic acid to papaya delayed ripening and induced associated biochemical alterations due to a diminished respiration rate and lower ethylene production, resulting in a considerably extended shelf life, whereas untreated fruits exhibited the shortest shelf life (Mandal *et al.*, 2017). Similar findings were made about the effectiveness of salicylic acid treatment in prolonging the shelf life of papaya (Bhanushree *et al.*, 2018 and Devarakonda *et al.*, 2020), strawberries (Babalar *et al.*, 2007) and bananas (Srivastava and Dwivedi, 2000).

CONCLUSION

The current investigation indicates that the application of 2 mM salicylic acid showed optimal results for physiological weight loss, total soluble solids, total sugars, reducing sugars, ascorbic acid, respiration rate and enhanced the shelf life of papaya.

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Informed consent

Not applicable.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish or preparation of the manuscript.

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