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Physicochemical Quality Changes of Strawberries Stored in Active Packaging Incorporated with Ethylene, Humidity and Oxygen Scavengers at Ambient Temperature

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ABSTRACT

Strawberry (*Fragaria x ananassa*) possesses high economic value but is highly perishable due to its soft texture and high moisture content. Active packaging (AP) technology serves as an innovative solution to extend the shelf life of horticultural products by controlling the internal conditions of the package. This study evaluates the effectiveness of AP containing $KMnO_4$ as an ethylene scavenger, vitamin C as an oxygen scavenger, and silica gel as a humidity absorber on the physical and chemical quality of strawberries during storage at room temperature. The experimental design used a 2 x 2 x 3 factorial Completely Randomized Design with five replications. The treatment factors comprised $KMnO_4$ (0 and 60 mg/mL), vitamin C (0 and 0.4 mg/mL), silica gel (0, 5, and 10 g/sachet). Visual observations indicated a significant decline in quality after the seventh day of storage, characterized by softened texture, darkening of the skin color, and the emergence of *Botrytis cinereal* mold due to high humidity. In the single-treatment test, the application of 5 g of silica gel was the most effective in minimizing the decrease in °Brix values of 4.58%. Meanwhile, the combination of 60 mg/mL $KMnO_4$, 0 mg/mL vitamin C and 5 g of silica gel yielded the best results with a °Brix value of 4.90%, and 0 mg/mL $KMnO_4$, 0 mg/mL vitamin C, and 5 g silica gel was capable of inhibiting the decline of vitamin C content during 7 days of storage. None of the treatments significantly influenced total sugar, free acid, sweetness levels, or vitamin C content, as the high rates of respiration and transpiration at room temperature triggered rapid fruit degradation.

Keywords: active packaging, $KMnO_4$, silica gel, strawberry, vitamin C.

INTRODUCTION

Strawberry (*Fragaria x ananassa*) is a high value commodity with rapidly increasing production, however it has a short shelf life due to its lack of a protective skin (Putri et al., 2024). The primary factors contributing to fruit deterioration are high respiration rates, exposure to ethylene gas, and excessive humidity, which trigger texture softening and microbial growth (Wulandari, 2021; Gupta, 2024). To overcome the limitations of conventional methods, active packaging technology has been developed to control the atmospheric conditions within the package (Ihsan & Derosya, 2024).

The simultaneous use of active agents has been proven to reduce weight loss to 4.4% and significantly extend shelf life compared to standard packaging (Devi & Handarini, 2025; Shahida & Swarup, 2024). Nevertheless, research that integrates three functions ethylene scavenging, oxygen scavenging, and moisture control simultaneously remains very limited. This study aims to evaluate the effectiveness of a combination of $KMnO_4$, silica gel, and vitamin C within a single active packaging system. The observation focuses on comprehensive physical and chemical quality changes, including firmness, vitamin C content, and total soluble solids (TSS) to provide a practical solution for maintaining strawberry freshness during distribution.

METHODOLOGY

The research was conducted at the Horticulture and Postharvest Laboratory, Faculty of Agriculture, University of Lampung, Lampung Province, Indonesia, from August to September 2025. The study employed a 2 x 2 x 3

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factorial completely randomized design (CRD) with five replications, using 250 g of strawberries per experimental unit. The treatment factors consisted of $KMnO_4$ (K) 0 and 60 mg/mL (as an ethylene scavenger), vitamin C (V) 0 and 0.4 mg/mL (as an oxygen scavenger), silica gel (S) 0, 5, and 10 g/sachet (as a moisture regulator). The active agents of $KMnO_4$ and vitamin C were absorbed into sponges per sachet and placed within partitioned containers to prevent direct contact with the fruit. Samples were stored at a room temperature of 25 ± 5°C.

The mechanism involved $KMnO_4$ oxidizing ethylene, vitamin C reducing O_2, and silica gel absorbing moisture to suppress respiration rates and microbial growth. Observations were conducted on the physical and chemical qualities of the strawberries, including weight loss, °Brix (with an atago refractometer), titratable acidity (titration with 0.1 N NaOH and phenolphthalein indicator), total sugar and vitamin C contents (HPLC, in the Academic Supporting Unit of Integrated Laboratory, IPB University, Bogor, Indonesia) and sweetness level (°Brix/acidity ratio). Data were analyzed using the Analysis of Variance (ANOVA), followed by the Least Significant Difference (LSD) test at a 5% significance level.

RESULT AND DISCUSSION

Visual observation

Significant differences were observed in strawberries stored in active packaging containing ethylene, oxygen, and moisture scavengers, particularly regarding texture and color. Quality deterioration became prominent after day 7 at room temperature. Fruit firmness decreased progressively during storage (Hossain & Iqbal, 2016), driven by rapid pectinolytic enzyme activity that degrades tissues into a watery consistency. This physiological decline, including skin darkening, is attributed to the degradation of cell wall components such as pectin, leading to tissue senescence (Velickova et al., 2013). Structural breakdown was evidenced by the accumulation of turbid red liquid due to cell lysis. Furthermore, the growth of *Botrytis cinerea* from day 3 to day 7 significantly contributed to the decay (Figure 1). The accumulation of heat from respiration and high humidity within the package atmosphere created an ideal microenvironment for this gray mold, ultimately leading to total tissue failure.

Figure 1. Exudation of Turbid Red Liquid on Day 4 and Fungal Growth Observed on Strawberries (Left and Right)

Physical and chemical quality observations of strawberries under single treatments

Based on the acquired data, the weight loss across all treatments was remarkably low, ranging from 0.00% to 0.01%, with no significant differences observed between them. The individual application of ethylene control agents such as $KMnO_4$ or moisture absorbers like silica gel proved insufficient to significantly minimize water transpiration from the fruit. Analysis of total soluble solids (°Brix) in the strawberries ranged from 4.02 to 4.58% (Table 1).

The 5 g silica treatment showed a significant effect, maintaining a value of 4.58%. Compared to the initial °Brix value (6.38%), the 5 g silica treatment exhibited a lower rate of decline relative to the other treatments. Observations of the total sugar variable indicated that no single treatment exerted a significant influence. The

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total sugar content in the treated strawberries ranged from 2.38 to 2.86 g/100 g, indicating a sharp decline of approximately 57-61% compared to the initial fresh strawberry content of 6.63 g/100 g. Titratable acidity (free acid) analysis during storage showed values ranging from 0.79% to 0.96%, where the application of $KMnO_4$, vitamin C, and silica gel did not yield significant effects.

The average scores for sweetness levels (2.94–3.56%) showed no statistically significant differences across all treatments. Furthermore the vitamin C content of the strawberries under single sachet treatments of $KMnO_4$, vitamin C, and silica gel was not significantly affected within the active packaging system. The vitamin C concentration was unchanged from an initial fresh level of 0.052 mg/100 mL to a range of 0.05-0.12 mg/100 mL after 7 days of storage at 25°C.

Table 1. Weight Loss, Total Soluble Solids (°Brix), Total Sugar, Titratable Acidity, Sweetness Level, and Vitamin C Content of Strawberries Based on Main Effect Treatments of $KMnO_4$, Vitamin C, and Silica Gel in an Active Packaging System

Individual Treatment	Weight Loss (%)	°Brix (%)	Total Sugar (g/100g)	Acidity (%)**	Sweetness (%)***	Vitamin C (mg/100mL)
$KMnO_4$ (K):						
K0 (0 mg/mL)	0.01 a	4.26 a	2.61 a	0.82 a	3.29 a	0.10 a
K1 (60 mg/mL)	0.00 a	4.24 a	2.63 a	0.96 a	3.16 a	0.05 a
LSD 5%	0.02	0.17	0.8	0.24	1.57 a	0.1
Vitamin C (V):						
V0 (0 mg/mL)	0.01 a	4.23 a	2.86 a	0.96 a	3.34 a	0.10 a
V1 (0.4 mg/mL)	0.00 a	4.27 a	2.38 a	0.82 a	3.10 a	0.05 a
LSD 5%	0.02	0.17	0.8	0.24	1.57	0.1
Silica gel (S):						
S0 (0 g/sachet)	0.01 a	4.02 a	2.61 a	0.94 a	2.94 a	0.05 a
S1 (5 g/sachet)	0.00 a	4.58 b	2.60 a	0.94 a	3.16 a	0.12 a
S2 (10 g/sachet)	0.01 a	4.15 a	2.65 a	0.79 a	3.56 a	0.06 a
LSD 5%	0.02	0.21	0.98	0.29	1.92	0.12

*The numbers followed by the same lower-case letter indicate no-significant difference with LSD at 5% level; **As citric acid; ***°Brix/Acid content ratio

Physical and chemical quality observations of strawberries under combination treatments

The interaction analysis for weight loss across combination treatments showed no statistically significant different, with values ranging from 0.00% to 0.05%. This minimal weight loss is attributed to the synergistic effect of $KMnO_4$, silica gel, and vitamin C in suppressing transpiration and respiration rates (Darmawati, 2023). Conversely, the interaction regarding total soluble solids (TSS/°Brix) revealed that the 60 mg/mL $KMnO_4$, 0 mg/mL Vitamin C, and 5 g Silica gel treatment (4.90%) was significantly different and more effective in maintaining TSS compared to the control (Table 2). This was consistent with the use of $KMnO_4$ in other fruits, which delays ripening and results in higher °Brix values (Tosetti et al., 2020).

Total sugar content experienced a drastic reduction of up to 49.4% from initial levels, with no significant differences observed between treatments (2.05–3.14 g/100 g). This indicates that in non-climacteric fruits, ethylene control does not significantly influence the conversion of starch to sugar as long as basal respiration persists (Plaza et al., 1988). Similarly titratable acidity (0.64–1.29%) and sweetness levels (2.62–4.82%) showed

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no significant differences, suggesting that the high respiration rate of strawberries continues to dominate organic acid metabolism during storage (Malakar et al., 2019)

Treatment interactions significantly influenced vitamin C content, with the 0 mg/mL $KMnO_4$, 0 mg/mL Vitamin C, and 5 g Silica gel combination emerging as the superior treatment (0.30 mg/100 mL). Nevertheless this value remains substantially below the typical threshold for fresh strawberries, which reaches 58.8 mg/100 g (Inggrid & Santoso, 2015). This sharp decline might be caused by storage at room temperature (25°C), which significantly accelerated the respiration rate, thereby triggering ascorbate oxidase activity that catalyzes the oxidation of vitamin C into its inactive form (Ayu, 2025).

Table 2. Weight Loss, Total Soluble Solids (°Brix), Total Sugar, Titratable Acidity, Sweetness Level, and Vitamin C Content of Strawberries Based on Interaction Treatments of $KMnO_4$, Vitamin C, and Silica Gel in an Active Packaging System

Combination Treatment**	Weight Loss (%)	°Brix (%)	Total Sugar (g/100g)	Acidity (%)***	Sweetness (%)****	Vitamin C (mg/100mL
KMnO4 x Vit C						
K0V0	0.03 b	4.16 a	2.93 a	0.82 a	3.69 a	0.15 a
K0V1	0.00 a	4.36 a	2.29 a	0.82 a	2.88 a	0.05 a
K1V0	0.00 a	4.30 a	2.80 a	1.10 a	2.99 a	0.05 a
K1V1	0.00 a	4.19 a	2.47 a	0.82 a	3.32 a	0.05 a
LSD 5%	0.02	0.24	1.13	0.34	2.22	0.14
KMnO4 x Silica gel						
K0S0	0.02 a	4.16 b	2.66 a	0.86 a	3.09 a	0.05 a
K0S1	0.01 a	4.50 c	2.55 a	0.88 a	3.03 a	0.18 a
K0S2	0.02 a	4.12 ab	2.61 a	0.73 a	3.74 a	0.07 a
K1S0	0.00 a	3.88 a	2.57 a	1.02 a	2.79 a	0.04 a
K1S1	0.00 a	4.66 c	2.64 a	1.00 a	3.29 a	0.06 a
K1S2	0.01 a	4.19 b	2.70 a	0.85 a	3.39 a	0.05 a
LSD 5%	0.03	0.29	1.38	0.41	2.72	0.17
Vit C x Silica gel						
V0S0	0.03 b	3.92 a	2.99 a	1.06 ab	3.03 a	0.05 a
V0S1	0.00 a	4.65 b	2.89 a	1.11 b	2.86 a	0.18 a
V0S2	0.02 ab	4.11 a	2.72 a	0.71 a	4.14 a	0.06 a
V1S0	0.00 a	4.12 a	2.24 a	0.81 ab	2.85 a	0.04 a
V1S1	0.01 a	4.50 b	2.30 a	0.77 ab	3.46 a	0.05 a
V1S2	0.00 a	4.20 ab	2.59 a	0.87 ab	2.99 a	0.06 a
LSD 5%	0.03	0.29	1.38	0.4l	2.72	0.17
KMnO4 x Vit C x Silica gel						
K0V0S0	0.05 b	4.09 ab	2.89 a	0.84 ab	3.43 a	0.06 a
K0V0S1	0.00 a	4.35 bc	2.76 a	0.99 ab	2.83 a	0.30 b

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K0V0S2	0.03 ab	4.04 b	3.14 a	0.64 a	4.82 a	0.07 ab
K0V1S0	0.00 a	4.23 bc	2.43 a	0.88 ab	2.75 a	0.04 a
K0V1S1	0.01 ab	4.64 cd	2.34 a	0.77 ab	3.23 a	0.05 a
K0V1S2	0.00 a	4.21 b	2.09 a	0.82 ab	2.66 a	0.07 ab
K1V0S0	0.01 ab	3.74 a	3.09 a	1.29 b	2.62 a	0.04 a
K1V0S1	0.00 a	4.90 d	3.02 a	1.23 b	2.90 a	0.06 a
K1V0S2	0.01 ab	4.10 ab	2.30 a	0.78 ab	3.45 a	0.05 a
K1V1S0	0.00 a	4.02 ab	2.05 a	0.75 ab	2.96 a	0.05 a
K1V1S1	0.01 ab	4.37 bc	2.26 a	0.78 ab	3.69 a	0.05 a
K1V1S2	0.00 a	4.18 b	3.10 a	0.93 ab	3.32 a	0.05 a
LSD 5%	0.04	0.42	1.95	0.58	3.84	0.23

*The numbers followed by the same lower-case letter indicate no-significant difference with LSD at 5% level; **See at Table 1; ***As citric acid; ****°Brix/Acid content ratio

CONCLUSION

Visual observations indicated a significant decline in quality after the seventh day of storage, characterized by softened texture, darkening of the skin color, and the emergence of *Botrytis cinerea* mold due to high humidity. In the single-treatment test, the application of 5 g of silica gel was the most effective in minimizing the decrease in °Brix values (4.58%). Meanwhile, the combination of 60 mg/mL $KMnO_4$, 0 mg/mL vitamin C and 5 g of silica gel yielded the best results with a °Brix value of 4.90%, and 0 mg/mL $KMnO_4$, 0 mg/mL Vitamin C, and 5 g Silica gel was capable of inhibiting the decline of vitamin C content during 7 days of storage. None of the treatments significantly influenced total sugar, free acid, sweetness levels, or vitamin C content, as the high rates of respiration and transpiration at room temperature triggered rapid fruit degradation.

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