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Effectiveness of $KMnO_4$ and activated carbon on the quality and storage properties of mango fruit

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Abstract: Cat Hoa Loc mango (*Mangifera indica* L.) is a well-known variety in Vietnam because of its distinct taste and aroma. However, it has a short shelf life and can suffer post-harvest losses if not handled and packaged correctly. The demand for fresh Cat Hoa Loc mangoes has been increasing worldwide, and this has led to the development of effective handling methods to extend their shelf life. To address this issue, this study was conducted to evaluate the effectiveness of $KMnO_4$ and activated carbon in preserving the quality and shelf life of Cat Hoa Loc mangoes in Vietnam. The Cat Hoa Loc mango variety in Cao Lanh, Dong Thap province, was chosen for the study. The study used five replications of a completely randomized block design. Six different treatments with $KMnO_4$ and activated carbon (1:1 ratio) were tested, including 0; 4; 8; 12; 16; 20 g/box. Six mangoes were stored in perforated cartons (36x26x9 cm) at room temperature (28-30°C) during the study period. The study evaluated several parameters to assess the quality and shelf life of the mangoes, including weight loss, fruit firmness, browning index, respiration, ethylene release rate, soluble sugar, and vitamin C. The results showed that the quality of the mangoes was extended when treated with 12 g of $KMnO_4$ and activated carbon per box. This treatment resulted in the lowest physiological weight losses, respiration, and ethylene release rate. Furthermore, this treatment showed the highest fruit firmness, soluble sugar, and vitamin C content, as well as the longest shelf life at the end of the storage period.

1. Introduction

Cat Hoa Loc mango (*Mangifera indica* L.) is a popular tropical fruit variety known for its unique flavor, aromatic fragrance, and vibrant color. It is highly valued for its nutritional content, abundant vitamins, and minerals (Athoo *et al.,* 2024). Cat Hoa Loc mangoes have gained

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significant recognition both domestically and internationally and are widely exported to various markets. Despite its popularity and economic importance, Cat Hoa Loc mango faces challenges related to its postharvest shelf life. The limited shelf life poses a considerable threat to its preservation and exportation (Nguyen *et al.,* 2024). To overcome this challenge, researchers and experts have focused on developing postharvest preservation methods to minimize quality deterioration and extend the shelf life of Cat Hoa Loc mangoes. Previous research focused on mango preservation has employed essential oils derived from four aromatic plant species, namely *Thymus vulgaris*, *Salvia mirzayanii*, *Artemisia persica,* and *Rosmarinus officinalis*. The objective has been to impede the proliferation of *Aspergillus niger*, thus prolonging the fruit's storage viability (Javadpour *et al.,* 2018). In addition to essential oils, a spectrum of chemical agents has been extensively utilized for fruit preservation. For instance, potassium phosphite has been employed in the preservation of *Citrus clementina*, while a composite of alginate and *Cyclea barbata* leaf powder has been implemented for guava preservation (Strano *et al.,* 2015; Utama *et al.,* 2022). In the various preservation methods, the use of potassium permanganate ($KMnO_4$) and activated carbon has gained attention. $KMnO_4$ has been utilized in the postharvest management of peaches and mangoes to uphold their quality (Alonso-Salinas *et al*., 2023; Fatima *et al*., 2023). The research findings indicate that the application of 30 g $KMnO_4$ is optimal for preserving and enhancing the color, taste, aroma, firmness, total sugar, pH, and total soluble solids of the fruits, while minimizing weight loss and waste percentage over a 20-day storage period (Fatima *et al*., 2023). Potassium permanganate is a powerful oxidizing agent with antimicrobial properties. When used in postharvest preservation, $KMnO_4$ can effectively inhibit the growth of pathogens and spoilage microorganisms that contribute to the deterioration of fruits (Alonso-Salinas *et al.,* 2023). The antimicrobial action of $KMnO_4$ is attributed to its ability to oxidize the cellular metabolism of microorganisms. $KMnO_4$ can interfere with the vital biochemical processes of microbes, such as respiration and energy production, which are essential for their survival and proliferation. The strong oxidizing properties of $KMnO_4$ can target and oxidize key enzymes and other critical cellular components involved in these metabolic pathways. This oxidative damage can impair the microorganism's ability to carry out normal metabolic functions, ultimately disrupting its ability to function and survive (Rudra *et al.,* 2013). By inhibiting microbial growth, $KMnO_4$ treatment helps to extend the shelf life of Cat Hoa Loc mangoes and maintain their quality during storage and transportation. However, the oxidation of ethylene by $KMnO_4$ requires time, so it is necessary to supplement with some ethylene-adsorbing carriers with porous structures and large surface areas to facilitate the redox reaction. In food preservation, activated carbon has a high capacity for adsorbing ethylene, especially in the form of granular activated carbon. Activated carbonis a highly porous material with a large surface area, which gives it excellent adsorption properties (Roopa *et al*., 2023). When applied in postharvest preservation of fruits, activated carbon acts as a purification agent by adsorbing and removing harmful substances such as ethylene gas, volatile compounds, and toxins (Nooun *et al.,* 2023). Ethylene is a natural plant hormone that accelerates the ripening process in fruits. By adsorbing ethylene, activated carbon helps low the ripening process, thus extending the shelf life. Additionally, activated carbon can also adsorb volatile compounds responsible for off-flavors and odors, thereby preserving the sensory quality of the fruit. Therefore, the objective of this research is to assess the effectiveness of potassium permanganate and activated carbon treatments on various quality parameters of postharvest Cat Hoa Loc mango. By studying the physiological and biochemical changes that occur during the ripening process under the influence of $KMnO_4$ and activated carbon, this research aims to optimize postharvest treatments to improve fruit quality, reduce losses, extend shelf life, and ensure a higher yield of marketable Cat Hoa Loc mangoes. The findings of this study will contribute to a better understanding of the preservation techniques for Cat Hoa Loc mangoes, enhancing their market value and global competitiveness.

2. Materials and Methods

Plant material and experimental design

The Cat Hoa Loc mangoes were harvested from a commercial orchard located in Cao Lanh City, Dong Thap Province, Vietnam. On May 25, 2023, mango fruits were collected from homogenous plants using

a randomized block pattern. The fruits, with an average weight of about 450 g, were picked precisely 85 days after the fruit set and were carefully hand-picked. After being picked, the mangoes were transported to the University of Science, located in Ho Chi Minh City. A total of 180 mango fruits were used and distributed into five replications using a completely randomized block design. Each replication consisted of six mangoes that were stored in perforated cartons (36 cm x 26 cm x 9 cm). To test the effects of $KMnO_4$ and activated carbon, a bag containing a mixture of the two substances in a 1:1 ratio was placed in each carton. The weight of the mixture ranged from 0, 4, 8, 12, 16, and 20 g per box. The mangoes were stored at a constant temperature of 28-30°C and ambient humidity of 70-80% throughout the study. The research evaluated several parameters, including weight loss, fruit firmness, color, browning index, respiration rate, ethylene release rate, soluble sugar content, vitamin C content, and the shelf life of the mangoes.

Determination of weight loss and browning index

Weight loss is determined by recording the initial weight of the fresh sample. After the storage period, the final weight is determined. The percentage of difference between the initial and final weight to initial weight represents the physiological weight loss (Workneh *et al*., 2012). The color of the outer layer of the fruit was determined using the L*a*b* (CIELAB) color space of a digital color meter from Apple Inc. To calculate the browning index (BI), the formula proposed by Ruangchakpet and Sajjaanantakul (2007) was used:

$$[100\ (x - 0.31)]/0.17.$$

In this formula, x is calculated as (a* + 1.75 L*)/(5.645 L* + a* −0.3012b*).

Determination of fruit firmness, respiration rate, and ethylene release rate

The fruit firmness was evaluated using a fruit firmness testing device (GY-3, Jiangsu, China) equipped with a cylindrical probe. For the assessment of the fruit's respiration rate in a sealed chamber, a CO_2 analyzer with a non-dispersive infrared sensor was utilized (Thang *et al*., 2022). Furthermore, the release of ethylene gas was determined by utilizing an ethylene gas analyzer with an electrochemical sensor (SKY2000-C_2H_4, Safegas, China) connected to the same sealed chamber.

Determination of soluble sugar and vitamin C

To determine the total sugar content, fresh fruit flesh (1 g) was finely ground and mixed with 10 mL of 96% ethanol. Following this, the mixture was heated in a water bath for 15 min and subjected to centrifugation at 10,000 rpm for 10 min to obtain the supernatant. Then, 1 mL of the extracted solution was combined with 1 mL of a 5% phenol solution and 5 mL of concentrated H_2SO_4. The resultant mixture was allowed to react, and the optical density was measured at a wavelength of 490 nm. The total sugar content was then calculated using a sucrose standard curve as a reference (Dubois *et al.,* 1956). To quantify the amount of vitamin C, 1 g of the sample was ground and mixed with 10 mL of a methanol solution. Subsequently, the mixture was centrifuged at 10,000 rpm for 10 min, and the supernatant was collected. Next, 1 mL of the extracted solution was combined with 2 mL of 1% sodium nitroprusside, 1 mL of 1% potassium dichromate, and 1 mL of concentrated sulfuric acid. The resultant mixture underwent a reaction, and the optical density was measured at a wavelength of 564 nm. The content of vitamin C was then determined by comparing it to a corresponding standard curve (Saeed *et al*., 2018).

Statistical analysis

The collected data was subjected to an analysis of variance (ANOVA) to determine the significant differences among the means at a 5% probability level. Duncan's Multiple Range Test was then employed using SPSS 20.0 to identify the significant differences. The results were presented as the mean values together with their corresponding standard deviations, and the 'ns' indicates that the differences were not statistically significant.

3. Results

The changes in weight loss and browning index

The utilization of $KMnO_4$ and activated C in mango preservation has yielded noteworthy results. The experiment revealed that on days 8 and 10, the control group and treated groups of 4, 12, 16, and 20 g/box did not exhibit significant differences in weight loss. However, the treated group with 8 g/box demonstrated a noticeable reduction in weight loss

percentage. Moreover, the treatment with $KMnO_4$ and C significantly enhanced the color changes in the mangoes. The treated fruit manifested a lower browning index than the control group. The flesh of the treated mangoes retained a vibrant, fresh yellow color, while the skin remained a bright green (Figs. 1 and 2).

Fig. 1 - The variations in fruit color among different treatments using $KMnO_4$ and C with various concentrations after a period of 12 days.

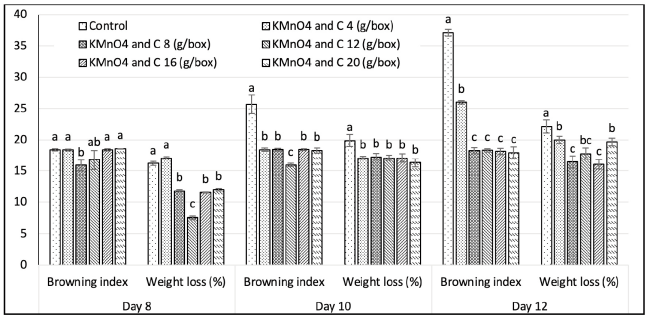

Fig. 2 - The changes in weight loss and browning index during the post-harvest ripening process of mango. Values with different letters are significantly different according to Duncan's test (p=0.05).

The changes in fruit firmness, respiration rate, and ethylene release rate

Throughout the course of the analysis period, the fruit's firmness gradually decreased. However, treatments utilizing $KMnO_4$ and activated carbon proved effective in maintaining the fruit's firmness across all three-time points analyzed. Of the treatments tested, $KMnO_4$ and activated carbon at a concentration of 12 g/box delivered the most effective outcomes in preserving fruit firmness. Similarly, the utilization of $KMnO_4$ and activated carbon treatments allowed for the extension of both the ethylene peak and respiration rate. In the control group, respiration intensity and ethylene release were high on the eighth day, decreasing gradually on days 10 and 12. In contrast, the fruits treated with $KMnO_4$ and activated carbon exhibited two peaks of ethylene release and respiration rate, occurring on day 10 (Fig. 3).

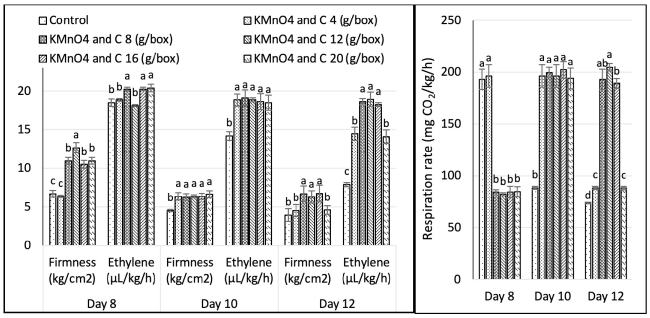

Fig. 3 - The changes in fruit firmness, respiration rate, and ethylene release during the post-harvest ripening process of mango. Values with different letters are significantly different according to Duncan's test (p=0.05).

The changes in soluble sugar and vitamin C

Throughout the process of mango ripening, the control group demonstrated a significant increase in total soluble sugar content, while the vitamin C content remained stable. Upon comparison of the control group with the $KMnO_4$ and activated C treatments, it was observed that treatment groups receiving 12, 16, and 20 g/box were instrumental in maintaining the highest level of total soluble sugars on day 12. However, no significant difference was found in vitamin C content between the control group and the $KMnO_4$ and activated C treatments, as noted in figure 4.

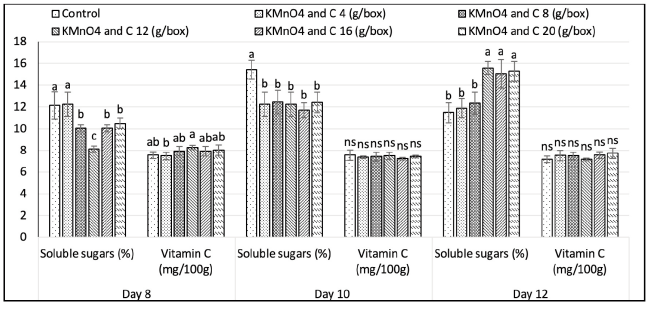

Fig. 4 - The changes in soluble sugar and vitamin C during the post-harvest ripening process of mango. Values with different letters are significantly different according to Duncan's test (p=0.05). NS= not significant.

4. Discussion and Conclusions

The preservation of mangoes post-harvest can be extended by utilizing $KMnO_4$ and activated carbon. The treated group, receiving 8 g/box of $KMnO_4$ and activated carbon, demonstrated a significant reduction in weight loss percentage compared to the control, as shown in figure 2. $KMnO_4$ and activated carbon act to preserve the natural color of mangoes by inhibiting the activity of enzymes, such as polyphenol oxidase, responsible for enzymatic browning (Mope *et al.,* 2024). This enzymatic reaction occurs when the fruit's phenolic compounds react with oxygen, resulting in a brownish discoloration. By inhibiting this enzymatic activity, $KMnO_4$ and activated carbon help preserve the fruit's natural color, rendering it visually appealing and marketable for a longer duration. The maintenance of firmness in mangoes is another critical aspect of preservation. $KMnO_4$ and activated carbon inhibit the activity of cell wall-degrading enzymes, such as pectinase and cellulase (Chen *et al*., 2021; Kumar *et al*., 2023). These enzymes break down the cell walls of the fruit, leading to softening and a loss of firmness. By inhibiting these enzymes, $KMnO_4$ and activated carbon help preserve the structural integrity of the fruit and maintain its firm texture over a longer period of time. $KMnO_4$ and activated carbon treatments delay the onset of senescence and over-ripening by extending the ethylene peak and respiration rate. The control group showed a progressive decline in respiration intensity and ethylene release on days 10 and 12, which peaked on the eighth day. In contrast, fruits treated with $KMnO_4$ and activated carbon showed two peaks in the respiration rate and ethylene release on day 10, as shown in figure 3. Ethylene is a natural plant hormone involved in the ripening process. $KMnO_4$ physically absorbs the surrounding ethylene through a porous medium, oxidizing it to produce CO_2, manganese oxide, potassium hydroxide, and water (Kumar *et al.,* 2023; Meena *et al*., 2024). Activated carbon, with its porous structure, can adsorb and remove volatile compounds, including those responsible for producing off-flavors. By reducing the presence of these compounds, activated carbon helps maintain the fruit's quality and freshness (Nooun *et al*., 2023; Roopa *et al.,* 2023). By reducing the peak production of ethylene and respiration rate, $KMnO_4$ and activated carbon slow down the ripening process, allowing the fruit to maintain its desirable qualities for a more extended period. Slowing down respiration helps fruits ripen more slowly, and as a result, the carbohydrate metabolism process occurs at a slower rate, allowing fruits to maintain a higher sugar content (Fig. 4). Furthermore, $KMnO_4$ acts as an antimicrobial agent by releasing oxygen and oxidizing organic matter. It helps inhibit the growth of microorganisms on the fruit's surface, reducing the risk of spoilage and extending the shelf life (Alonso-Salinas *et al*., 2023). The treatment regimens of $KMnO_4$ and activated carbon at levels ranging from 12 to 20 g/box each exhibited significant efficacy. However, the most optimal treatment for enhancing fruit quality and extending postharvest shelf-life was observed at the 12 g/box dosage. At this level, minimal weight losses were recorded, and essential fruit attributes such as firmness, soluble sugar, and vitamin C content were well-preserved. Notably, elevating the concentration of the $KMnO_4$ and activated carbon mixture beyond 12 g/box did not yield additional benefits in terms of prolonging storage life. Conversely, it resulted in escalated costs due to the higher treatment dosage.

The current study elucidates the physiological changes that occur during the ripening of mango fruit and the efficacy of $KMnO_4$ and activated carbon treatment in this regard. $KMnO_4$ and activated carbon (12 g/box) treatment can effectively delay the ethylene climacteric, which is responsible for the rapid deterioration of fruits. This delay in ethylene production and subsequent ripening processes significantly extends the storage period, consequently enhancing the flexibility in handling and distributing mango fruits for farmers and distributors alike. The treatment also aids in preserving the firmness and weight of the fruit, ultimately enhancing the nutritional quality of the fruit through increased sugar content and vitamin C. These outcomes enable consumers to enjoy mango fruits that have an extended shelf life and improved nutritional value.

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