POTASSIUM PERMANGANATE ($KMnO^4$) ON THE POSTHARVEST QUALITY OF TOMATO (*Solanum lycopersicum* L.) FRUITS

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ABSTRACT: Tomatoes (*Solanum lycopersicum* L.) is an economically important crop and a rich source of vitamins, minerals, and antioxidants. However, the climacteric nature leads to rapid ripening and significant post-harvest losses, particularly in tropical regions. While various preservation methods exist, potassium permanganate ($KMnO^4$) has emerged as a promising ethylene absorber for extending shelf life. This study investigated the effects of varying concentrations of $KMnO^4$ (0, 2, 4, 6 and 8g) on the postharvest quality and shelf life of tomato fruits during 21 days of storage. This research evaluated multiple parameters including firmness, color change, freshness, physiological weight loss, decay percentage, nutritional composition, and mineral content. The experiment was completely randomized and replicate three times. Data collected was subjected to analysis of variance at 5% level of significance and treatment mean were separate using least significant difference (LSD). Results showed that 6g$KMnO^4$ treatment significantly maintained optimal firmness and highest freshness throughout storage, while 4g$KMnO^4$ demonstrated the lowest physiological weight loss (0.37-11.07%). Color development showed no significant differences among treatments, though control fruits exhibited more pronounced changes by day 21. The tomato fruits treated with 8g$KMnO^4$ maintained the highest levels of Total Soluble Solids (3.60%), Vitamin C (11.2%), and lycopene content (0.95%). While mineral content showed general decline across all treatments, $KMnO^4$ treated fruits better maintained their nutritional composition compared to control samples. This study revealed that $KMnO^4$, particularly at 4 and 6g, effectively functions as an ethylene scavenger, regulating ripening processes and maintaining fruit quality through several methods of action.

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INTRODUCTION

Tomatoes (*Solanum lycopersicum*. L) belong to the Solanaceae family, a group of plants that also includes other significant crops like potatoes, peppers, and eggplants, making it one of the most important plant families in terms of vegetable and fruit production, with many economically valuable species (Knapp and Peralta, 2016). Tomatoes are widely cultivated across Nigeria, with the Savannah agro-ecological zone being the most suitable region due to fewer disease and pest issues. The primary production areas are located between latitudes 7.5°N and 13°N, where temperatures range from 25°C to 34°C. In the southwest, tomatoes are grown during the rainy season, while in the northern regions; they are cultivated under irrigation (Ayandiji *et al.*, 2011). Nigeria is also ranked second largest producers of tomato in Africa producing 3.68million tonnes of tomato annually (FAO, 2022). Tomatoes are a rich source of various beneficial compounds, including vitamins, carotenoids, and phenolic compounds, making them a valuable crop for both economic and nutritional reasons. Furthermore, tomatoes have become a key subject for scientific research, serving as a model for understanding the development and ripening processes of fleshy fruits (Quinet *et al.*, 2019). The growing awareness of the importance of healthy eating has led to a significant increase in demand for tomatoes, a nutrient dense food that offers numerous health benefits (Tilahun *et al.*, 2021). The consumption of tomatoes has been shown to have a profound impact on human health, exhibiting anti-inflammatory properties that reduce the risk of chronic diseases, anti-genotoxic and anti-mutagenic properties that protect cells from damage, anti-proliferative properties that prevent the growth of harmful cells, and chemopreventive properties that help prevent the development of cancer (Chaudhary *et al.*, 2018). Tomatoes are packed with antioxidants that fight harmful free radicals and cell damage, plus essential vitamins and minerals (potassium, folate, and vitamin K) that support overall health (Akhtar *et al*,. 2023).

The texture of fruits, influenced by cell wall composition and enzyme activities during growth and ripening, significantly impacts consumer perception of quality and shelf life, as biochemical changes lead to softening due to the breakdown of cell wall polymers. (Wabali and Esiri, 2021). Tomatoes, a climacteric fruit, are prone to rapid spoilage, resulting in significant losses. Advanced packaging techniques, such as edible coatings, modified atmosphere packaging, active packaging, and nano packaging, offer improved shelf life and quality preservation, controlling physicochemical, microbiological, and environmental factors that contribute to spoilage, thereby reducing postharvest losses (Khalid *et al.,* 2024). As consumers become more health conscious and seek fresh produce, the need to develop innovative preservation methods for tomatoes has become more pressing, aiming to minimize waste and extend shelf life, in line with the growing demand for nutritious and fresh fruits and vegetables (Fagundes et al., 2015). Edible coatings have been shown to preserve the nutritional value of fruits more effectively than traditional packaging methods (Patanè *et al.,* 2019), and their natural ingredients make them safe and suitable for human consumption (Khalil *et al.,* 2020). Tomatoes face various challenges during transportation, storage, and marketing, leading to significant losses (Babatola and Udemba,. 2020). In tropical countries, a staggering 35-70% of tomatoes are lost between harvest and consumption due to physiological and biochemical processes like transpiration, respiration, and ripening, which continue after harvesting (Adewoyin *et al.,* 2022). Extending the shelf life of tomatoes with minimal loss during storage is crucial for efficient transportation and storage, reducing waste and improving the overall supply chain. (Alonso-Salinas *et al* ., 2019) stated that the ripeness of tomatoes significantly influences ethylene production, with fully ripe tomatoes producing more ethylene gas than their less ripe counterparts. As tomatoes ripen, their ethylene production increases, reaching its peak when they are fully ripe. This means that storing tomatoes when they are greener or less ripe can help minimize the amount of ethylene they produce, which in turn can slow down the ripening process. By choosing tomatoes that are not yet fully ripe, you can reduce the amount of ethylene they emit and create a more balanced storage environment (Janjarasskul and Suppakul, 2018).

Potassium permanganate ($KMnO_4$) extends shelf life and preserves postharvest quality by oxidizing ethylene, a spoilage promoting gas (Alonso-Salinas *et al*., 2022). Potassium permanganate ($KMnO_4$) captures surrounding ethylene through a porous medium, triggering an oxidation reaction that transforms ethylene into manganese oxide, potassium hydroxide, water, and carbon dioxide. When the purple solution becomes brown, it means the potassium permanganate has been completely used up in the reaction (Ali et al,.2015). While various methods aim to eliminate ethylene, potassium permanganate stands out for its effectiveness in high humidity settings. By delaying fruit ripening, this technology plays a vital role in the food industry by helping to extend the freshness and storage life of produce (Alonso-*Salinas et al.,* 2022). Research has shown that treating tomatoes with potassium permanganate ($KMnO_4$) extends their shelf life to 21 days at room temperature by delaying ripening, reducing weight loss, inhibiting microbial growth, and maintaining quality attributes such as firmness, color, and reduced ethylene production rate (Muhammed *et al.,* 2023).

The tomato industry faces significant challenges due to the crop's short shelf life, which leads to substantial postharvest losses (Yadav et al., 2022). Nigeria, the largest producer of tomatoes, faces significant postharvest losses of this crop due to inadequate handling of the produce after harvesting (Siddiqui *et al.,* 2015). To combat this issue, postharvest activities, such as simultaneous crop storage, offer a promising solution to minimize food waste and promote a more sustainable food supply chain. Recent development of edible coatings offers a promising, environmentally friendly, and sustainable solution to address these challenges (Yadav e*t al.,* 2022). However, proper postharvest handling is crucial to prolong the shelf life of tomatoes, including the reduction of ethylene content. One effective method for achieving this is by using potassium permanganate ($KMnO_4$), which acts as an ethylene scavenger, absorbing excess ethylene and thereby extending the fruit's storage life (Widyastuti and Gahayu, 2022). The selection of potassium permanganate as the ethylene scavenger was based on its affordability and widespread use in active packaging technology (Singh *et al.,* 2017). This study investigates the most effective ways to use $KMnO_4$ to prolong the freshness and quality of tomatoes, providing valuable insights to improve postharvest handling practices and advance the use of $KMnO_4$ in the horticulture sector. Therefore the main objective of this study is to investigate the efficacy and optimal rate of potassium permanganate ($KMnO_4$) as a postharvest treatment for extending the shelf life of tomatoes, while maintaining their physical and chemical properties.

MATERIALS AND METHODS

2.1 Experimental Site

The experiment was conducted in the Horticultural laboratory in the Department of Crop and Horticultural Science, University of Ibadan, Ibadan ($7^0$24'N, $3^0$54'S).

2.2 Experimental Materials

Materials used are mature tomatoes fruits (breaker stage), weighing balance, measuring spoon, plastic storage containers, tea bags and potassium permanganate crystals.

2.3 Source of Experimental Sample

Cobra F1 variety of tomato fruits at breaker stage was obtained from a farm located in Iseyin Oyo State, Nigeria. Fruits were selected based on visual observations and transported in normal conditions to the laboratory. Tomato fruits having uniform color, size, and shape without any defects were selected for the experiment and divided into 5 groups (treatments).

2.4 Preparation of Fruits for Storage

After harvesting and conveying the tomato fruits to the Horticultural laboratory of the Department of Crop and Horticultural Sciences, the tomato fruits were precooled by spreading out on the laboratory table for free air to flow over them in order to remove field heat. The fruits was sorted to ensure they are free of spots and bruises. The tomato fruits were washed with clean running water to remove dirt and then dipped into a fungicide solution (5gram of fungicide to 5liters of water). The washed tomato fruits were drained, air dried and 7fruits were placed inside each of the Plastic storage container which have been washed and dried.

2.5 Method of Treatment Application

Potassium permanganate ($KMnO_4$) crystals were weighed, 2, 4, 6 and 8gram of $KMnO_4$ were measured and put in a 6×8 muslin tea bag and placed beside the stored fruit in a plastic container.

2.6 Treatments

- Treatment 1= 0g$KMnO_4$ (Control)
- Treatment 2= 2g$KMnO_4$
- Treatment 3= 4g$KMnO_4$
- Treatment 4= 6g$KMnO_4$
- Treatment 5= 8g$KMnO_4$

2.7 Experimental Design

Treatments were completely randomized with three replicates.

2.8 Experimental Observation

The following data were collected during the experiment: Physiological weight loss (%), Decay percentage (%), Storability/Shelf life, Firmness, Color, Freshness.

- Firmness: This was determined in three day interval by hand feel and the result was rated on a subjective scale as follows; 5= Not firm, 4=Slightly firm, 3=Moderately firm, 2=Firm, 1=Very firm (Modification of Babatola *et al*., 2002).
- Colour: Data were collected for colour in three days interval based on USDA (1975) tomato colour chart which defines the fruit ripening stages as 1=green, 2=breaker, 3= turning, 4=pink, 5=light red and 6=red.
- Freshness: The overall freshness of the fruits was evaluated by using a scale of 0 - 4 in line with the method of IPGRI/IITA (1998), where 4 = excellent; 3 = good; 2 = acceptable; 1 = unacceptable and 0 = poor. Data for freshness will collected in three day interval.
- Physiological Weight Loss (PLW): Weight loss was determined in three day interval. Weight loss in tomatoes was calculated from the difference in weight at day 1 and on each respective day of quality evaluation, using the following formula;

  Where W1 is the percentage weight loss, W0 is the initial weight of fruits at harvest and Wt is the weight of the fruits at the designated time (Tefera *et al*., 2007).
- Decay percentage (%): Decayed fruits were detected by visual observation i.e. fruit showing the rotting symptoms. The decay percentage was calculated using the formular;

  Where DF is the number of decayed fruits and DI is the initial number of fruits (Dadzie and Orchard, 1997).

2.8.1 Chemical Analysis of Tomato Fruit

- Total Soluble Solid (TSS): Tomato samples (50g) were homogenized with 200mL deionized water and evaluated for total soluble solids content using a digital refractometer (PAL-α, ATAGO, Japan). The °Brix value was determined applying a dilution factor based on AOAC (2000) guidelines.
- Titratable acidity (TA): TA was determined on the first and last day of the research. The acidity will be estimated as per standard procedures of (AOAC, 2005). To measure titratable acidity (TA) in tomatoes, blend 100-200g of crushed tomatoes with 100mL of distilled water, then centrifuge or filter to obtain clear juice. Pipette 10-20mL of juice into a flask, add 2-3 drops of 1% phenolphthalein indicator, and titrate with 0.1N NaOH until the solution turns pink. Record the NaOH volume used and calculate TA (%) as: TA (%) = (Volume of NaOH x Normality of NaOH x 0.0064) / Sample weight (g).
- Lycopene Content: Lycopene content in tomatoes was determined using the method

of AOAC (2005). Tomato sample (5-10 g) was extracted with hexane/acetone (50:50) and centrifuged. The supernatant was evaporated, reconstituted in tetrahydrofuran, and separated by High-Performance Liquid Chromatography (HPLC) on a C30 column. Lycopene was detected at 472 nm and quantified using a calibration curve. This method provides a precise measurement of lycopene, a potent antioxidant and carotenoid pigment responsible for tomato's red color.

- Ascorbic Acid Content (Vitamin C): Tomato juice was extracted with metaphosphoric acid, then oxidized with 2,6-dichlorophenolindophenol. The reaction was measured spectrophotometrically at 520 nm. Results are expressed as mg/100g of fresh weight (FW). This colorimetric method measures total Vitamin C content. Ascorbic acid (Vitamin C) in tomatoes was determined using the method of AOAC (2005)
- Proximate Analysis: The proximate composition of tomato samples after 20 days was evaluated by determining moisture content through oven drying, analyzing crude fat using AOAC extraction, determining crude fiber with the defatted sample method, analyzing crude protein via the Kjeldahl method, and calculating carbohydrate content by difference, following methods recorded by AOAC (2005).
- Minerals Present in Tomato: Minerals in tomatoes were analyzed using the method of AOAC (2005), which involves dry ashing. The ash is then dissolved in acid (HCl or HNO3) and analyzed for mineral content using Atomic Absorption Spectroscopy (AAS) or Inductively Coupled Plasma (ICP) Spectroscopy (AOAC International, 2005). The results are expressed as mg/100g of fresh weight (FW) or dry weight (DW), providing quantitative data on essential minerals such as calcium, magnesium, potassium, and sodium.

2. 9 Statistical Analysis

Data collected was subjected to Analysis of Variance (ANOVA), and the separation of treatment means will be done by the use of Least Significant Difference (LSD) at 5% level of significance.

RESULT

3.1 Effect of Potassium Permanganate on Tomato Firmness.

Analysis of variance (ANOVA) indicated significant differences ($p < 0.05$) in firmness of tomato fruits throughout the period of storage, with control treatment showing significantly higher values for firmness while the fruits treated with 6g$KMnO_4$ showed the lowest value although it was not significantly different from 2, 4, 6 and 8g$KMnO_4$ treatment with exception of day 21 where the 6g$KMnO_4$ treatment was significantly different from all other treatments as shown in Table 4.1. It was also observed that control samples consistently maintained higher firmness values, while 6g $KMnO_4$ treated fruits exhibited the lowest firmness values making it more firmer after 21 days of storage, fruits treated with 6g $KMnO_4$ maintained optimal firmness levels

3.2 Effect of Potassium Permanganate Rates on Color Change of Tomato Fruits.

Statistical analysis demonstrated no significant differences ($p > 0.05$) in color change among all $KMnO_4$ treatments throughout the 21days storage period. Similar color change patterns were observed across all treatments, though control treatments exhibited more pronounced color development during days 21 as shown in Table 4.

3.3 Effect of Potassium Permanganate Rates on Freshness of Tomato Fruits.

Table 4.3 shows the effect of potassium permanganate rates on the freshness of tomato fruits. Significant differences ($p < 0.05$) in freshness were observed throughout the experiment with exception of day 12. The control treatment showed significantly lower value on day 3,6,9,15,18 and 21 although it was not significantly different from the fruits treated with 2g$KMnO_4$ on day 9, 15, 18 and 21. Also the rate of freshness during the days of storage was observed that the tomato fruits treated with 6g$KMnO_4$ had the highest freshness throughout the days of storage although it was not significantly different from 2, 4, 8g $KMnO_4$ treated fruits on day 3, 6, 9 and it was also not significantly different from 4 and 8g $KMnO_4$ treated fruits on day 15, 18 and 21.

Table 3. 1: Effect of Potassium Permanganate Rates on Tomato Firmness.

Treatments ($gKMnO_4$)	Days of Storage 3	6	9	12	15	18	21
0	1.15a	1.33a	1.95a	2.67a	2.80a	3.08a	3.72a
2	1.00b	1.00b	1.14b	1.52b	1.72b	2.03ab	2.14bc
4	1.00b	1.00b	1.10b	1.14b	1.13b	1.31b	1.57bc
6	1.00b	1.00b	1.00b	1.00b	1.00b	1.00b	1.09c
8	1.00b	1.05ab	1.11b	1.39b	1.63b	1.71b	2.65ab
Lsd (5%)	0.1183	0.3001	0.4920	0.8711	0.8775	1.1257	1.2917

Means with different letters along a column are significant. ns-Non significant.

Table 3. 2: Effect of Potassium Permanganate on the Color Change of Tomato Fruits

Treatments ($gKMnO_4$)	Days of Storage 3	6	9	12	15	18	21
0	4.43	4.48	4.76	4.90	5.13	5.14	5.57
2	4.19	4.90	4.91	5.00	5.05	5.14	5.38
4	4.00	4.67	4.67	4.67	4.71	5.10	5.33
6	4.00	4.76	4.76	4.86	4.86	5.14	5.43
8	3.81	4.71	4.90	4.95	5.00	5.19	5.38
Lsd (5%)	ns	ns	ns	ns	ns	ns	ns

Means with different letters along a column are significant. ns-Non significant

Table 3. 3: Effect of Potassium Permanganate on the Freshness of Tomato Fruits.

Treatments ($gKMnO_4$)	Days of Storage 3	6	9	12	15	18	21
0	3.48b	3.33b	3.23b	3.00a	1.95b	1.48c	0.62b
2	4.00a	4.00a	3.62ab	3.10a	2.33b	1.86bc	1.33b
4	4.00a	4.00a	4.00a	3.90a	3.71a	3.33ab	2.29ab
6	4.00a	4.00a	4.00a	3.94a	3.90a	3.81a	3.81a
8	4.00a	4.00a	3.81ab	3.57a	3.38a	3.10ab	2.29ab
Lsd (5%)	0.4224	0.4861	0.6455	ns	0.9689	1.6134	1.77

Means with different letters along a column are significant. ns-non significant

3.4 Effect of Potassium Permanganate on the Physiological Weight Loss of Tomato Fruits

Statistical analysis revealed there significant differences ($p > 0.05$) in weight loss among tomato fruits treated with varying rates of Potassium permanganate (0g, 2g, 4g, 6g, and 8g) throughout the experimental period. However, it was observed that the control treatment consistently exhibited significant higher weight loss compared to treated samples, with an exception on day 18 where control and 2g $KMnO_4$ treatment showed the highest weight loss of 26.34 and 22.06% respectively. The 4g KMnO4 treatment demonstrated the lowest weight loss throughout storage (0.37-11.07%), performing similar to 6g KMnO4 (0.63-14.80%), while both treatments were significantly different from control, 2g, and 8g KMnO4 treatments during most storage periods, particularly after day 12.

3.5 Effect of Potassium Permanganate on the Decay of Tomato Fruits

Table 4.5 shows the effect of potassium permanganate rates on the decay percentage of tomato fruits. It was obseved that there was significant difference throughout the days of storage with the control treatment having a significantly higher decay percentage except day 15, 18 and 21 where it was not significantly different from 2g $KMnO_4$ treated fruits and also with the 4g $KMnO_4$ on day 18. The tomato fruits treated with 6g $KMnO_4$ recorded the lowest decay percentage on day 15, 18 and 21, although it was not significantly different from 2, 4 and 8g $KMnO_4$ treated fruits on day 18 and it was also not significantly different from 4 and 8g $KMnO_4$ treated fruits on day 21.

Table 3. 4: Effect of Potassium Permanganate Rates on Weight Loss of Tomato Fruits.

Treatments	Days of Storage						
	3	6	9	12	15	18	21
Control	2.08a	3.90a	7.89a	20.57a	24.75a	26.34a	27.84a
2g$KMnO_4$	1.31b	1.67b	1.84b	4.19bc	18.37ab	22.06a	22.76ab
4g$KMnO_4$	0.37c	0.61c	0.96b	1.72d	5.97c	7.47b	11.07c
6g$KMnO_4$	0.63c	0.78c	1.13b	2.60cd	7.62c	9.21b	14.80bc
8g$KMnO_4$	0.65c	0.84c	1.69b	5.57b	11.45bc	13.37b	18.04bc
LSD	0.6535	0.6703	3.0223	2.2084	6.9836	7.5111	9.4191

Means with different letters along a column are significant. NS-Non significant, LSD-Least significant difference, $KMnO_4$ – Potassium permanganate

Table 3. 5: Effect of Potassium Permanganate on the Decay of Tomato Fruits.

Treatments	Days of Storage						
	3	6	9	12	15	18	21
Control	14.29a	14.29a	23.81a	52.38a	61.90a	71.43a	80.95a
2g$KMnO_4$	0.00b	0.00a	4.76b	19.05b	42.86ab	57.14ab	66.67ab
4g$KMnO_4$	0.00b	0.00a	4.76b	4.76b	19.05b	33.33ab	38.10bc
6g$KMnO_4$	0.00b	0.00a	4.76b	4.76b	23.81b	23.81b	28.57c
8g$KMnO_4$	0.00b	4.76a	9.53ab	23.81b	28.57b	38.10ab	57.14abc
LSD	12.028	15.137	15.915	21.684	28.635	42.382	36.742

Means with different letters along a column are significant. NS-Non significant, LSD-Least significant difference, $KMnO_4$

3.6 Effect of Potassium Permanganate Rates on Titratable Acidity, Total Soluble Solid, Vitamin C, Lycopene Content of Tomato Fruits

Table 3.6 shows the effect of potassium permanganate rates (0g, 2g, 4g, 6g and 8g) on the titratable acidity, total soluble solid, vitamin C content and lycopene content of tomato fruits which was recorded before and after storage. There was no significant difference recorded among all treatments in the titratable acidity, vitamin C and lycopene content before and after storage. Although there was significant difference recorded after storage for total soluble solid of tomato fruits. The fruits with control treatment had a significantly lower total soluble solid of 2.80% while the tomato fruits treated with 8g$KMnO_4$ had a significantly higher total soluble solid value of 3.60%. The control treatment recorded a significantly lower total soluble solid, vitamin C and lycopene content of 2.8%, 9.5% and 0.8% respectively while the tomato fruits treated with 8g$KMnO_4$ recorded a higher total soluble solid of 3.6%, 11.2%, 0.95% respectively after storage. Table 4.6 also shows the effect of $KMnO_4$ rates on the titratable acidity, total soluble solid, vitamin C and lycopene content of tomato fruits. It was observed that there was a decline in the titratable acidity, total soluble solid, vitamin C and lycopene content after the storage period. The control treatment maintained a lower value for titratable acidity, total soluble solid, vitamin C and lycopene content while the tomato fruits treated with 8g$KMnO_4$ had a higher value total soluble solid, vitamin C and lycopene content and the fruits treated with 4g$KMnO_4$ had a higher titratable acidity value after storage.

Table 3. 6: Effect of Potassium Permanganate rates on the Titratable Acidity and Total Soluble Solid of Tomato Fruits.

Treatment ($gKMnO_4$)	% TA		%TSS	
	BS	AS	BS	AS
0	0.38	0.21	4.60	2.80
2	0.38	0.26	4.60	3.10
4	0.38	0.27	4.60	3.00
6	0.38	0.25	4.60	3.35
8	0.38	0.26	4.60	3.60
Lsd (5%)	ns	Ns	ns	0.2063

Means with different letters along a column are significant. Ns-Non significant, TA-Titratable acidity, TSS- Tota soluble solid, BS-Before Storage, AS-After Storage.

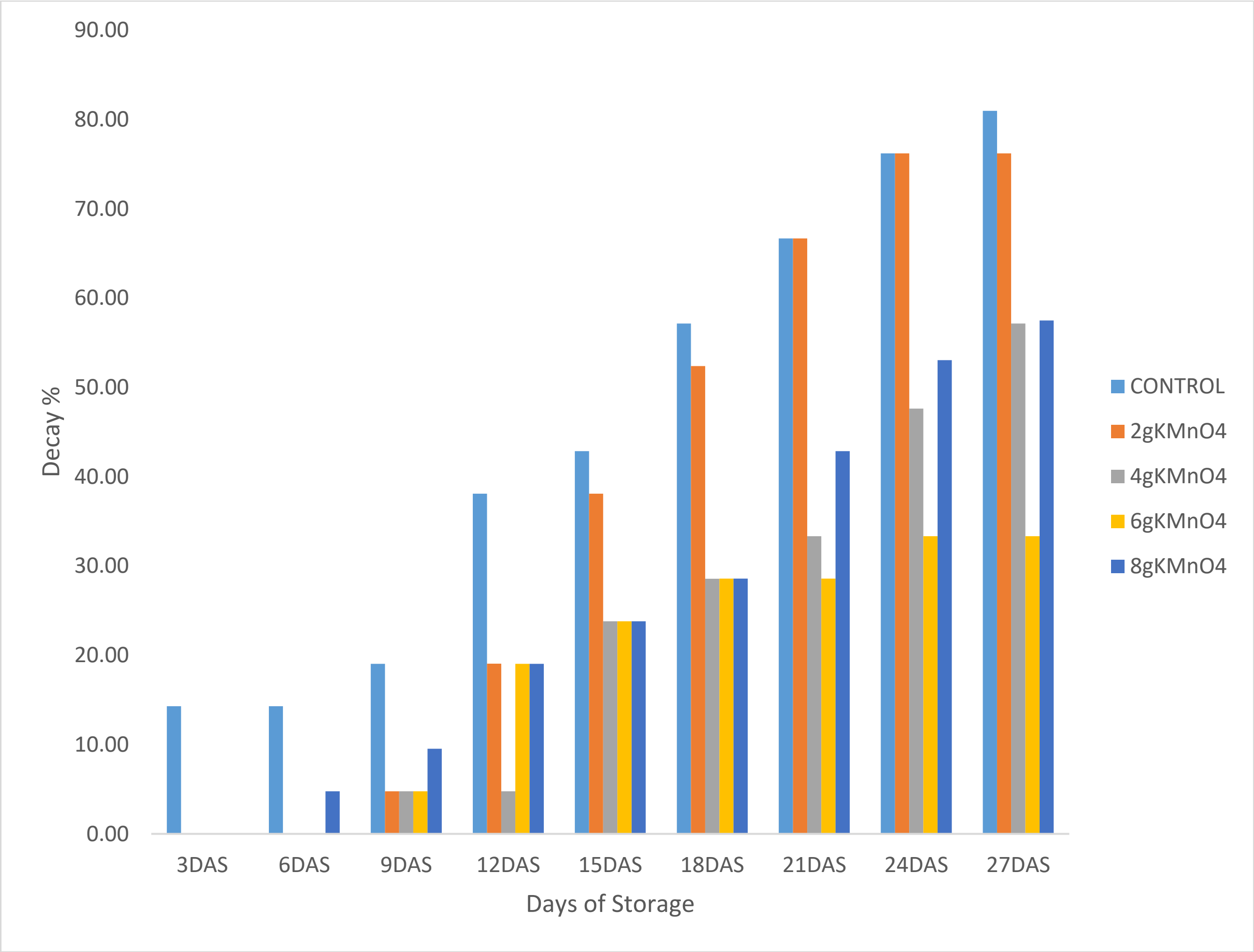

Figure 3. 1: Effect of KMnO4 of the decay of tomato fruits.

Table 3. 7: Effect of Potassium Permanganate rates on the Vitamin C and Lycopene Content of Tomato Fruits.

Treatment ($gKMnO_4$)	Vit C Mg/100g		Lycopene Mg/100g	
	BS	AS	BS	AS
0	13.50	9.50	1.20	0.80
2	13.50	10.05	1.20	0.88
4	13.50	10.30	1.20	0.93
6	13.50	11.00	1.20	0.94
8	13.50	11.20	1.20	0.95
Lsd (5%)	ns	ns	Ns	ns

Means with different letters along a column are significant. Ns-Non significant, Vit C-Vitamin C, BS-Before Storage, AS-After Storage.

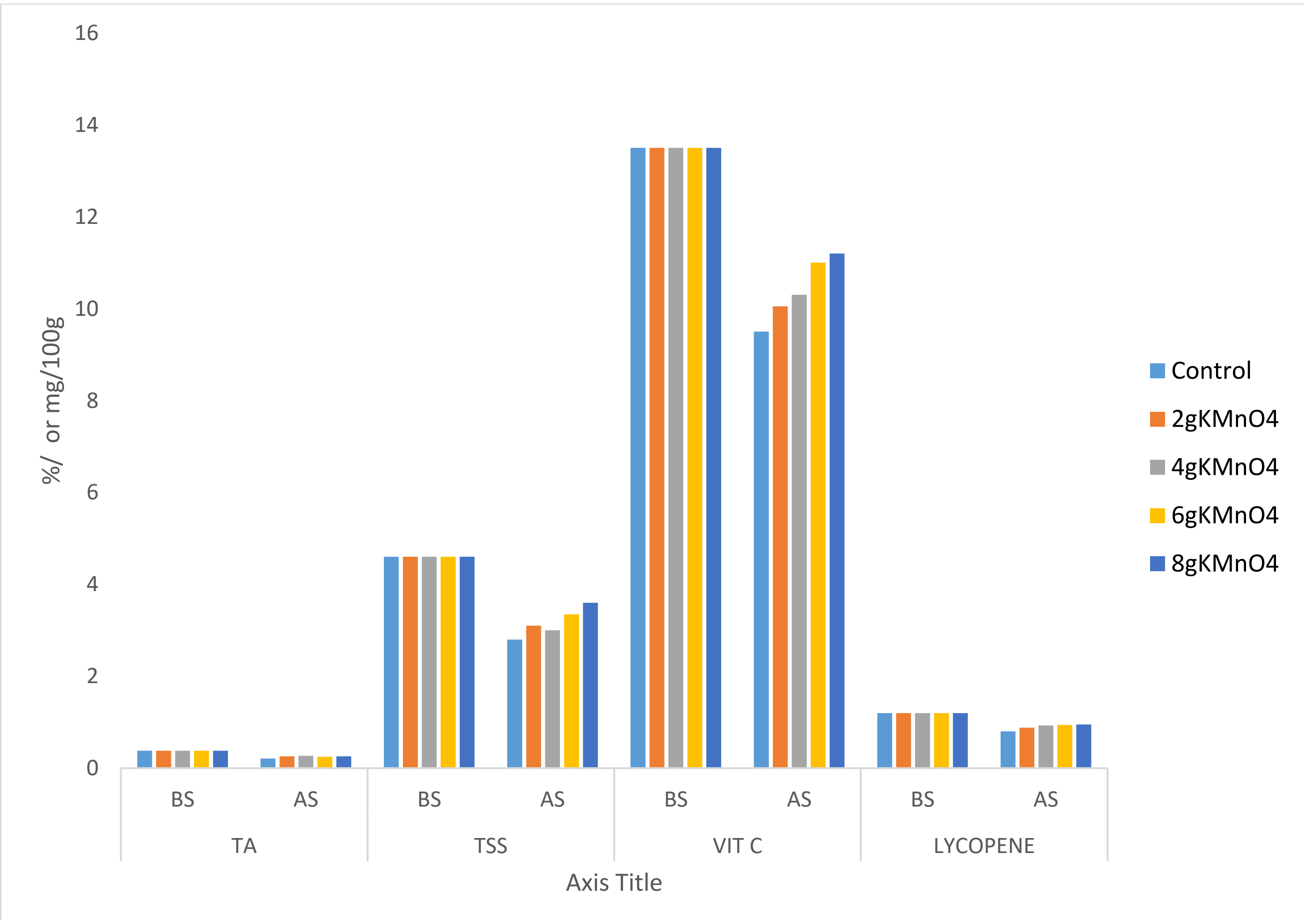

Fig 3. 2: Effect of KMnO4 on the TA, TSS, Vit C and Lycopene content of Tomato Fruits.

3.7 Effect of Potassium Permanganate Rates on the Proximate Analysis of Tomato Fruits.

Table 4.7 shows the effect of potassium permanganate rates on the on the proximate analysis of tomato fruits. It was recorded that there was no significance difference among all treatment rate before and after storage. It was observed that there was a decline in the proximate analysis among all variables except for the carbohydrate which was increased after storage. The tomato fruit treated with 2g$KMnO_4$ and 8g$KMnO_4$ had a lower Ash content of 0.20% while the control and 6g$KMnO_4$ had the higher Ash content of 0.15% after storage (fig 4.7). The tomato fruits treated with 4gKMnO4 had a lower moisture of 91.5% while the tomato fruits treated with 2g$KMnO_4$ had a higher moisture of 92.20% after storage (fig 4.7). The tomato fruits treated with 2g$KMnO_4$ and 8g$KMnO_4$ had a lower crude protein of 0.30% while the tomato fruits treated with 4g$KMnO_4$ had a higher crude protein of 0.40% after storage. The control treatment had a lower Crude fiber and Crude fat of 0.80% and 0.20% respectively while the tomato fruits treated with 6g$KMnO_4$ had a higher Crude fiber and Crude fat of 1.10% and 0.12% respectively after storage (fig 4.7). The tomato fruit treated with 2g$KMnO_4$ shows a lower Carbohydrate of 6.25% while the tomato fruits treated with 4g$KMnO_4$ had a higher carbohydrate of 6.91% after storage

Table 3. 8: Effect of Potassium Permanganate on the Proximate Analysis of Tomato Fruits

Treatment	Ash		Moisture		Crude Protein		Crude Fiber		Crude Fat		Carbo-hydrate	
	%											
g$KMnO_4$	BS	AS	BS	AS	BS	AS	BS	AS	BS	AS	BS	AS
0	0.50	0.20	93.80	92.00	0.60	0.35	1.30	0.80	0.20	0.01	3.60	6.52
2	0.50	0.15	93.80	92.20	0.60	0.30	1.30	1.00	0.20	0.10	3.60	6.25
4	0.50	0.18	93.80	91.50	0.60	0.40	1.30	0.90	0.20	0.11	3.60	6.91
6	0.50	0.20	93.80	91.80	0.60	0.31	1.30	1.10	0.20	0.12	3.60	6.47
8	0.50	0.15	93.80	92.10	0.60	0.30	1.30	1.05	0.20	0.11	3.60	6.29
Lsd (5%)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means with different letters along a column are significant. NS-Non significant, LSD-Least significant difference, $KMnO_4$ – Potassium permanganate, BS- Before Storage, AS- After Storage.

3.8 Effect of Potassium Permanganate Rates on the Mineral Properties of Tomato Fruits.

Table 4.8 Shows the effect of potassium permanganate rates on the mineral properties of tomato fruits. It was recorded that there was no significant different among all treatment and variables before and after storage. There was also a decline of the mineral content after storage except for the to carbon content which increased for all treatment. The percentage phosphorus of tomato fruits treated with 2g$KMnO_4$ and 4g$KMnO_4$ recorded the highest %P of 0.02% while the fruits with control, 6g$KMnO_4$, 8g$KMnO_4$ treatment recorded the lowest %P of 0.01% respectively. The percentage carbon of tomato fruits treated with 2g$KMnO_4$ and 4g$KMnO_4$ recorded the highest %P of 0.08% while the fruits with control and 8g$KMnO_4$ had the lowest %Ca of 0.02% after storage.

The percentage magnesium of tomato fruits treated with 6g$KMnO_4$ had a lower value of 0.007% while the tomato fruits treated with 2g$KMnO_4$ had a higher value of 0.023% after storage. The percentage potassium of tomato fruits treated with 8g$KMnO_4$ had the lowest value of 0.212% while the tomato fruits with control treatment had the highest value of 0.298% after storage. The percentage Sodium of tomato fruits treated with 8g$KMnO_4$ had the lowest value of 0.031% while the tomato fruits treated with 4g$KMnO_4$ had the highest value of 0.040% after storage.

Table 3. 9: Effect of Potassium Permanganate on the Mineral Properties of Tomato Fruits.

Treatment	P		Ca		Mg		K		Na	
	%									
$gKMnO_4$	BS	AS	BS	AS	BS	AS	BS	AS	BS	AS
0	0.06	0.01	0.01	0.02	0.02	0.01	0.33	0.30	0.09	0.03
2	0.06	0.02	0.01	0.08	0.02	0.02	0.33	0.26	0.09	0.04
4	0.06	0.02	0.01	0.08	0.02	0.01	0.33	0.28	0.09	0.04
6	0.06	0.01	0.01	0.04	0.02	0.01	0.33	0.22	0.09	0.03
8	0.06	0.01	0.01	0.02	0.02	0.01	0.33	0.21	0.09	0.03
Lsd (5%)	ns	ns	Ns	ns	ns	ns	Ns	ns	Ns	ns

Means with different letters along a column are significant. NS-Non significant, BS- Before Storage, AS- After Storage

DISCUSSION

The preservation of fruits and vegetables poses significant challenges in post-harvest management due to their highly perishable nature. The findings revealed several significant effects on physiological, biochemical, and mineral properties during storage. The study showed significant differences ($p < 0.05$) in firmness across treatments. Control fruits showed higher firmness values while $6gKMnO_4$ treated fruits maintained optimal firmness through 21 days. This finding corroborates with Kumar et al. (2018), who reported that $KMnO_4$ treatments effectively preserved fruit firmness by delaying cell wall degradation and maintaining cellular integrity. The mechanism behind improved firmness retention can be attributed to $KMnO_4$'s role in ethylene oxidation, as suggested by Patel et al. (2019). By reducing ethylene accumulation, $KMnO_4$ helps delay ripening-related softening processes, thereby maintaining structural integrity for extended periods.

No significant differences ($p > 0.05$) were observed among treatments for color development, though control fruits showed more pronounced color changes by day 21. This delayed color development in $KMnO_4$ treated fruits suggests effective regulation of ripening processes, supporting findings by Wabali et al. (2017), who reported similar effects on color retention in stored fruits. The gradual color development observed across all treatments indicates that $KMnO_4$ does not completely inhibit ripening but rather regulates the process, allowing for controlled maturation while preventing premature deterioration.

For freshness, Significant differences ($p < 0.05$) were observed throughout storage except on day 12. The $6gKMnO_4$ treatment maintained highest freshness, supporting findings by (Rahman *et al.* 2012) who demonstrated that $KMnO_4$ treatments effectively preserve fresh produce quality by reducing respiration rates.

The application of $KMnO_4$ demonstrated notable effects on reducing physiological weight loss in tomato fruits, statistical analysis also revealed significant differences in weight loss among treatments. The $4gKMnO_4$ treatment showed lowest weight loss, This finding aligns with research by Alonso-Salinas *et al* (2019), who reported that $KMnO_4$ treatments effectively reduced weight loss in stored fruits. The 6g $KMnO_4$ treatment showed lowest decay, particularly during days 15-21. This finding aligns with research by Singh et al. (2019), who reported that $KMnO_4$ treatments significantly reduced decay incidence in stored fruits through its antimicrobial properties and regulation of ripening processes.

The results showed no significant differences in Titratable Acidity (TA), Vitamin C, and lycopene content, but significant differences in Total Soluble Solids (TSS) after storage. The 8g$KMnO_4$ treatment maintained highest TSS (3.60%), Vitamin C (11.2%), and lycopene (0.95%). This aligns with Sammi and Masud (2007) who reported that ethylene scavengers help preserve nutritional quality by slowing down metabolic processes. The preservation of Vitamin C specifically supports findings by Castro et al. (2019) showing that reduced ethylene exposure maintains ascorbic acid content in fruit. No significant differences were observed among treatments, but general decline occurred in all parameters except carbohydrates. The 4g$KMnO_4$ treatment showed optimal results for protein (0.40%) and carbohydrates (6.91%). These findings aligns with research by Kumar and Singh (2015) demonstrating that ethylene absorption helps maintain nutritional composition during storage. The increase in carbohydrates aligns with Mahajan et al. (2014) who explained this phenomenon as a result of moisture loss concentrating the nutrients.: No significant differences were observed among treatments, with general decline in all minerals except carbon. Key findings include: Phosphorus and Calcium highest in 2g and 4g$KMnO_4$ (0.02% and 0.08% respectively), Potassium highest in control (0.298%) and Sodium highest in 4g$KMnO_4$ (0.040%). These results support work by Ahmed and Palta (2016) showing that mineral content changes during storage are primarily influenced by moisture loss rather than ethylene levels. However, the better retention of some minerals in treated fruits aligns with findings by Reddy and Sharma (2018) suggesting that slower ripening helps maintain mineral composition.

CONCLUSION

This study demonstrates that potassium permanganate ($KMnO_4$) treatments effectively extend the shelf life and maintain quality parameters of tomato fruits during storage. The 6g $KMnO_4$ treatment emerged as particularly effective, showing optimal results in maintaining firmness and freshness while minimizing decay throughout the 21-day storage period. The 4g $KMnO_4$ treatment proved most effective in minimizing physiological weight loss (0.37-11.07%), while the 8g $KMnO_4$ treatment showed superior results in maintaining nutritional qualities, particularly Total Soluble Solids (3.60%), Vitamin C (11.2%), and lycopene content (0.95%). While color development was not significantly affected by $KMnO_4$ treatments, the controlled ripening process observed across treated fruits suggests that $KMnO_4$ successfully modulates rather than completely inhibits the ripening process. This modulation allows for gradual maturation while preventing premature deterioration. The preservation of nutritional and mineral content, though showing some decline across all treatments, was generally better maintained in $KMnO_4$ treated fruits compared to the control. The findings indicate that $KMnO_4$ functions as an effective ethylene scavenger, helping to regulate ripening processes and maintain fruit quality through multiple mechanisms, including delayed cell wall degradation, reduced respiration rates, and antimicrobial properties. This study revealed that potassium permanganate treatments, particularly at 4-6g concentrations, can be recommended as an effective post-harvest treatment for extending the shelf life and maintaining the quality of tomato fruits during storage.