



Ripening and Shelf-life Behavior of Banana- Effect of Potassium Permanganate, Calcium and Vacuum Packaging

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ABSTRACT

Background: Bananas are susceptible to several diseases that can cause significant losses after harvest and have a very short shelf life owing to their high perishability. The product's shelf life is extended using a variety of post-harvest management approaches. These include slowing down the ripening process, reducing respiration rate and managing disease-causing organisms during storage and transportation. Approximately 21.67 per cent of bananas spoil after harvest. Post-harvest treatments are hence required to extend the shelf life and reduce the postharvest losses in the crop.

Methods: The research was undertaken at the department of post-harvest Technology to investigate the effects of vacuum packaging and post-harvest chemical compounds on the ripening process of unripe banana fruits at room temperature. During the current experiment, vacuum packing was used in conjunction with chemicals, including 0.1 per cent CaCl_2 , 0.2 per cent CaCl_2 , 1g KMnO_4 , 2 g KMnO_4 and 3 g KMnO_4 .

Result: Among the different treatment combinations, applying 1 gram of KMnO_4 with vacuum packaging reduced the physiological loss in weight and increased the firmness, TSS, acidity and shelf life of poovan bananas up to 21 days without spoilage.

Key words: Banana, CaCl_2 , KMnO_4 , Ripening, Shelf life, Vacuum packaging.

INTRODUCTION

The diverse aroma and flavor of bananas make them one of the most widely consumed fruits across the globe. This fruit's elevated water content renders it very vulnerable to several diseases, with fungal infection being the most prevalent (Nguyen *et al.*, 2024). The climacteric phase is marked by enhanced C_2H_4 generation, increased oxygen consumption, conversion of starch to sugar, degradation of chlorophyll and redistribution of micro and macro nutrients within the pulp and other plant tissues. Significant postharvest losses occur primarily due to inadequate transportation systems and the lack of efficient infrastructure for value addition and storage (Pundir *et al.*, 2025). Post-production losses of bananas can be mitigated by implementing several post-harvest management measures now utilised worldwide to prolong their shelf-life. To maintain the quality of fresh produce, various postharvest treatments have been developed, such as the use of modified and controlled atmospheres, heat treatments, edible coatings and preservation through chemical and natural preservatives (Ashitha *et al.*, 2020).

A range of compounds significantly contributes to the post-harvest control of banana fruits by inhibiting the ripening process. Potassium permanganate is a potent oxidising agent that facilitates the conversion of ethylene into carbon dioxide and water (Mariah *et al.*, 2022). Numerous studies have demonstrated that the application of KMnO_4 delays fruit softening and prolongs shelf life of banana (Gutierrez-Aguirre *et al.*, 2023). KMnO_4 is not advised for direct application on fruits due to its toxicity at high doses and potential to cause purple stains. Consequently,

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supplementary materials are employed as the bonding matrix for KMnO_4 to provide safer application. Calcium is an essential macronutrient central to several physiological processes, including cell wall formation, enzyme activity

regulation and signal transmission (Islam *et al.*, 2024 and Kumari *et al.*, 2025). Crucially, it helps preserve the post-harvest quality of produce. It strengthens the cell wall structure and cellular membrane by connecting with pectin to create a pectate-calcium complex. By stabilizing these structures, calcium delays the aging (senescence) of fruits and vegetables, maintaining quality without any adverse effect on consumer acceptability. Calcium treatment enhanced the stability of plant cell wall and membrane integrity, increased textural hardness, reduced membrane lipid catabolism and extended the shelf-life of bananas (Le *et al.*, 2018) and Dhali *et al.*, 2024).

Vacuum packing is a technique employed to extend the shelf life of bananas (Marpaung *et al.*, 2021). The process entails keeping bananas in vacuum-sealed polythene bags. This approach has been shown to decrease weight loss and preserve the green hue of the bananas. Vacuum packing also postpones the ripening of bananas, as evidenced by the lowest total soluble solids (TSS) recorded. Moreover, vacuum packing has demonstrated efficacy in reducing alterations in firmness, moisture content and colour, hence prolonging the shelf life of bananas. Thus, this study was conducted to examine the effects of chemicals and vacuum packaging on the nutritional composition, ripening and shelf-life of banana fruit.

MATERIALS AND METHODS

Materials

"Poovan" was harvested at physiological maturity. Subsequent to the wrapping of the fruits in newspaper, they were conveyed to the post-harvest technology laboratory at SRM College of Agricultural Sciences, Campus, in thermal containers. Intact bananas of uniform size were extracted from their clusters, let to desiccate for one hour to eliminate residual latex and thereafter subjected to different tests. After a one-minute soak in a chlorinated solution, the fruits were set to air dry at ambient temperature. Aqueous solutions of CaCl_2 (0.1 or 0.2 per cent) were generated by dissolving the requisite amount of the compound in 5 litres of water. The fruits were immersed in this solution for ten minutes. The treated fruits underwent air drying. The sachet containing potassium permanganate was developed, enclosed in TNT (non-woven fabric) sachets and positioned into the fruit packaging.

Experimental details

The experiment was executed with eight treatment combinations during 2024-2025; each reproduced three times under a Completely Randomised Design (CRD). The laboratory's environmental conditions, including temperature and humidity, were recorded and monitored during the enquiry and observation of fruit storage. The treatments consist of the following combinations: 0.1 per cent CaCl_2 with vacuum packaging (T_1), 0.1 per cent CaCl_2 with ambient storage (T_2), 0.2 per cent CaCl_2 with vacuum

packaging (T_3), 0.1 per cent CaCl_2 with vacuum packaging (T_4), 1-gram KMnO_4 with vacuum packaging (T_5), 2 grams KMnO_4 with vacuum packaging (T_6), 3 grams KMnO_4 with vacuum packaging (T_7), water (T_8) and untreated control (T_9). The gathered data were later structured with MS Excel and examined with statistical tools.

Parameters evaluated

Ripening bananas are identified by observing changes in weight, TSS and firmness, which are all significant indicators of banana ripening.

Physiological weight loss (PWL %)

The bananas were weighed using a weighing balance and the weight loss percentage was calculated by using the following formula:

$$\text{PWL} = \frac{\text{Initial weight} - \text{Next measurement weight}}{\text{Initial weight}} \times 100$$

TSS (Total soluble solid)

The Total Soluble Solids (TSS) of the fruit were determined using a refractometer. The banana was pulverized and a small amount of the fruit juice, approximately 2-3 drops, was applied onto the prism of the refractometer. The resulting reading was then seen through the eyepiece. The measurement was recorded in degrees Brix.

Titration acidity (TA)

To determine the total acidity (TA), 50 grams of the fruit pulp were ground, combined with 20 milliliters of water and then filtered. After undergoing filtration, 10 mL of juice was transferred to a second conical flask and the volume was subsequently raised to 50 mL. The resulting solution was then titrated using 0.1 N NaOH, with phenylethylene serving as the indicator. The pink color's presence marked the endpoint. Subsequently, the estimation of TA was conducted using the prescribed formula.

$$\text{TA} = \frac{\text{ml of NaOH used} \times \text{molarity of base} \times \text{equivalent wt. of acid}}{\text{Volume of sample in ml} \times 10}$$

Firmness

Utilizing a penetrometer, the firmness of fruits was determined. The instrument was applied to the fruit in three locations: the top, middle and bottom. The fruit's firmness was determined by averaging the three readings. The value of the result was kg/cm^2 .

Ripening period and shelf-life

The ripening time was determined by analyzing the changes in color, hardness and TSS value of the bananas. The ripening period of the fruits was noted as the number of days it took for them to reach the completely mature state in each treatment. To calculate their shelf life, which is defined as the period from the beginning of ripening till the end of their marketable life, fruits were visually examined on alternate days.

Statistical analysis

The collected data were examined using the statistical program. The data underwent Analysis of Variance (ANOVA) to assess the major treatment effects. The treatment means were compared using the Least Significant Difference (LSD) test at a significance level of 5 per cent.

RESULTS AND DISCUSSION

Physiological weight loss

Treatment reduces this response factor to the concentration level of KMnO_4 . The weight-loss rates were lowest when employing 1 gramme of KMnO_4 in conjunction with vacuum packing (Fig 1). The rationale for this is that KMnO_4 induces a delay in fruit ripening, thus diminishing tissue permeability. Consequently, weight loss is diminished. Numerous studies indicate that the application of KMnO_4 leads to negligible weight reduction in comparison to the control group. For instance, Elzubeir *et al.* (2017) investigated bananas, Shalini *et al.* (2018) focused on kiwis and Tasmim *et al.* (2020) analysed mangoes. The continuous moisture loss due to transpiration and respiration resulted in significant weight loss during daily storage across all treatments, as anticipated (Nath *et al.*, 2011). Li *et al.* (2021) identified weight loss as a possible factor affecting the ripening process regulated by the hormone ethylene. Deshmukh *et al.* (2016) demonstrated

that the scavenger KMnO_4 reduces ethylene concentrations. The variations in the rate of ripening can be attributed to the differing concentrations of KMnO_4 .

The control treatment had the highest weight loss rate of 12.18 per cent over seven days, whereas the KMnO_4 treatments reduced this loss by as much as 30.68 per cent. This conclusion corresponds with the research of Deshmukh *et al.* (2016), which indicates that the treatment of KMnO_4 significantly decreased weight loss to 0.21 per cent over the first seven days post-harvest of bananas. Under vacuum conditions, a reduction in oxygen concentration is believed to suppress ethylene biosynthesis while concurrently retarding the rate of respiration (Meena *et al.*, 2017). Consistent observations have been documented by Moradinezhad and Dorostkar (2021). Experimental research showed that bananas stored unwrapped experienced an 11.82 per cent weight loss due to transpiration and respiration after 7 days.

TSS (Total soluble solids)

The ripening process and storage conditions can affect the total soluble solids or °Brix of fruits like bananas. The influence of treatment during ripening and storage is widely understood. An investigation was performed to assess the effect of various treatments on the total soluble solids in bananas. The results of this investigation are illustrated in Fig 2 shows that, substantial variation in the total soluble

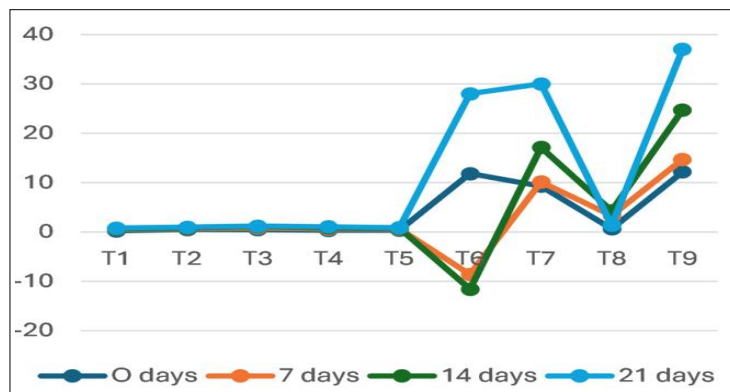


Fig 1: Effect of potassium permanganate, calcium and vacuum packaging on physiological loss in weight.

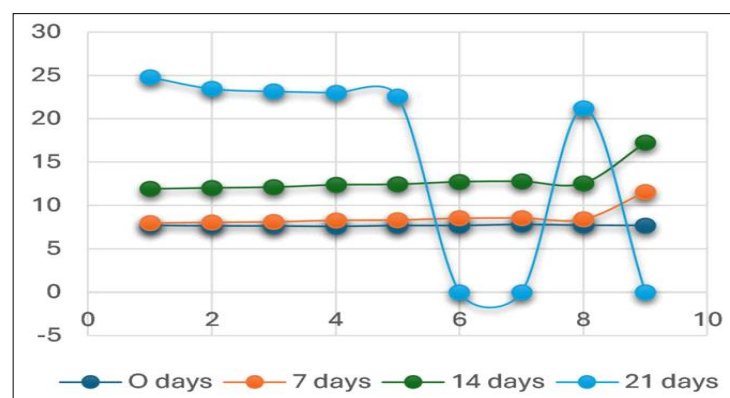


Fig 2: Effect of potassium permanganate, calcium and vacuum packaging on TSS.

Solids (TSS) content ($p < 0.05$) among the treatments across the storage duration. This parameter demonstrated a statistically significant difference ($p < 0.05$) between treatments and days. On each day, the control treatment had the highest °Brix across all soluble solids measurements. Ultimately, the highest solubility of solids was seen with 1 gramme of vacuum-sealed KMnO_4 . The breakdown of starch into glucose accounts for this rise. The delay in respiration and the conversion of starch to sugar were both facilitated by KMnO_4 , as evidenced by the variation across treatments. The decreased total soluble solids (TSS) in fruit treated with KMnO_4 can be ascribed to the ethylene-absorbing characteristics of KMnO_4 , leading to postponed fruit ripening (Zewter, 2012). Elzubeir *et al.* (2018) and Fatima *et al.* (2023) also noted a reduction in total soluble solids (TSS) in mangoes with the application of KMnO_4 during storage. Vacuum packing likely lowered the total soluble solids (TSS) and total sugar content, a result that can be attributed to the low oxygen environment's role in reducing ethylene production.

Titration acidity (TA)

Fig 3 illustrates that TA decreased across all treatments during storage. The reduction in total acidity (TA) can be ascribed to the senescence process, since TA serves as a quantitative measure of organic acids that diminish over

time (Latifah *et al.*, 2013). Moreover, the use of acid in the development of delicious compounds during ripening concurrently decreases the total acidity (TA) during storage (Bhattarai and Gautam, 2006). Notwithstanding a reduction in total acidity (TA) during storage, the peak TA (0.44%) was attained with 1 gramme of KMnO_4 . The application of KMnO_4 may increase CO_2 levels due to the degradation of ethylene, leading to the formation of carbonic acid in the fruit and inducing acidosis. This result may be due to the increase in CO_2 concentration caused by the KMnO_4 application, since CO_2 is a byproduct of ethylene degradation. A similar finding was reported by Dhakal *et al.* (2021) in banana.

Firmness

Various post-harvest treatments led to a significant difference in the hardness of banana fruit, as seen in Fig 4. The data reveals a progressive decline in the fruit's firmness over a span of 22 days. Fruits exposed to the atmosphere had a more accelerated reduction in firmness relative to all other examined treatments. Fruits subjected to potassium permanganate treatment and kept in vacuum packing had the greatest firmness retention. The alterations in fruit firmness correlated to the pattern of colour change. This is due to both being results of the same source, namely ripening. As the fruit matures, the cell walls deteriorate, the middle lamella loses cohesion due to the

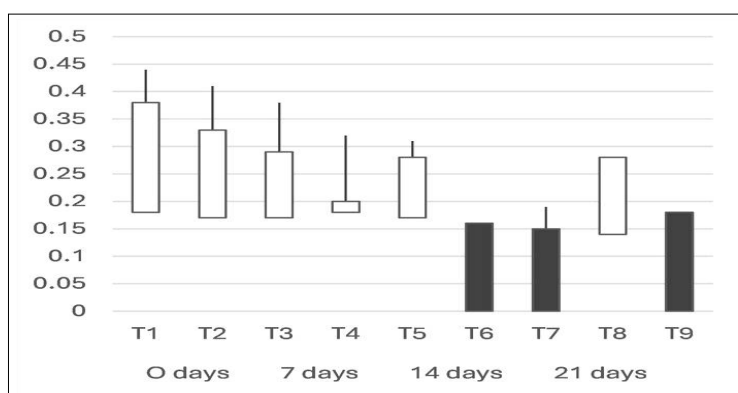


Fig 3: Effect of potassium permanganate, calcium and vacuum packaging on titrable acidity.

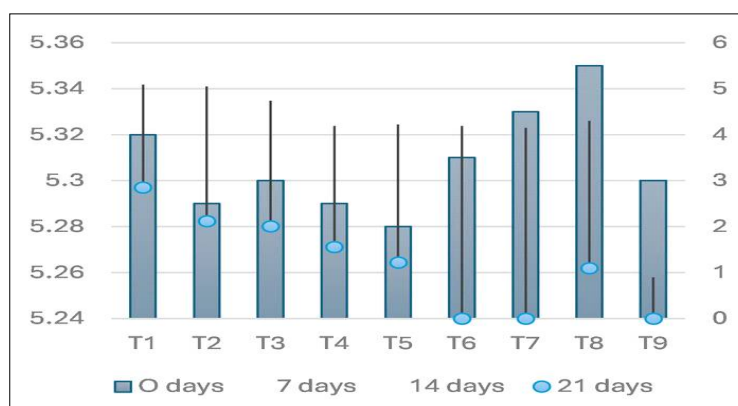


Fig 4: Effect of potassium permanganate, calcium and vacuum packaging on firmness.

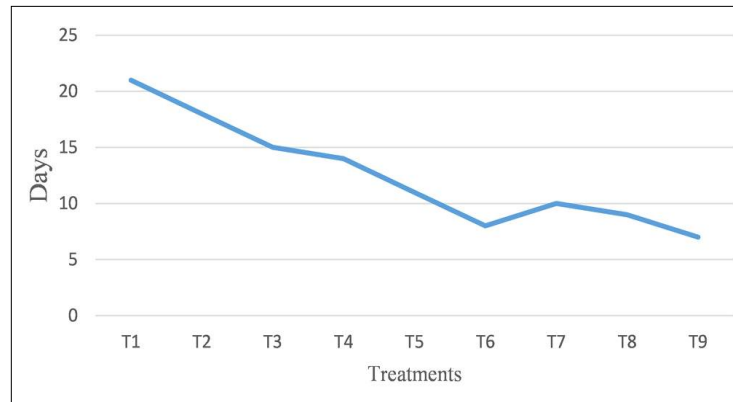


Fig 5: Effect of potassium permanganate, calcium and vacuum packaging on shelf life (days).

dissolution of pectic substances and water migrates from the skin to the flesh via osmosis. These processes result in the softening of the fruit. The variation in fruit firmness seen in this study may be ascribed to both the direct and indirect impacts of the treatments on respiration and ripening rates. This retention is posited to result from the slowing of cell wall degradation, specifically the reduction in the solubilization of pectin and the hydrolysis of starch and hemicelluloses. In climacteric fruit, this maintained firmness is a key metric indicating delayed ripening. Similar effects were documented in sapota (Umme Seema *et al.*, 2021). The delayed firmness of fruit stored in vacuum packaging with the inclusion of the ethylene absorber KMnO_4 may be ascribed to the interaction between potassium permanganate and ethylene. Vacuum treatment likely promotes fruit firmness by inducing a state of low ethylene production. Given that ethylene activates crucial cell wall-degrading enzymes, this reduction in ethylene emission leads to lower enzyme activity and, consequently, better maintenance of cell wall integrity (Ntsoane *et al.*, 2019). Kaur and Kaur, (2018) attained increased firmness in bananas with the use of KMnO_4 , leading to the highest degree of firmness. The combined research confirmed our findings.

Shelf life (Days)

The shelf life denotes the period following harvest during which fruits retain their freshness and remain fit for human consumption without exhibiting any indications of spoilage. The essential consideration for fruit storage is their shelf life, which dictates the period they may be preserved without deterioration. Thus, the selection of treatments and preservation techniques is mostly determined by the shelf life of the fruits and their derivatives. This study investigates the effects of different concentrations of potassium permanganate and storage temperatures on the shelf life of preserved bananas. Fig 5 illustrates that banana fruits treated with 1 g of potassium permanganate and vacuum packaging displayed the longest shelf life, lasting 22.81 days. Conversely, the shelf life diminished to 7.90 days under standard circumstances (control). The demonstrated delay in maturation and prolongation of marketable quality afforded by KMnO_4 is consistent with observations in banana (Yin *et al.*, 2020; Ahmed *et al.*, 2021; Devkota *et al.*, 2025).

CONCLUSION

The process of packing food is a procedure that guarantees that a fresh produce or processed product is delivered from the manufacturing centre to the end customer in a secure and healthy state at a price that is affordable. An option that has been discovered as a potential method for mitigating post-harvest losses is the utilisation of an appropriate packaging method for the wrapping of food. For the purpose of this experiment, a variety of banana samples were subjected to a one per cent variation of KMnO_4 treatment, following which they were vacuum packaged and stored in ambient circumstances. The purpose of this enquiry was to evaluate the influence that this treatment had on the extension of shelf life. The findings of the research led the researchers to the conclusion that the sample T_4 had the lowest levels of Physiological Loss in Weight, as well as the greatest levels of Total Soluble Solids (TSS), acidity and shelf life of poovan banana.

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Conflict of Interest

All authors declare that they have no conflicts of interest.

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