Optimizing $KMnO_4$ and activated carbon ratios to extend the shelf life of papaya (*Carica papaya* L.)

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Abstract

The postharvest preservation of papaya (Carica papaya L.) is essential for maintaining fruit quality and extending shelf life. This study investigates the physiological and biochemical changes during the ripening process of papaya and the effects of varying ratios of potassium permanganate ($KMnO_4$) and activated carbon on the storage life and quality of harvested papaya. Fruits were treated with $KMnO_4$ and activated carbon mixtures in ratios of 1:1, 1:2 and 2:1 alongside a control group (no treatment) and stored in cardboard boxes under room temperature conditions (30°C). The ripening process was monitored over time, assessing parameters such as fruit weight, firmness, respiration rate, ethylene production and nutritional content including starch, sugars, proteins, carotenoids, vitamins E and C. Results demonstrated that the 2:1 $KMnO_4$ to activated carbon ratio significantly extended the storage life to 14.33 days, compared to 10.66 days for the control.

This treatment also preserved fresh weight (536.73 g), dry weight (38.83 g) and firmness (0.85 kg/cm²), while effectively reducing respiration (11.11 mg CO_2/g/h) and ethylene release (1.91 µl/kg/h). Additionally, soluble sugar and starch levels were enhanced, contributing to better flavor and nutritional value. The findings suggest that optimizing the combination of $KMnO_4$ and activated carbon can substantially improve postharvest preservation strategies for papaya, benefitting growers and consumers alike.

Keywords: Activated carbon, $KMnO_4$, papaya, postharvest, shelf life.

Introduction

The postharvest preservation of fruits is a critical aspect of the agricultural industry, directly affecting the quality and shelf life of produce. Among tropical fruits, papaya (*Carica papaya* L.) stands out for its delicious taste, nutritional benefits and medicinal properties, making it highly valued in both local and international markets[5]. Widely cultivated in many countries, papaya plays a significant role in the economy, contributing to the livelihoods of farmers and suppliers. However, its highly perishable nature poses challenges for storage and transportation, often leading to significant losses in both quality and quantity[13]. Effective preservation techniques are essential to maintain the freshness and nutritional value of papaya during its journey from farm to consumer.

In recent years, there has been growing interest in exploring novel postharvest treatments to extend the storage life and to enhance the quality of papaya. Various methods, including controlled atmosphere storage, refrigeration and the use of natural preservatives, have been researched. Among these, potassium permanganate ($KMnO_4$) and activated carbon have gained attention for their promising roles in delaying fruit ripening, inhibiting microbial growth and reducing oxidative damage[3].

$KMnO_4$ is particularly effective due to its ability to decompose ethylene, a key hormone that accelerates ripening, into water and carbon dioxide. This reaction helps to slow down the ripening process and to prolong the storage life of fruits[8]. Meanwhile, activated carbon acts through adsorption, effectively trapping ethylene and other volatile compounds that contribute to spoilage. By removing these substances from the surrounding environment, activated carbon further aids in maintaining the quality of harvested fruits[4]. Previous research has primarily focused on the individual effects of these compounds on postharvest preservation. While results have shown that both $KMnO_4$ and activated carbon can be effective, studies combining these compounds remain scarce.

The interactions between them and their combined effects on papaya preservation have not been thoroughly investigated. Notably, the effectiveness of these compounds is significantly influenced by their ratio, which can affect their efficacy in preserving fruit quality[16]. To better understand the effectiveness of preservation methods such as $KMnO_4$ and activated carbon on papaya, it is essential to study the fruit's ripening process. This process involves significant physiological and biochemical transformations including increased ethylene production and other compounds related to ripening.

Therefore, this study aims to fill this research gap by investigating the ripening process of papaya under normal conditions and examining the postharvest effects of different ratios of $KMnO_4$ and activated carbon on the storage life and quality of papaya. By optimizing the combination of these compounds at suitable ratios, this research seeks to maximize their potential synergistic effects, leading to improved preservation outcomes. The findings of this study will contribute to the development of optimized postharvest preservation strategies for papaya, benefitting growers, suppliers and consumers in the agricultural industry. Ultimately, enhancing the storage life and quality of papaya can lead to reduced waste, increased marketability and improved nutritional access for consumers.

Material and Methods

Plant material and investigation of ripening process of papaya over time: The papaya fruits in a physiologically mature state were harvested in Cai Be district, Tien Giang province, Vietnam. Physiologically mature papaya fruits with an average weight of about 600 g were selected. External dirt was removed and the fruits were treated with 2.5% $CaCl_2$ for 15 minutes, then allowed to dry before being transported to the Department of Plant Physiology, Faculty of Biology and Biotechnology, University of Science, Vietnam National University, Ho Chi Minh City. Upon arrival at the laboratory, the fruits were placed under room temperature conditions (30°C). The ripening process was observed over time, noting parameters such as fruit weight, fruit firmness, respiration rate, ethylene gas production and nutritional content (starch, total sugar, protein, carotenoid, vitamin C and vitamin E).

Investigation of effects of $KMnO_4$ and activated carbon ratios on the quality of harvested papaya: The fruits were placed in cardboard boxes (50 x 40 x 32 cm) with six fruits per box upon arrival at the laboratory. Each box contained a bag with 6 g of a mixture of $KMnO_4$ and activated carbon in varying ratios of 1:1, 1:2, 2:1 and a control group (no treatment). The cardboard boxes were stored under room temperature conditions (30°C). The ripening process was observed over time, noting parameters such as fruit weight, fruit firmness, respiration rate, ethylene gas production and nutritional content (starch, total sugar, protein, carotenoid, vitamin C and vitamin E).

Determination of fruit firmness, respiration rate and ethylene release rate: Fruit firmness was measured using a fruit firmness tester (GY-3, Jiangsu, China) equipped with a cylindrical probe, with results expressed in kg/cm^2. The respiration rate of the fruit was assessed using a CO_2 analyzer featuring a non-dispersive infrared sensor, operated within a sealed chamber[15]. Ethylene production was measured with an ethylene gas analyzer (SKY2000-C2H4, Safegas, China) that utilizes an electrochemical sensor, also connected to a sealed chamber[16].

Determination of soluble sugar, starch and protein: A sample of 1 g of fresh fruit flesh was ground with 10 mL of 96% ethanol, which was heated in a water bath for 15 minutes. The mixture was then centrifuged at 10,000 rpm for 10 minutes to collect the supernatant. To determine total sugar content, 1 mL of the extract was combined with 1 mL of a 5% phenol solution and 5 mL of concentrated H_2SO_4. The optical density was measured at 490 nm and total sugar content was calculated using a sucrose standard curve[11]. The residue from the sugar extraction was hydrolyzed with 10 mL of 10% HCl, also heated in a water bath for 60 minutes. After hydrolysis, the solution was neutralized with NaOH and centrifuged to collect the supernatant. For starch determination, 0.5 mL of the extract was mixed with 0.5 mL of DNS reagent and heated in a water bath for 3 minutes.

The optical density was then measured at 530 nm, with starch content calculated based on a glucose standard curve using a conversion factor of 0.9[12]. Additionally, 1 g of fresh fruit flesh was ground in 20 mL of phosphate buffer (pH 7.5). The mixture was centrifuged to obtain the protein extract. To measure protein content, 0.5 mL of the protein extract was combined with 2.5 mL of Bradford reagent and the optical density was measured at 595 nm[2]. Protein content was calculated using a standard albumin curve.

Determination of carotenoid, vitamin E and C: A sample of 1 g of fresh fruit flesh was ground with 5 mL of 96% ethanol. The mixture was then centrifuged at 5,000 rpm for 3 minutes and the supernatant was collected. The optical density was measured at 470 nm, 648 nm and 664 nm to assess the carotenoid content[9]. To determine the quantities of vitamins E and C, another 1 g sample was ground with 10 mL of methanol solution. This extract was centrifuged at 10,000 rpm for 10 minutes and the supernatant was collected. Subsequently, 1 mL of the extract was mixed with 2 mL of 1% sodium nitroprusside, 1 mL of 1% potassium dichromate and 1 mL of concentrated sulfuric acid. The optical density was measured at a wavelength of 564 nm. The concentrations of vitamins E and C were calculated by comparing the results to their respective standard curves[14].

Statistical analysis: The experiment was conducted thrice utilizing a randomized block design and the resultant data underwent analysis through ANOVA. In order to discern the means at a significance level of 5%, Duncan's multiple range test was administered using SPSS 20.0. The findings were subsequently presented as the mean accompanied by the standard deviation.

Results

The ripening process of papaya over time: As fruits ripen, various changes take place in their color, weight, respiration rate and nutrient content. Initially, the flesh of the fruit is yellow, but over the course of days 1-3, it transits to orange-red in half of the fruit. Then, over days 4-5, the other half of the fruit undergoes the same color change. From days 6-8, the entire flesh of the fruit undergoes a complete color change, while the skin turns completely yellow. By day 9, the flesh becomes deep orange-red and small brown spots appear on the skin. Eventually, the brown spots on the skin spread and the flesh gradually became pale, not meeting commercial standards by day 10 (Fig. 1). During the ripening process, the weight and fruit firmness of the fruit gradually decreased, with a noticeable decrease in dry weight from day 7 to day 10 (Fig. 2A and B).

At the same time, the respiration rate and ethylene content increased significantly, peaking on day 7 (at 11.77 mg

CO_2/g/h) and day 6 (at 3.43 µl ethylene/kg/h) respectively. However, after reaching their peak, the respiration rate and ethylene content decrease sharply and continuously (Fig. 2C). Regarding the nutrient content of the fruit, various changes occur during the ripening process. The sugar and protein content increase continuously, reaching their respective peaks on days 8 and 6 (with values of 56.46 mg/g and 6.1 mg/g respectively). Subsequently, the sugar and protein content gradually decrease. The starch content, on the other hand, decreases continuously from day 0 to day 10 (Fig. 3A). The levels of carotenoids, vitamin C and vitamin E also increase significantly from day 0 to day 6, after which they stabilize and begin to decline on day 10 (Fig. 3B).

Effects of $KMnO_4$ and activated carbon ratios on the quality of harvested papaya: The effects of different $KMnO_4$ and activated carbon ratios on the quality of harvested papaya reveal that the 2:1 ratio is the most effective treatment (Table 1 and fig. 4). With a storage time of 14.33 days, the 2:1 ratio significantly extends shelf life, surpassing the control's 10.66 days and the shorter durations of the 1:1 and 1:2 ratios. This treatment also maintains the highest fresh weight (536.73 g) and dry weight (38.83 g), indicating better mass retention and overall quality. Additionally, firmness is maximized at 0.85 kg/cm², suggesting enhanced structural integrity. The 2:1 ratio effectively reduces respiration rate to 11.11 mg CO_2/g/h and ethylene release to 1.91 µl/kg/h, both of which are critical for slowing ripening.

In contrast, the control group exhibits the highest respiration and ethylene production, leading to accelerated ripening. Furthermore, the 2:1 treatment enhances soluble sugar and starch content, contributing to improved flavor and nutritional value. While protein and carotenoid levels remain stable across treatments, vitamins E and C are elevated in the 2:1 ratio, indicating better nutritional benefits.

Figure 1: The ripening of papaya fruits progresses over time after harvest.

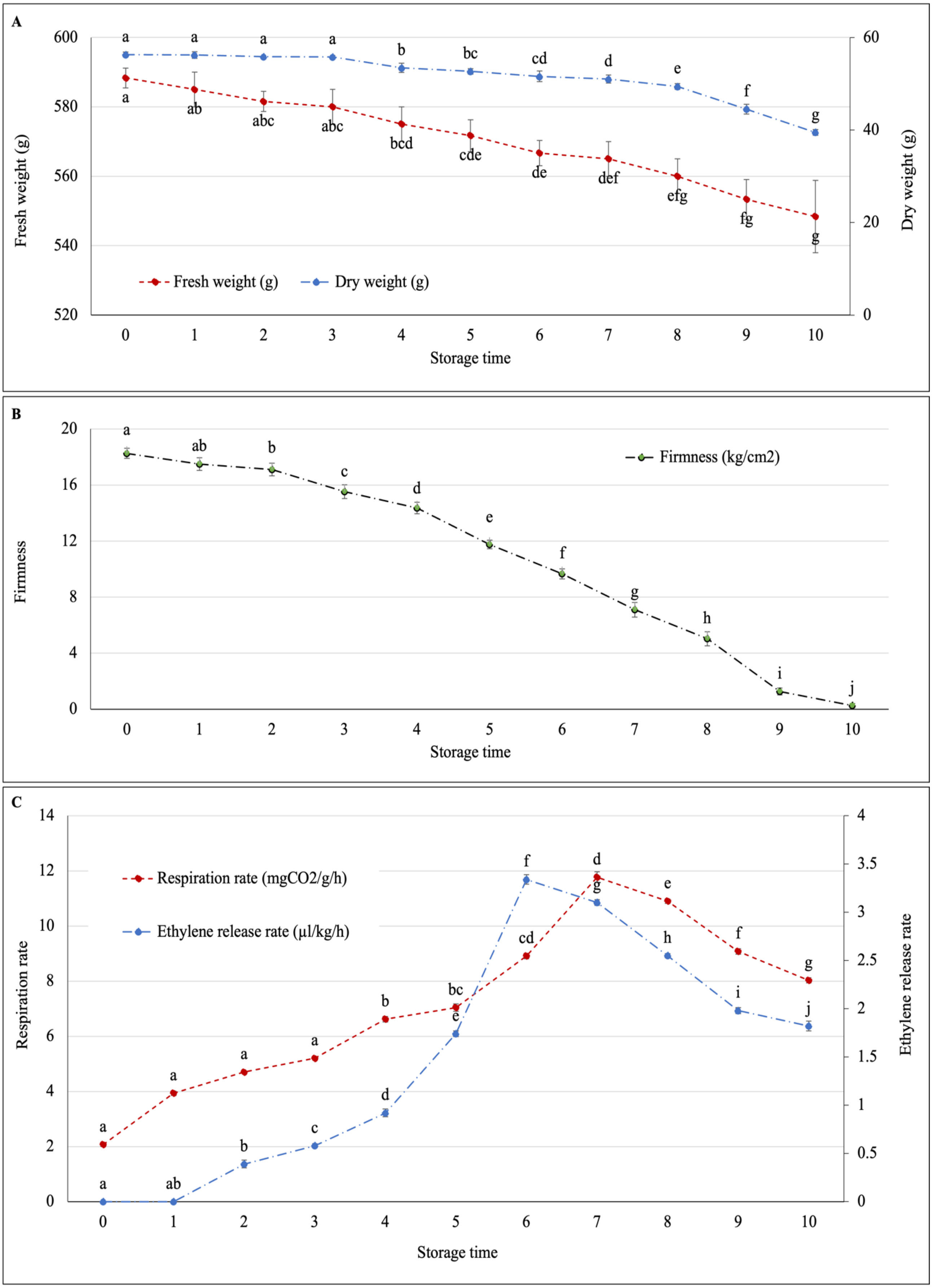
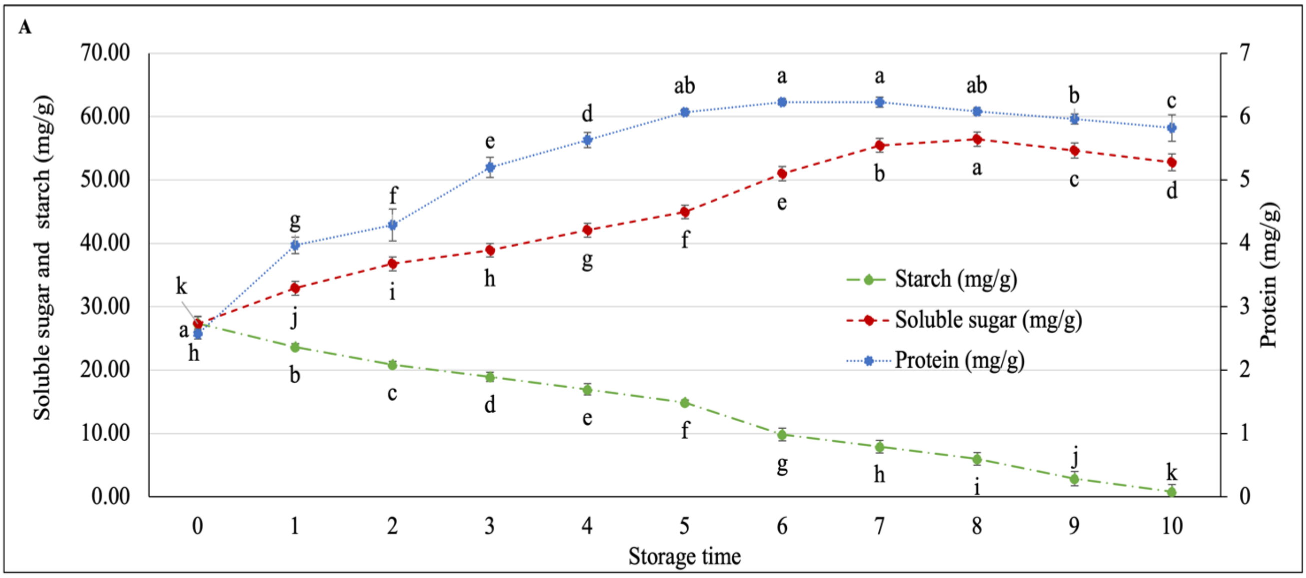


Figure 2: The physiological changes during the post-harvest ripening process of papaya. (A) fresh and dry weight; (B) fruit firmness; (C) respiration and ethylene release rate. Values with different letters are significantly different according to Duncan's test (p=0.05)



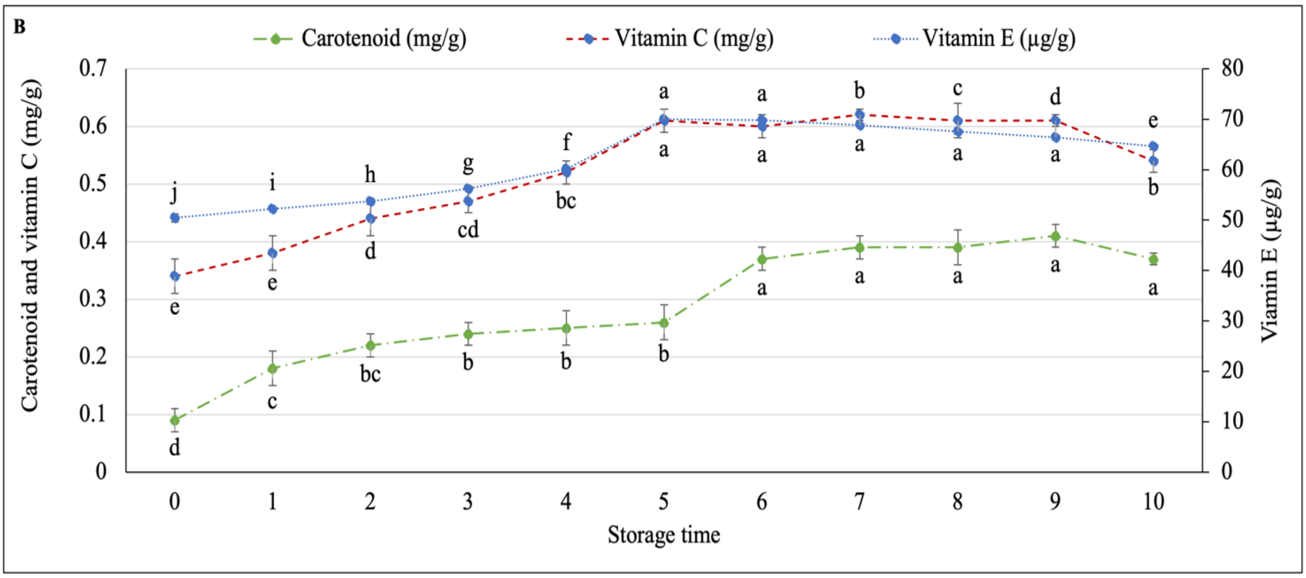


Figure 3: The biochemical changes during the post-harvest ripening process of papaya. (A) the content of soluble sugar, starch and protein; (B) the content of carotenoid, vitamin C and E. Values with different letters are significantly different according to Duncan's test (p=0.05)

Table 1
Effects of $KMnO_4$ and activated carbon ratios on the quality of harvested papaya after 15 days

Treatment	Control	$KMnO_4$ and activated carbon ratios		
		1 : 2	1 : 1	2 : 1
Storage time (day)	10,66 ± 0,57 ^{c}	11,00 ± 0,21 ^{c}	12,00 ± 0,53 ^{b}	14,33 ± 0,57 ^{a}
Fresh weight (g)	491,00 ± 7,00 ^{b}	497,00 ± 4,00 ^{b}	535,67 ± 8,72 ^{a}	536,73 ± 7,00 ^{a}
Dry weight (g)	30,12 ± 0,16 ^{b}	30,03 ± 0,20 ^{b}	37,33 ± 0,15 ^{a}	38,83 ± 0,42 ^{a}
Firmness (kg/cm^2)	0,43 ± 0,25 ^{b}	0,26 ± 0,11 ^{c}	0,87 ± 0,03 ^{a}	0,85 ± 0,36 ^{a}
Respiration ($mgCO_2/g/h$)	12,53 ± 0,17 ^{a}	11,15 ± 0,17 ^{b}	11,08 ± 0,07 ^{b}	11,11 ± 0,09 ^{b}
Ethylene release (µl/kg/h)	2,38 ± 0,03 ^{a}	2,45 ± 0,03 ^{a}	2,02 ± 0,05 ^{b}	1,91 ± 0,05 ^{b}
Soluble sugar (mg/g)	50,73 ± 0,25 ^{d}	52,33 ± 0,34 ^{c}	54,16 ± 0,14 ^{b}	55,71 ± 0,25 ^{a}
Starch (mg/g)	0,28 ± 0,03 ^{d}	0,82 ± 0,29 ^{c}	1,87 ± 0,18 ^{b}	2,46 ± 0,20 ^{a}
Protein (mg/g)	5,33 ± 0,07 ^{ns}	6,00 ± 0,11 ^{ns}	5,70 ± 0,15 ^{ns}	5,97 ± 0,18 ^{ns}
Carotenoid (mg/g)	0,48 ± 0,03 ^{ns}	0,47 ± 0,04 ^{ns}	0,49 ± 0,01 ^{ns}	0,47 ± 0,02 ^{ns}
Vitamin E (µg/g)	62,99 ± 0,11 ^{c}	63,64 ± 0,45 ^{bc}	65,33 ± 0,12 ^{a}	65,32 ± 0,25 ^{a}
Vitamin C (mg/g)	0,58 ± 0,02 ^{b}	0,58 ± 0,01 ^{b}	0,62 ± 0,03 ^{a}	0,64 ± 0,03 ^{a}

Values with different letters in a row are significantly different with Duncan's test (p=0.05)

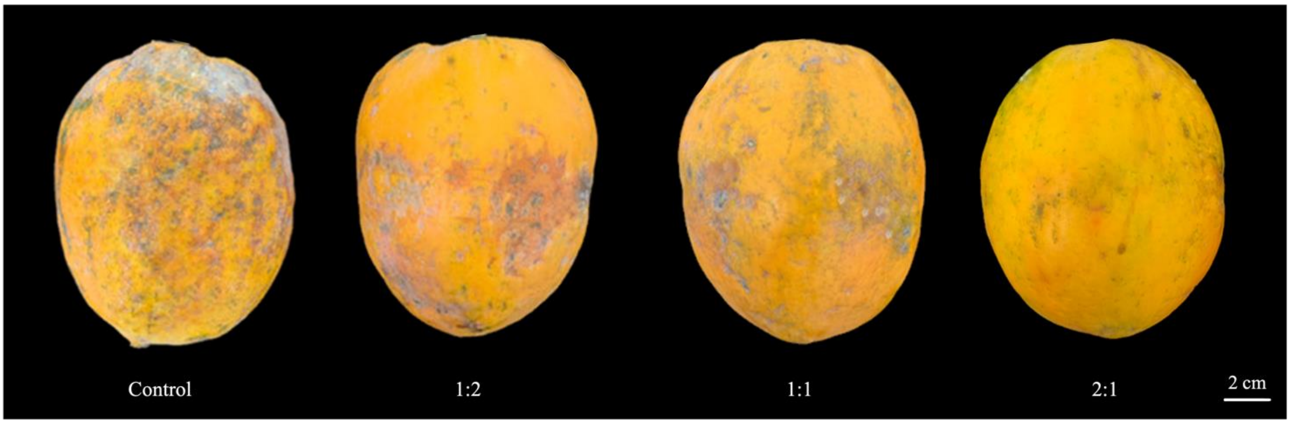


Figure 4: Effects of $KMnO_4$ and activated carbon ratios on the quality of harvested papaya after 15 days

Discussion

As fruits ripen, they undergo a complex series of physiological and biochemical changes that significantly impact their color, weight, respiration rate and nutrient content. For papaya, these changes are particularly pronounced and can be observed over a span of just ten days (Fig. 1). Initially, the flesh of the papaya begins as a yellow hue. Within the first three days, this color transits to an orange-red in half of the fruit, signaling the onset of ripening. This gradual change is primarily driven by the production of pigments such as carotenoids, which are responsible for the fruit's vibrant color[6]. The complete color transformation occurs by day 9, as the entire flesh adopts the deep orange-red color, while the skin turns a bright yellow.

The appearance of small brown spots on the skin indicates the fruit's aging process and as these spots spread, the flesh begins to pale, failing to meet commercial standards by day 10. This decline in quality is often linked to the breakdown of cellular structures and the accumulation of undesirable compounds that occur as the fruit continues to ripen[1]. Throughout this ripening process, both the weight and firmness of the fruit decrease significantly (Fig. 2 A and B). Notably, the dry weight experiences a marked decline from day 7 to day 10, which can be attributed to moisture loss and the breakdown of structural polysaccharides in the fruit's cell walls. As the fruit ripens, enzymes such as cellulase and pectinase become more active, leading to the softening of the flesh[17]. This softening is desirable for taste and texture but also indicates a loss of structural integrity.

Accompanying these physical changes is an increase in the respiration rate and ethylene production, both of which peak on days 7 and 6 respectively (Fig. 2C). Ethylene is a key plant hormone that regulates ripening; its production triggers a series of metabolic processes that accelerate ripening[7]. The peak in respiration rate reflects the heightened metabolic activity as the fruit transits from a mature to a ripe state. However, after reaching these peaks, both the respiration rate and ethylene content decline sharply, which may suggest that the fruit has reached a stage of over-ripeness, leading to senescence. Nutritionally, the changes during ripening are quite dynamic. The sugar and protein content increase steadily, reaching their maximum levels on days 8 and 6 respectively (Fig. 3A). This increase is often associated with the breakdown of starches into simpler sugars, enhancing the fruit's sweetness.

However, after these peaks, both sugar and protein levels begin to decrease, likely due to the fruit's energy expenditure in respiration and the conversion of nutrients into energy to support continued metabolic activity. Conversely, starch content decreases continuously from day 0 to day 10, indicating that starch is being converted into sugars (Fig. 3A). This biochemical transition is crucial for flavor development, as the increase in soluble sugars contributes to the fruit's palatability. The levels of carotenoids, vitamin C and vitamin E also rise significantly until day 6, after which they stabilize and begin to decline by day 10 (Fig. 3B). The increase in these vitamins during the initial stages of ripening is important, as they play vital roles in human nutrition and antioxidant activity[10].

The study's findings regarding the effects of varying ratios of $KMnO_4$ and activated carbon on the quality of harvested papaya reveal that a 2:1 ratio is the most effective treatment. This combination extends the storage life to 14.33 days, significantly surpassing the control group's 10.66 days and the shorter durations observed with the 1:1 and 1:2 ratios (Table 1 and fig. 4). The extended shelf life can be attributed to the ability of $KMnO_4$ to absorb ethylene, thereby slowing down the ripening process[3,16]. By reducing ethylene levels in the storage environment, the 2:1 ratio effectively mitigates the physiological changes associated with ripening.

Additionally, the 2:1 treatment maintains the highest fresh weight (536.73 g) and dry weight (38.83 g), indicating better mass retention and overall quality. This improved quality is further evidenced by the maximized firmness at 0.85 kg/cm², suggesting enhanced structural integrity. The reduction in respiration rate to 11.11 mg CO_2/g/h and ethylene release to 1.91 µl/kg/h under this treatment is critical for slowing ripening, as elevated respiration rates are often linked to faster deterioration. In contrast, the control group exhibits the highest respiration and ethylene production, leading to accelerated ripening and subsequent quality loss. The 2:1

treatment also enhances soluble sugar and starch content which contribute to improved flavor and nutritional value. Protein and carotenoid levels remain stable across different treatments whereas the elevated levels of vitamins E and C in the 2:1 ratio indicate enhanced nutritional benefits. These vitamins are crucial for consumer health, making the 2:1 treatment particularly valuable. This is explained by activated carbon adsorbing ethylene due to its high surface area and porous structure, reducing its concentration and slowing down the ripening process[4]. Meanwhile, $KMnO_4$ aids in the decomposition of ethylene, further enhancing its effectiveness[18]. This optimal ratio ensures a balanced approach, maximizing both adsorption and decomposition and ultimately extending the shelf life and quality of the fruit.

Conclusion

This study confirms that optimizing the ratio of $KMnO_4$ and activated carbon enhances the postharvest preservation of papaya. The 2:1 ratio significantly extended shelf life to 14.33 days, improved fruit quality by maintaining weight and firmness and reduced respiration and ethylene production. These results indicate that optimized treatments can effectively reduce losses and can enhance the quality of papaya for consumers.

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