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Effects of $KMnO_4$ and Activated Carbon on the Quality of Postharvest Papaya (*Carica papaya* L.)

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ABSTRACT

Papaya is extensively cultivated in tropical and subtropical regions due to its rich nutritional profile and high concentrations of vitamins and minerals. However, its limited postharvest shelf life poses significant challenges for storage and international trade. This study evaluated the effectiveness of a combined treatment of potassium permanganate ($KMnO_4$) and activated carbon, mixed in a 2:1 weight ratio, at concentrations ranging from 0 to 15 g per box, in delaying fruit ripening during postharvest storage. The findings indicated that a 12 g per box application of the $KMnO_4$ and activated carbon mixture was the most effective, extending the storage period from approximately 10 to 16 days, representing a 60% increase. Furthermore, this treatment helped preserve postharvest fruit quality by maintaining high levels of protein, total sugars, and vitamin C. The combination also delayed the peaks of respiration and ethylene production, thereby contributing to the extended shelf life of the fruit. These results provide a valuable foundation for enhancing postharvest preservation and quality maintenance of papaya, which is essential for supporting its international trade and distribution.

Introduction

Carica papaya L., a tropical fruit known for its high nutritional value, contains essential vitamins and minerals such as calcium, folate, iron, potassium, and fiber (Choudhary et al., 2025). It holds considerable economic importance as a major export commodity to European and American markets. The Food and Agriculture Organization of the United Nations (FAO) and the Organization for Economic Co-operation and Development (OECD) have identified papaya—alongside mango, pineapple, avocado, and banana—as a key contributor to global agricultural production between 2021 and 2030 (Hejkrlik et al., 2024). Despite its economic relevance, postharvest storage and transportation of papaya are challenged by its limited shelf life, which varies depending on the cultivar (Lamatungga et al., 2024). As a result, ongoing research aims to develop postharvest storage strategies that minimize quality degradation and extend shelf life, while preserving the fruit's nutritional and sensory properties.

Various methods have been explored, including cold storage, controlled atmosphere storage, and surface coatings. However, the use of cold storage is limited due to papaya's sensitivity to chilling injury, a consequence of its high water content. Consequently, surface coatings and controlled atmosphere storage have emerged as more promising techniques for postharvest preservation (Tabassum and Khan, 2020). In Vietnam, the preservation of papaya is further complicated by the region's persistently high temperature and humidity, which accelerate ethylene production within the fruit (Wee et al., 2023). One strategy to counteract ethylene accumulation involves the application of potassium permanganate ($KMnO_4$), which oxidizes ethylene into carbon dioxide and water. This method has proven effective in extending the storage life of other climacteric

fruits such as chili and mango (Widdyastuti and Gahayu, 2022; Tran et al., 2024).

However, the ethylene oxidation process facilitated by $KMnO_4$ requires time, thereby necessitating the use of carrier materials with porous structures and large surface areas to adsorb ethylene and support the redox reaction. Granular activated carbon, characterized by mesopores (~20 μm) and macropores (~50 μm), exhibits strong ethylene adsorption capacity (Bailén et al., 2006). In addition to its ethylene-binding capabilities, activated carbon also adsorbs water vapor and oxygen, which can further contribute to extending the shelf life of fresh produce while reducing spoilage compounds and undesirable odors during storage.

This study aims to investigate the effects of $KMnO_4$ and activated carbon on enhancing the storage efficiency and overall quality of papaya fruit. The findings are expected to contribute to a deeper understanding of the morphological, physiological, and biochemical changes that occur during papaya ripening under the influence of $KMnO_4$ and activated carbon treatment. Furthermore, this research seeks to offer a practical approach for extending storage duration while preserving the nutritional and sensory quality of papaya fruit.

Materials and Methods

Plant materials and experimental design

The papayas, weighing approximately 500 g, with red color on some areas of the pulp, were harvested from a commercial orchard in Tien Giang Province. They were then treated with a 2.5% $CaCl_2$ solution for 15 min, after which they were removed, allowed to dry, and transported to the Department of Plant Physiology at the University of Science, Vietnam National University, Ho Chi Minh City, Vietnam. A total of 1080 papaya fruits were utilized and distributed into five replications utilizing a completely randomized block design. Each replication comprised three carton boxes, each measuring 36 cm × 26 cm × 9 cm, with six fruits in each. To investigate the effects of $KMnO_4$ and activated carbon, a bag containing a blend of the two substances in a 2:1 ratio was inserted into each carton. The quantity of the $KMnO_4$ and activated carbon mixture varied from 0, 3, 6, 9, 12, to 15 g per box. The papayas were stored at 28-30 °C throughout the study. The research assessed various parameters (8, 10, and 12 d), including fruit firmness, respiration rate, ethylene release rate, starch content, protein content, soluble sugar content, vitamin C content, and the shelf life of the fruit.

Determination of respiration rate, ethylene release rate, fruit firmness

The respiration rate and ethylene release of the fruit were measured in a sealed chamber with a volume of 10 L (maintained at a temperature of 30 °C), where each measurement was conducted on a single fruit for 60 min. This was achieved using a CO_2 analyzer with a non-dispersive infrared sensor (Thang et al., 2022) followed by an ethylene gas analyzer equipped with an electrochemical sensor (Tran et al., 2024). After these measurements, fruit firmness was evaluated using a fruit firmness tester (GY-3, Jiangsu, China) with a cylindrical probe. Each fruit was placed on a stable surface, and the probe was gently pressed into the fruit's surface. Care was taken to ensure the probe was positioned perpendicular to the surface to obtain consistent measurements. The maximum force exerted by the probe during penetration was recorded as the fruit's firmness value.

Determination of soluble sugar, starch, protein, and vitamin C

To quantify biochemical components, 1 g of fresh fruit flesh was homogenized with 10 mL of 96% ethanol, followed by heating in a water bath for 15 min. The mixture was then centrifuged at 10,000 rpm for 10 min, and the resulting supernatant was collected. For total sugar determination, 1 mL of the extract was combined with 1 mL of a 5% phenol solution and 5 mL of concentrated sulfuric acid. The optical density (OD) was measured at 490 nm, and sugar content was quantified using a sucrose standard curve (Yue et al., 2022). The residue remaining after sugar extraction was hydrolyzed with 10 mL of 10% HCl and heated in a water bath for 60 minutes. The hydrolysate was neutralized with NaOH, followed by centrifugation to collect the supernatant. Subsequently, 0.5 mL of this extract was mixed with 0.5 mL of dinitrosalicylic acid (DNS) reagent, heated for 3 min in a water bath, and the OD was measured at 530 nm. Starch content was calculated based on a glucose standard curve, applying a conversion factor of 0.9 (Masuko et al., 2005).

For protein analysis, 1 g of fresh fruit tissue was ground in 20 mL of phosphate buffer (pH 7.5), and the mixture was centrifuged to obtain the protein extract. A volume of 0.5 mL of the extract was reacted with 2.5 mL of Bradford reagent, and the OD was recorded at 595 nm. Protein concentration was determined using a standard curve prepared with bovine serum albumin (He, 2011). Vitamin C content was assessed by extracting 1 g of the sample in 10 mL of methanol, followed by centrifugation at 10,000 rpm for 10 min. The supernatant was then mixed with 2 mL of 1% sodium nitroprusside, 1 mL of 1% potassium dichromate, and 1 mL of concentrated sulfuric acid. The OD was measured at 564 nm, and vitamin C concentration was calculated based on a corresponding standard curve (Tran et al., 2024).

Statistical analysis

The experiment was conducted in triplicate using a randomized block design, and the resulting data were analyzed through analysis of variance (ANOVA). To determine significant differences among means at the 5% significance level, Duncan's Multiple Range Test was employed using SPSS version 20.0. Results were expressed as mean values accompanied by their corresponding standard deviations.

Results

Changes in storage time and fruit firmness

Treatment with $KMnO_4$ and activated carbon resulted in a significant extension of the storage life of papaya fruits. Treated fruits exhibited a glossy appearance, with the majority of the peel area retaining its green and yellow-orange coloration, while control fruits experienced browning (Fig. 1). With an increase in the concentration of the treatment mixture, the maximum storage life extended from approximately 10 to 16 d, representing an increase of 60% in the 12 and 15 g per box treatment groups. Additionally, the treated fruits maintained their firmness considerably from 8-12 d. Fruit firmness in the 9, 12, or 15 g per box treatments reached 3.5 kg cm^{-2} on d 12, in contrast to approximately 1 kg cm^{-2} in the control fruits (Fig. 2).

Changes in respiration and ethylene release rate

The results of the statistical analysis revealed that the fruits subjected to treatments involving $KMnO_4$ and activated charcoal exhibited delayed time to peak respiration rate and ethylene production in comparison to the control group (Fig. 3). In the control group, a significant increase in respiration rate was noted from d 8 (approximately 28 mg CO_2 kg^{-1} h^{-1}), reaching its peak on d 10 (around 33 mg CO_2 kg^{-1} h^{-1}), followed by a sharp decline by d 12 (approximately 13 mg CO_2 kg^{-1} h^{-1}). However, the treated fruits demonstrated a gradual rise in respiration rate from d 8 (about 24 mg CO_2 kg^{-1} h^{-1}) to d 10, stabilizing at around 23 mg CO_2 kg^{-1} h^{-1} by d 12. Notably, on d 8 and 10, the respiration rate in the treated fruits was lower compared to the control group; however, this trend reversed by d 12. A similar trend was observed in the ethylene release rate. The control group showed a notably high ethylene release rate on d 8 and 10 (approximately 5 µL kg^{-1} h^{-1}), followed by a 50% decrease by d 12. In contrast, the treated fruits exhibited a low ethylene release rate on d 8 (around 2 µL kg^{-1} h^{-1}), which increased by d 10 and stabilized at around 4 µL kg^{-1} h^{-1} by d 12 (Fig. 3).

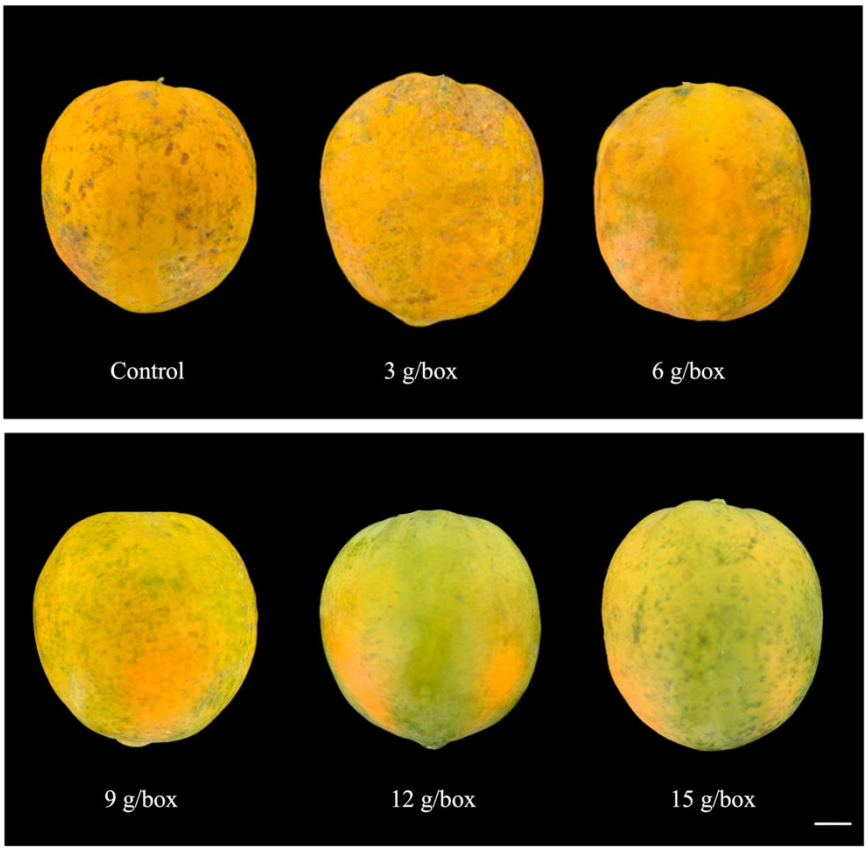

Fig. 1. Variations in fruit color among different treatments using $KMnO_4$ and activated carbon in a 2:1 weight ratio with various concentrations after a period of 12 d. Scale bar = 2 cm.

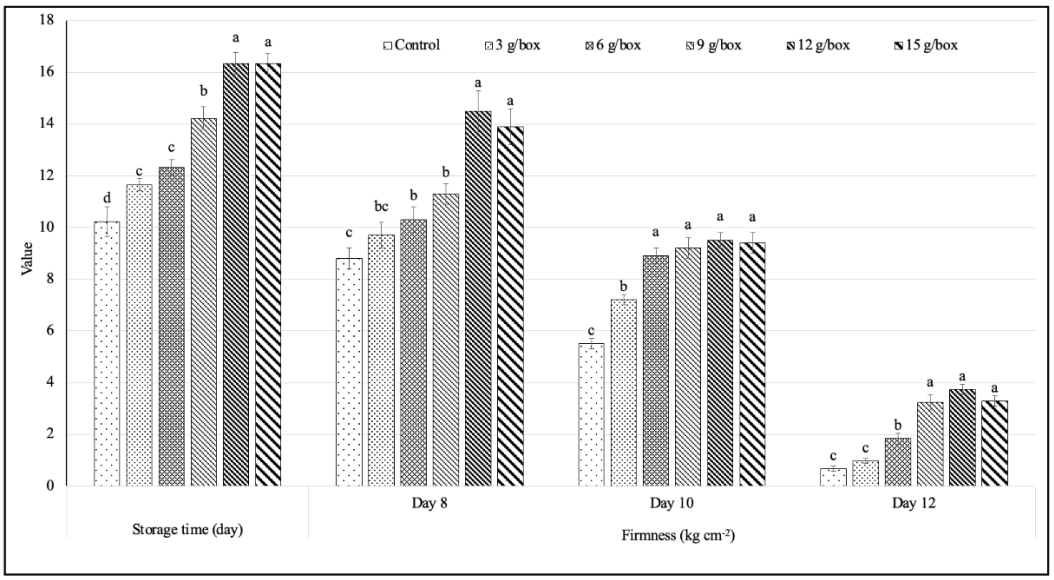

Fig. 2. Changes in storage time and fruit firmness among different treatments using $KMnO_4$ and activated carbon in a 2:1 weight ratio with various concentrations after a period of 12 d (n = 20). Values with different letters are significantly different according to Duncan's test (P = 0.05).

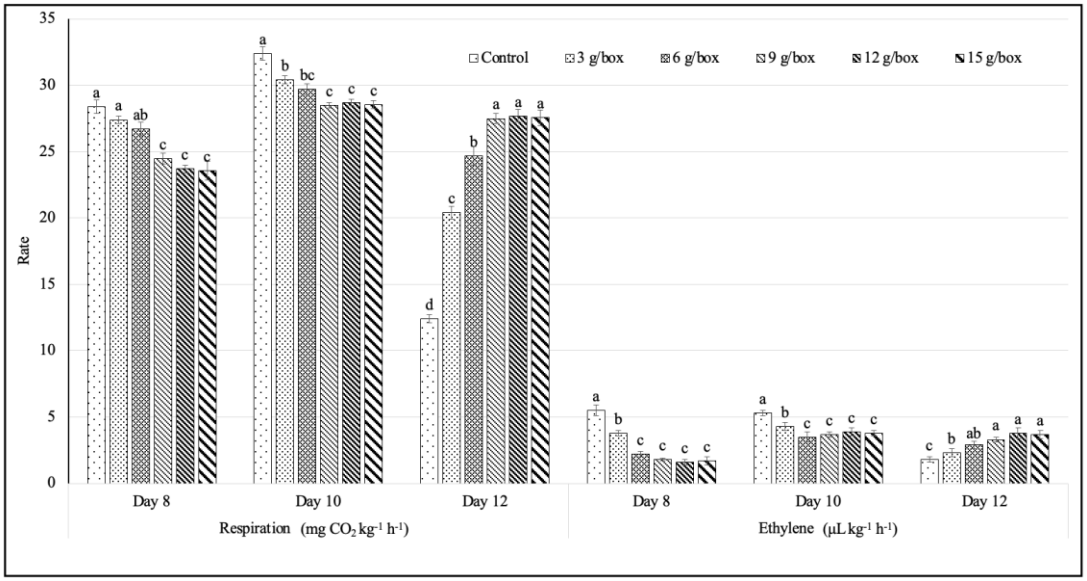

Fig. 3. Changes in respiration rate and ethylene release rate among different treatments using $KMnO_4$ and activated carbon in a 2:1 weight ratio with various concentrations after a period of 12 d (n = 20). Values with different letters are significantly different according to Duncan's test (P = 0.05).

Changes in soluble sugar, starch, protein, and vitamin C content

In terms of the fruit's nutrient content, the application of either 12 or 15 g per box of $KMnO_4$ and activated carbon yielded optimal results. This treatment effectively maintained a high starch content from 8-10 d in comparison to the control. However, by d 12, no significant difference was observed, with levels stabilizing at approximately 9.5 mg g^{-1}. Conversely, the protein content in the treated fruit was lower than that of the control on d 8 (approximately 10 mg g^{-1} compared to 8.2 mg g^{-1}). On d 10, both were around 9.5 mg g^{-1}, while on d 12, the treated fruit exhibited notably higher levels than the control group (around 10 mg g^{-1} compared to 8 mg g^{-1}) (Fig. 4). With respect to the total sugar content, fruits under the control treatment demonstrated consistent maintenance from 8-10 d and experienced a sharp decline by d 12, dropping from 60 mg g^{-1} to approximately 40 mg g^{-1}. Conversely, the treated fruits showcased a substantial increase from around 45 mg g^{-1} on d 8 to

about 68 mg g^{-1} on d 10, maintaining stability at around 60 mg g^{-1} on d 12. Notably, the application of 9, 12, or 15 g box^{-1} of the $KMnO_4$ and activated carbon mixture resulted in an approximate 60 mg g^{-1} increase in total sugar content by d 12, a level approximately 20 mg g^{-1} higher than that of the control (Fig. 5). Furthermore, the utilization of the $KMnO_4$ and activated carbon mixture at 9, 12, or 15 g per box also facilitated an increase in the fruit's vitamin C value. While the vitamin C content in the fruit did not vary among treatments on d 8 (approximately 62 mg 100 g^{-1}), the values on d 10 and 12 demonstrated a decline in the control treatment to around 55 mg 100 g^{-1} and 50 mg 100 g^{-1}, respectively. Conversely, in treated fruits, these values increased to around 67 mg 100 g^{-1} and 65 mg 100 g^{-1} on d 10 and 12, respectively (Fig. 5).

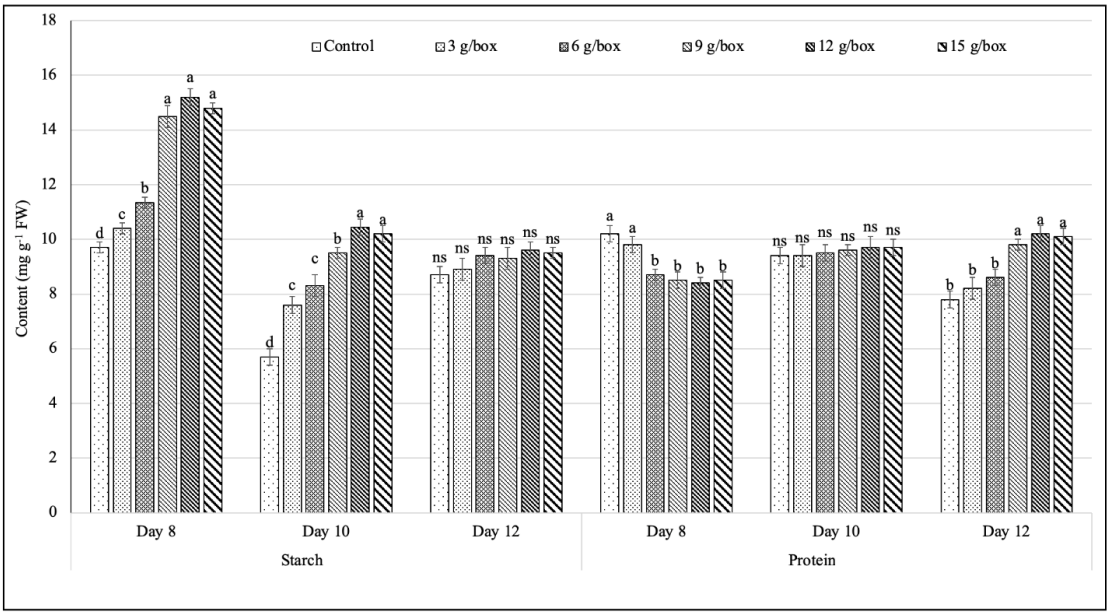

Fig. 4. Changes in starch and protein content among different treatments using $KMnO_4$ and activated carbon in a 2:1 weight ratio with various concentrations after a period of 12 d (n = 20). Values with different letters are significantly different according to Duncan's test (P = 0.05).

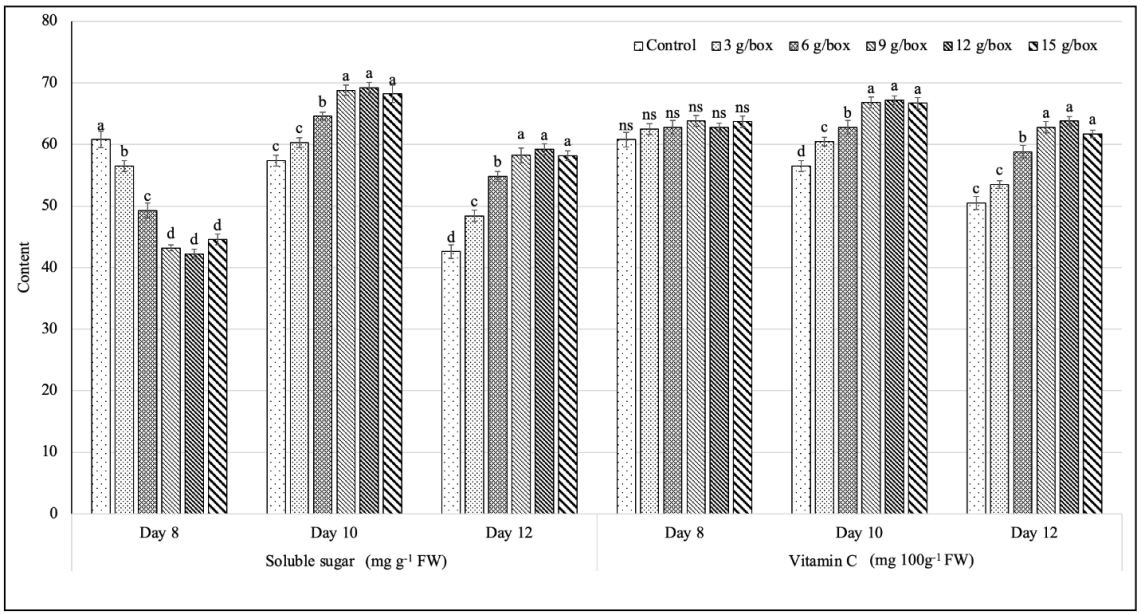

Fig. 5. Changes in soluble sugar and vitamin C content among different treatments using $KMnO_4$ and activated carbon in a 2:1 weight ratio with various concentrations after a period of 12 d (n = 20). Values with different letters are significantly different according to Duncan's test (P = 0.05).

Discussion

The findings of this study demonstrate that the application of potassium permanganate ($KMnO_4$) and activated carbon significantly extends the storage life of papaya fruits from approximately 10 to 16 days (Fig. 2). This notable improvement is good for enhancing the marketability and distribution of papayas, particularly in the context of international trade, where shelf life is a critical determinant of fruit quality and commercial value. The extension of storage duration is primarily attributed to the effective regulation of two key physiological processes—ethylene production and respiration—both of which are integral to fruit ripening and senescence.

Ethylene functions as a plant hormone and signaling molecule that regulates several developmental processes, including the acceleration of fruit ripening (Liu et al., 2024). $KMnO_4$ acts as a potent oxidizing agent that removes ethylene by converting it into carbon dioxide and water (Kumar et al., 2024). This oxidative reaction not only reduces ethylene concentration in the fruit's surrounding environment but also inhibits the respiration process, which is otherwise stimulated by ethylene. Furthermore, when used in conjunction with activated carbon, $KMnO_4$ enhances the adsorption of ethylene, further lowering its levels and thereby retarding the onset of ripening. As a result, $KMnO_4$ treatment slows down respiration and associated metabolic activities, ultimately prolonging the fruit's shelf life and preserving quality. Similar effects have been observed in other climacteric fruits such as chili and mango, where $KMnO_4$ treatment has successfully extended postharvest storage periods (Widdyastuti and Gahayu, 2022; Tran et al., 2024).

Respiration, which involves the uptake of oxygen and release of carbon dioxide, is closely linked to ripening and senescence in fruits (Umeohia and Olapade, 2024). In the control group, the respiration rate peaked at day 10, reaching approximately 33 mg CO_2 kg^{-1} h^{-1}, indicating elevated metabolic activity and accelerated deterioration. In contrast, fruits treated with $KMnO_4$ and activated carbon exhibited a more gradual increase in respiration, with stabilization at significantly lower rates by day 12 (Fig. 3). This trend suggests that the treatment effectively suppresses respiratory activity, delays senescence, and helps maintain firmness and other quality parameters over an extended storage period.

Beyond extending shelf life, the $KMnO_4$ and activated carbon treatment was also found to preserve the nutritional quality of papaya fruits. Treated fruits retained higher levels of protein, total sugars, and vitamin C compared to untreated controls (Figs. 4 and 5). For example, protein content in the treated group increased significantly by day 12, whereas the control group showed a decline. Similarly, total sugar levels rose in treated fruits, contributing to enhanced sweetness and flavor—factors that are vital for consumer acceptance. Preservation of vitamin C, a key nutritional and antioxidant component, was also more effective in treated fruits, thereby enhancing both health benefits and market appeal. Altogether, these results underscore the efficacy of $KMnO_4$ and activated carbon in improving both the physical and nutritional attributes of papayas during storage. By reducing ethylene levels and suppressing respiration, this combined treatment presents a valuable strategy for improving postharvest handling, extending shelf life, and maintaining the commercial quality of papayas and potentially other perishable fruits.

In several studies on the papaya cultivar 'Red Lady,' a 40% extension in shelf life was achieved through the application of zinc oxide and silver nanoparticles at concentrations ranging from 100 to 150 mg L^{-1} (Timilsina et al., 2024). However, the synthesis of these nanoparticles requires advanced techniques and incurs higher production costs, which indirectly elevate the final product price. Moreover, the efficacy of this approach is comparatively lower than that of the combined application of potassium permanganate ($KMnO_4$) and activated carbon, which resulted in a notable 60% extension in shelf life. This outcome also surpasses that of melatonin treatment, where a concentration of 400 μmol L^{-1} applied for 2 hours extended the shelf life from 10 to 13 days—an increase of only 30% relative to the control group (Fan et al., 2022). Despite the significant impact of $KMnO_4$ and activated carbon in prolonging shelf life, this treatment does not effectively mitigate microbial spoilage. In contrast, Yu et al. (2024) demonstrated that the application of thyme oil nanoemulsion at a concentration of 0.25 mg L^{-1} on 'Tainung No. 2' papaya extended shelf life to 16 days by inhibiting surface microbial growth. These findings provide valuable insights into effective postharvest treatment strategies and establish a foundation for continued research in the agricultural sector. There is considerable potential to further enhance fruit preservation techniques that benefit both producers and consumers by integrating physiological senescence inhibition with antimicrobial protection. Future studies could focus on optimizing the concentrations and application methods of $KMnO_4$, activated carbon, and complementary antimicrobial agents, as well as evaluating their effects across a range of fruit cultivars. Such efforts would broaden the scope and practical utility of these findings, ultimately contributing to improved fruit quality and reduced postharvest losses.

Conclusion

The findings of this study demonstrated that the application of 12 g per box of $KMnO_4$ and activated

carbon in a 2:1 ratio is an effective strategy for significantly extending the shelf life of papaya fruits from 10 to 16 days—representing a 60% increase compared to untreated controls. Beyond merely delaying senescence, this treatment also played a key role in preserving nutritional parameters of the fruit, including protein content, total sugars, and vitamin C levels. Such retention of nutritional quality enhances both the health value and market appeal of papayas. These results highlight the potential of this approach as a low-cost, scalable postharvest management strategy, particularly valuable for producers and exporters aiming to meet the demands of international markets where extended shelf life is essential. Moreover, the combined use of $KMnO_4$ and activated carbon offers a promising alternative to more expensive or technically complex methods, such as nanoparticle or hormone-based treatments. Overall, this study contributes practical insights into fruit preservation technologies and provides a foundation for future research aimed at integrating physiological and microbial control for more comprehensive postharvest solutions.

Author contributions

Conceptualization, methodology, software, validation, TTT and NHP; formal analysis, investigation, resources, data curation, NHP; writing—original draft preparation, writing—review and editing, visualization, supervision, TTT. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest

The authors indicate no conflict of interest in this work.

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