

# Effect of fertilizer types and ethylene remediation agents on weight loss and shelf life of stored tomato (*Solanum lycopersicum* L.) fruits

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**Summary:** This experiment was conducted to determine the influence of fertilizer types and ethylene remediation agents on postharvest shelf-life of tomato fruit. The experiment was conducted at the Federal University of Agriculture, Abeokuta, Nigeria. Fruits were produced under four fertilizer treatment levels (Poultry manure, NPK 15:15:15, Poultry manure + NPK 15:15:15 and Control) and were harvested at breaker stage of maturity. The post-harvest treatments consist of eight ethylene remediation agents (ERAs) which includes three levels of 1-Methylcyclopropene (0.1 µL/L 1-MCP, 0.3 µL/L 1-MCP, 0.5 µL/L 1-MCP), two levels of Potassium tetraoxomanganate VII (5% 10% KMnO<sub>4</sub>), two levels of Zeolite (10 g and 20 g) and Open shelf as control. The parameters observed included fruit weight loss and days to spoilage (1<sup>st</sup>, 50% and 100%). It was observed that fruits produced with sole poultry manure and NPK 15-15-15 and stored in the media of 5% KMnO<sub>4</sub> had a shelf life of 45 days, longer than observed in other fertilizer regimes. Fruits stored in 0.3 µL/L1-MCP, 0.5µL/L1-MCP and 5% KMnO<sub>4</sub> concentrations as ERAs had reduced weight loss and delayed spoilage that translated to longer shelf-life. Fruits grown with poultry manure and treated with 0.3 µL/L1-MCP, 0.5µL/L1-MCP and 5% KMnO<sub>4</sub> had better performance in terms of fruit firmness and shelf life compared to other treatments. The use of either 1-MCP or 5% KMnO<sub>4</sub> is recommended as efficient ethylene scavengers in a storage medium for tomato fruit shelf-life extension.

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**Key words:** ethylene, fertilizer types, shelf-life, ethylene remediation agents, postharvest, tomato

## Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most significant crop in the world and as well valued as both fresh and processed vegetable. It belongs to the Solanaceae family which also includes sweet pepper, Irish potato, chili, and eggplant (Shimizutani et al., 2021), It is cherished for its nutritional composition, anti-oxidant, anti-inflammatory and anticancer properties (Salehi et al., 2019). In 2021, global production of tomato was recorded as 190 million tonnes. However, about 40% of tomato fruits produced is lost annually (FAO, 2023). Tomato is an important source of income for African farmers (Arah et al., 2015) and the fruit can be consumed fresh in sandwiches, salads or processed and eaten as soups, sauces, juices, and pastes (Beckles, 2012). The produce has been recommended as part of a healthy diet as a result of its high fiber, low fat and calorie content and zero cholesterol (Zingwari et al., 2024).

Fertilizer management also affects horticultural crops' post-harvest behavior aside plant growth. Quite a number of recent research demonstrate that fertilizer types affect tomato fruit weight loss during storage and shelf life (Kumar et al., 2022; Mutua et al., 2021; Singh et al., 2022). Chemical fertilizers are widely used in agriculture, however their continual application can alter the properties of the soil and cause heavy metals to build up in plant tissues (Adhikari et al., 2020). Fruits grown

on such soils are not only less nutritious and of lower quality, but they are also more vulnerable to pest and disease attacks (Zingwari et al., 2019). On the other hand, tomato fruits' post-harvest storage behavior seems to be enhanced by organic fertilizers (Araujo & Telhado, 2015; Laxmi et al., 2015 and Pradhan and Srijaya, 2022), most likely through increased fruit structural integrity. Teshome et al. (2025) reported that application of chemical fertilizers resulted in higher weight loss compared to organic fertilizers. But the complementary application of these chemical fertilizers with organic manures has shown better performance on shelf life and quality of tomato (Muthukumar et al., 2019).

Ethylene is a plant hormone which serves as the principal regulator of ripening in climacteric fruits. Fruit exposed to ethylene loses weight more rapidly because ripening causes increased respiration, increased metabolic activity, water vapour loss, softening and tissue degradation (Zakriya et al., 2023). The aggressive production of this ethylene leads to enhanced ripening, softening of fruit cell walls, weight loss and eventual spoilage of the fruit, thus increasing food waste Dhall (2013). Most fresh horticultural produces are highly perishable, and ethylene often contributes considerably to the ripening and senescence process (Alvarez-Hernández et al., 2018). The shelf life of these produces may be increased by lowering the

ethylene concentrations in the area by slowing down metabolic activities (Zakriya et al., 2023). Post-harvest treatments cause significant effect on post-harvest quality of horticultural crops (Sinha et al. 2019) and the use of some post-harvest treatments such as Potassium permanganate (KMnO<sub>4</sub>), Zeolite and 1-methylcyclopropene as ethylene remediation agents have been reported to inhibit ethylene production due to its absorbent, adsorbent and repellent characteristics (Ali et al., 2015) thus significantly reduce weight loss during storage and thereby extend shelf-life of produce.

Tomato is a climacteric fruit with short shelf life which is due to its high moisture content (Zingwari et al., 2019). It is highly perishable thus quality loss and weight loss during transportation, storage and shelf life are serious issues in horticultural production. In order to prolong shelf life, maintain quality and minimize losses of tomato, weight loss interventions are essential. It is important to use handling techniques that reduce or remove ethylene from the storage environment. The combined use of ethylene remediation agents and appropriate soil management practices offers a promising strategy to enhance fruit quality, extend shelf life of tomato fruits and as well ensure a more consistent supply of the produce throughout the year. Therefore, it is both technically and practically suitable to evaluate both fertilizer types and ethylene remediation agents in order to extend the shelf life of tomato fruits. The work is aimed to determine effect of fertilizer types and ethylene remediation agents on weight loss and shelf life of stored tomato fruits.

## Materials and methods

The experiments were conducted twice and identified as experiment 1 and experiment 2. For both experiments, seeds of tomato variety Beske were raised into seedlings in the nursery for four (4) weeks, after which they were transplanted to the main field. Four fertilizer types; NPK 15:15:15 (300 kg ha<sup>-1</sup>), Poultry manure (10 t ha<sup>-1</sup>), NPK 15:15:15 (150 kg ha<sup>-1</sup>) + Poultry manure (5 t ha<sup>-1</sup>) and a control (No fertilizer) were used. The field experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications.

After production, fruits from each fertilizer treatment were harvested at Breaker stage (when there is a definite break in colour from green to tannish-yellow/pink (<10% red colour)). Fruits harvested were stored in the laboratory, Department of Horticulture, Federal University of Agriculture, Abeokuta, Nigeria. prior to storage, fruit samples were cooled, sorted and graded according to uniformity of size. Sample fruits were inspected to screen out those with defects or signs of disease infection. Approximately 500 g treated fruits were stored in perforated plastic containers (size of 659.75 cm<sup>3</sup>). Thus, there were 32 treatment combinations derived from four fertilizer types and eight exposures (ERAs plus control).

The sample fruits were subjected to the seven (7) ethylene remediation treatments that were made up of an Ethylene Absorber which is Potassium tetraoxomanganate VII (KMnO<sub>4</sub>) at two levels, one Ethylene Adsorber (Zeolite at two levels) and Ethylene inhibitor which is 1-Methylcyclopropene (1-MCP at three levels) and control. The three concentrations of the ethylene inhibitor were 0.1 µl/L 1-MCP, 0.3 µl/L 1-MCP, and 0.5µl/L 1-MCP. Ethylene Absorber was used at two levels of 5% and 10 % conc. KMnO<sub>4</sub> solution) while Ethylene Adsorber (Zeolite) was at two levels 10 g and 20 g while an Open shelf served as control.

## Ethylene remediation agents preparation and application

SmartFresh™ (AgroFresh Inc.) commercial powder (0.14% of active ingredient) was used to create gaseous 1-MCP. Application of 0.1, 0.3, and 0.5 µl/L for 24 hours at 25 °C and 85–90% relative humidity was done in airtight plastic containers with a volume of 1 m<sup>3</sup>. Fruit samples were placed next to potassium permanganate (KMnO<sub>4</sub>) solutions of 5% and 10% concentrations, which were made by dissolving 5 g and 10 g of KMnO<sub>4</sub> powder, respectively, in 100 ml of distilled water. Additionally, 10 and 20 grams of granular zeolite were placed next to fruit samples in small containers.

The laboratory experiment was laid out in Completely Randomized Design (CRD) with three replications, in the Laboratory of the Department of Horticulture, Federal University of Agriculture, Abeokuta, Nigeria.

Five fruits were randomly selected from each treatment per replication for the storage observation, and they were assessed for percentage weight loss (%), days to 1<sup>st</sup> spoilage, 50% and 100% spoilage and shelf-life (days). Spoilage was assessed by observing the incidences of fruit shrinkage, rotting, and cracking along storage days.

## Statistical analysis

Data collected were subjected to Analysis of Variance (ANOVA) using PROC GLM in SAS version 9.3 (SAS, 2012). Treatment means were separated using Least Significant Difference (LSD) for set of means not more than six and Duncan's Multiple Range Test (DMRT) for set of means more than six, both at 5% probability level.

## Results

### Effect of fertilizer type on weight loss (%) of stored tomato fruits

Generally, weight loss increased with storage, regardless of ethylene remediation agent. The different fertilizer type significantly ( $p < 0.05$ ) influence weight loss of tomato fruits till day 16 for both experiments (**Tables 1-2**). Fruits from control plots (with no fertilizer) in both experiments showed higher weight loss than fruits from fertilized plots. However, the effect of different levels of organic and inorganic fertilizers did not differ much in weight change of treated fruits. However, there was a higher weight loss of fruits in the first year of experiment from plots treated with 300 kg ha<sup>-1</sup> NPK 15-15-15 and 10 t ha<sup>-1</sup> of poultry manure at the early period of storage when compared with other fertilizer treatments. In the second experiment, weight loss was high for fruits from control plots at the beginning of the storage period, when compared with other treatments. As storage period progressed, fruits of all remediation treatments responded similarly to all the fertilizer types until the end of the storage period.

### Effect of ethylene remediation substances on weight loss (%) of stored tomato fruits

The weight loss of tomato fruits was significantly ( $p < 0.05$ ) affected by ripening remediation treatments (**Tables 3-4**). Fruits exposed to 0.5µl/L of 1-MCP showed the lowest percentage weight loss at the beginning of the storage period in the first experiment, whereas fruits stored on an open shelf

**Table 1:** Effect of fertilizer type on weight loss (%) of stored tomato fruits in experiment 1.

TREATMENTS	DAYS															
	4	7	10	13	16	19	22	25	28	31	34	37	40	43	46	49
<b>F1</b>	7.14	18.08	29.32	36.09	45.68	55.33	62.16	75.99	79.58	81.28	88.83	90.44	93.44	95.4	96.8	-
<b>F2</b>	6.62	17.13	27.61	38.8	49.86	58.69	64.11	73.94	75.58	87.81	88.4	91.71	91.71	95.2	97	-
<b>F3</b>	6.92	17.58	27.29	35	46.8	56.04	63.65	67.72	76.91	82.71	87.4	89.32	89.32	93.22	96.38	-
<b>F4</b>	7.72	18.73	29.8	35.7	46.72	54.75	61.95	71.68	77.14	82.63	89.48	93.38	94.38	96.05	99.87	-
<b>LSD (0.05)</b>	1.08	1.07	1.52	3.19	2.86	2.64	2.67	6.06	4.6	4.05	1.62	2.45	2.67	1.07	1.52	-

F1- NPK 15-15-15, F2- Poultry manure, F3- NPK 15-15-15 + Poultry manure, F4- Control

**Table 2:** Effect of fertilizer type on weight loss (%) of stored tomato fruits in experiment 2.

TREATMENT	DAYS															
	4	7	10	13	16	19	22	25	28	31	34	37	40	43	46	49
<b>F1</b>	5.18	15.02	24.88	33.27	42.14	47.4	45.6	58.25	60.07	73.19	80.18	86.5	91.84	95.45	98.06	99.38
<b>F2</b>	5.69	15.92	24.99	33.72	40.91	46.56	46.7	59.12	60.38	73.03	80.89	86.96	92.4	96.16	98.58	99.53
<b>F3</b>	5.51	15.41	26.17	34.95	43.26	48.65	47.39	59.18	59.44	71.85	81.3	86.37	93.05	96.05	98.31	99.24
<b>F4</b>	6.25	16.67	25.37	36.66	41.6	46.9	45.5	59.97	60.55	72.45	78.24	88.15	94.7	97.4	99.44	99.86
<b>LSD (0.05)</b>	1.04	1.59	2.68	2.43	2.04	1.62	2.46	1.05	1.12	1.73	1.61	2.73	2.96	2.5	1.75	0.82

F1- NPK 15-15-15, F2- Poultry manure, F3- NPK 15-15-15 + Poultry manure, F4- Control

**Table 3:** Effect of ethylene remediation substance on weight loss (%) of stored tomato fruits in experiment 1.

TREATMENT	DAYS															
	4	7	10	13	16	19	22	25	28	31	34	37	40	43	46	49
<b>P1</b>	5.33 <sup>bc</sup>	11.84 <sup>d</sup>	18.12 <sup>c</sup>	27.21 <sup>de</sup>	38.71 <sup>d</sup>	49.32 <sup>cd</sup>	55.71 <sup>ed</sup>	74.16 <sup>b</sup>	75.64 <sup>bc</sup>	87.01 <sup>b</sup>	91.63 <sup>b</sup>	93.81 <sup>b</sup>	95.35 <sup>b</sup>	98.26 <sup>a</sup>	98.66 <sup>a</sup>	-
<b>P2</b>	6.74 <sup>b</sup>	11.86 <sup>d</sup>	16.59 <sup>c</sup>	21.92 <sup>c</sup>	29.44 <sup>e</sup>	36.93 <sup>f</sup>	41.68 <sup>g</sup>	60.29 <sup>dc</sup>	64.19 <sup>de</sup>	75.72 <sup>d</sup>	80.57 <sup>d</sup>	83.04 <sup>cd</sup>	88.43 <sup>dc</sup>	91.44 <sup>c</sup>	95.27 <sup>c</sup>	-
<b>P3</b>	2.78 <sup>c</sup>	14.55 <sup>cd</sup>	19.37 <sup>c</sup>	29.36 <sup>d</sup>	39.18 <sup>d</sup>	46.14 <sup>e</sup>	51.07 <sup>ef</sup>	66.61 <sup>bc</sup>	69.33 <sup>dc</sup>	78.9 <sup>dc</sup>	82.02 <sup>dc</sup>	86.1 <sup>c</sup>	89.08 <sup>c</sup>	95.07 <sup>b</sup>	96.9 <sup>c</sup>	-
<b>P4</b>	7.5 <sup>b</sup>	16.5 <sup>cd</sup>	22.78 <sup>c</sup>	29.09 <sup>de</sup>	35.85 <sup>de</sup>	43.07 <sup>ef</sup>	47.56 <sup>gf</sup>	52.64 <sup>d</sup>	60.57 <sup>e</sup>	68.97 <sup>e</sup>	70.12 <sup>e</sup>	80.94 <sup>d</sup>	85.15 <sup>d</sup>	91.34 <sup>c</sup>	97.77 <sup>b</sup>	-
<b>P5</b>	6.53 <sup>b</sup>	18.65 <sup>cb</sup>	33.19 <sup>b</sup>	46.23 <sup>b</sup>	57.35 <sup>cb</sup>	61.04 <sup>c</sup>	64.48 <sup>c</sup>	73.7 <sup>b</sup>	80.19 <sup>b</sup>	81.95 <sup>bc</sup>	86.65 <sup>bc</sup>	92.68 <sup>b</sup>	97.74 <sup>ba</sup>	-	-	-
<b>P6</b>	5.79 <sup>b</sup>	21.62 <sup>ab</sup>	40.71 <sup>a</sup>	54.7 <sup>a</sup>	65.98 <sup>ab</sup>	69.23 <sup>b</sup>	82.44 <sup>b</sup>	87.12 <sup>a</sup>	93.54 <sup>a</sup>	98.73 <sup>a</sup>	99.2 <sup>a</sup>	-	-	-	-	-
<b>P7</b>	6.98 <sup>b</sup>	19.22 <sup>cb</sup>	30.09 <sup>b</sup>	40.69 <sup>bc</sup>	49.98 <sup>c</sup>	54.58 <sup>cd</sup>	61.97 <sup>cd</sup>	68.8 <sup>bc</sup>	75.4 <sup>bc</sup>	77.96 <sup>dc</sup>	84 <sup>dc</sup>	91.13 <sup>b</sup>	-	-	-	-
<b>P8</b>	14.36 <sup>a</sup>	24.8 <sup>a</sup>	31.18 <sup>b</sup>	58 <sup>c</sup>	95.62 <sup>a</sup>	-	-	-	-	-	-	-	-	-	-	-
<b>LSD(0.05)</b>	3.03	4.86	6.69	7.66	8.43	8.10	8.28	8.69	6.61	5.82	5.02	4.51	3.21	2.41	1.93	-

P1- 0.1µL/L 1-MCP, P2- 0.3µL/L 1-MCP, P3- 0.5µL/L 1-MCP, P4- 5% KMnO<sub>4</sub>, P5- 10% KMnO<sub>4</sub>, P6- 10g of Zeolite, P7- 20g of Zeolite, P8-Open shelf

Means followed by the same alphabet in the same row are not significantly different at 5% probability level

**Table 4.** Effect of ethylene remediation substance on weight loss (%) of tomato fruits in experiment 2.

TREATMENT	DAYS															
	4	7	10	13	16	19	22	25	28	31	34	37	40	43	46	49
<b>P1</b>	4.41 <sup>c</sup>	10.16 <sup>de</sup>	21.79 <sup>b</sup>	33.05 <sup>b</sup>	39.21 <sup>b</sup>	43.52 <sup>bc</sup>	50.44 <sup>ab</sup>	56.35 <sup>bc</sup>	64.91 <sup>ab</sup>	71.05 <sup>cd</sup>	82.54 <sup>c</sup>	90.73 <sup>c</sup>	93.98 <sup>b</sup>	95.99 <sup>b</sup>	98.2 <sup>ab</sup>	-
<b>P2</b>	4.66 <sup>bc</sup>	10.44 <sup>dec</sup>	17.44 <sup>c</sup>	29.19 <sup>dc</sup>	34.53 <sup>d</sup>	37.89 <sup>fe</sup>	41.12 <sup>c</sup>	51.86 <sup>d</sup>	56.53 <sup>cb</sup>	66.32 <sup>ed</sup>	72.71 <sup>d</sup>	77.63 <sup>e</sup>	84.16 <sup>c</sup>	89.74 <sup>c</sup>	94.58 <sup>c</sup>	97.81 <sup>b</sup>
<b>P3</b>	5.33 <sup>bc</sup>	11.25 <sup>dbc</sup>	17.51 <sup>c</sup>	25.72 <sup>de</sup>	35.07 <sup>dc</sup>	40.03 <sup>de</sup>	44.15 <sup>cb</sup>	52.11 <sup>dc</sup>	57.85 <sup>cb</sup>	64.77 <sup>e</sup>	72.43 <sup>d</sup>	83.68 <sup>d</sup>	93.26 <sup>b</sup>	97.96 <sup>ab</sup>	-	-
<b>P4</b>	4.37 <sup>c</sup>	9.04 <sup>e</sup>	15.22 <sup>c</sup>	22.38 <sup>e</sup>	29.77 <sup>e</sup>	35.75 <sup>f</sup>	40.46 <sup>c</sup>	45.53 <sup>e</sup>	50.46 <sup>c</sup>	57.67 <sup>f</sup>	63.63 <sup>e</sup>	70.33 <sup>f</sup>	78.94 <sup>d</sup>	89.03 <sup>c</sup>	97 <sup>b</sup>	99.16 <sup>a</sup>
<b>P5</b>	5.49 <sup>b</sup>	12.4 <sup>bc</sup>	22.64 <sup>b</sup>	31.05 <sup>bc</sup>	37.88 <sup>dbc</sup>	44.25 <sup>bc</sup>	50.02 <sup>ab</sup>	57.15 <sup>b</sup>	64.61 <sup>ab</sup>	74.77 <sup>c</sup>	86.29 <sup>c</sup>	93.16 <sup>cb</sup>	-	-	-	-
<b>P6</b>	5.29 <sup>bc</sup>	12.64 <sup>b</sup>	23.17 <sup>b</sup>	31 <sup>bc</sup>	38.26 <sup>bc</sup>	45.99 <sup>b</sup>	51.93 <sup>a</sup>	58.58 <sup>b</sup>	69.38 <sup>a</sup>	82.59 <sup>b</sup>	92.72 <sup>b</sup>	96.65 <sup>ab</sup>	-	-	-	-
<b>P7</b>	4.66 <sup>bc</sup>	10.36 <sup>dec</sup>	21.72 <sup>b</sup>	32.69 <sup>bc</sup>	39.08 <sup>b</sup>	42.41 <sup>dc</sup>	46.14 <sup>cab</sup>	51.45 <sup>d</sup>	57.88 <sup>cb</sup>	63.87 <sup>e</sup>	70.89 <sup>d</sup>	83.77 <sup>d</sup>	99.61 <sup>a</sup>	-	-	-
<b>P8</b>	12.25 <sup>a</sup>	53.76 <sup>a</sup>	63.32 <sup>a</sup>	76.11 <sup>a</sup>	91.99 <sup>a</sup>	-	-	-	-	-	-	-	-	-	-	-
<b>LSD(0.05)</b>	0.91	2.06	3.79	3.63	3.46	3.12	3.30	4.30	5.64	5.26	5.05	6.85	3.85	2.86	2.12	0.86

P1- 0.1µL/L 1-MCP, P2- 0.3µL/L 1-MCP, P3- 0.5µL/L 1-MCP, P4- 5% KMnO<sub>4</sub>, P5- 10% KMnO<sub>4</sub>, P6- 10g of Zeolite, P7- 20g of Zeolite, P8-Open shelf  
 Means followed by the same alphabet in the same row are not significantly different at 5% probability level

**Table 5.** Effect of fertilizer type on days to spoilage of stored tomato fruits.

Fertilizer type	Days to spoilage					
	Onset of spoilage		50% spoilage		100% spoilage	
	Experiment 1	Experiment 2	Experiment 1	Experiment 1	Experiment 1	Experiment 2
<b>F1</b>	10.89	9.63	20.03	27.81	35.13	35.19
<b>F2</b>	11.15	10.38	22.56	26.94	37.19	40.44
<b>F3</b>	9.58	10.88	20.94	28.38	35.06	34.88
<b>F4</b>	8.09	10.19	20.75	26.15	34.09	33.18
<b>LSD (0.05)</b>	1.78	1.14	1.93	2.17	2.03	6.78

F1- NPK 15-15-15, F2- Poultry manure, F3- NPK 15-15-15 + Poultry manure, F4- Control

**Table 6.** Effect of ethylene remediation substance on days to spoilage of stored tomato fruits.

Ethylene remediation agent	Days to spoilage					
	Onset of spoilage		50%		100%	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2	Experiment 1	Experiment 2
P1	12.88 <sup>a</sup>	9.13 <sup>d</sup>	23.75 <sup>a</sup>	28.63 <sup>c</sup>	36.63 <sup>b</sup>	38.88 <sup>ab</sup>
P2	10.75 <sup>ab</sup>	10.50 <sup>dc</sup>	25.63 <sup>a</sup>	30.13 <sup>b</sup>	43.25 <sup>a</sup>	41.00 <sup>ab</sup>
P3	11.38 <sup>b</sup>	12.13 <sup>b</sup>	25.88 <sup>a</sup>	29.00 <sup>c</sup>	41.88 <sup>a</sup>	42.25 <sup>ab</sup>
P4	12.63 <sup>a</sup>	14.38 <sup>a</sup>	26.13 <sup>a</sup>	35.25 <sup>a</sup>	44.63 <sup>a</sup>	47.30 <sup>a</sup>
P5	9.00 <sup>b</sup>	11.00 <sup>bc</sup>	16.75 <sup>c</sup>	27.18 <sup>c</sup>	36.38 <sup>b</sup>	33.5 <sup>b</sup>
P6	7.88 <sup>c</sup>	10.08 <sup>bc</sup>	15.38 <sup>c</sup>	26.20 <sup>c</sup>	27.75 <sup>c</sup>	30.250 <sup>cb</sup>
P7	9.00 <sup>b</sup>	9.00 <sup>d</sup>	20.38 <sup>b</sup>	27.55 <sup>c</sup>	35.50 <sup>b</sup>	36.75 <sup>ab</sup>
P8	5.50 <sup>d</sup>	5.13 <sup>e</sup>	14.13 <sup>c</sup>	12.13 <sup>d</sup>	18.25 <sup>d</sup>	17.88 <sup>c</sup>
LSD (0.05)	2.47	1.66	2.68	2.92	2.89	2.49

P1- 0.1 $\mu$ L/L 1-MCP, P2- 0.3 $\mu$ L/L 1-MCP, P3- 0.5 $\mu$ L/L 1-MCP, P4- 5% KMnO<sub>4</sub>, P5- 10% KMnO<sub>4</sub>, P6- 10g of Zeolite, P7- 20g of Zeolite, P8-Open shelf  
Means followed by the same alphabet in the same column are not significantly different at 5% probability level

showed the largest percentage loss. Fruits stored in an open shelf showed the most percentage weight loss on day 16 of the storage period, followed by those exposed to 10% KMnO<sub>4</sub> and 10 g of zeolite. Fruits kept with 5% KMnO<sub>4</sub> solution and exposed to 0.1 $\mu$ L/L, 0.3 $\mu$ L/L, and 0.5 $\mu$ L/L 1-MCP concentrations showed reduced percentage weight loss until the end of the storage period. Fruits exposed to 0.1 $\mu$ L/L, 0.3 $\mu$ L/L, and 0.5 $\mu$ L/L 1-MCP, as well as those with 5% KMnO<sub>4</sub> solution, had the lowest percentage weight loss at the start of the second phase of storage, whereas those stored on an open shelf showed the maximum percentage loss. Fruits placed with 10% KMnO<sub>4</sub> solution, 10 and 20 g of zeolite medium, and open shelf exhibited the maximum percentage weight loss at day 16 while fruits kept with 5% KMnO<sub>4</sub> solution and those exposed to 0.3 $\mu$ L/L 1-MCP retained a lower percentage of weight loss, extending their shelf life until day 51.

#### **Effect of fertilizer types on days to spoilage of stored tomato fruits**

For both experiments, there were significant differences ( $p < 0.05$ ) in the effect of fertilizer type on days to commencement of fruit spoilage (**Table 5**). The first experiment had fruits from control plots attaining first spoilage earlier than those from 10 t ha<sup>-1</sup> poultry manure (day 8) whereas those from plots treated with 300 kg ha<sup>-1</sup> NPK 15-15-15 and complementary fertilizer were observed at day 11. As storage advanced, fruits from plots treated with 300 kg ha<sup>-1</sup> NPK 15-15-15 attained 50% spoilage (20 days) earlier than those from 10 t ha<sup>-1</sup> poultry manure. Fruits from the control plots attained 100% spoilage earlier than other treatments (day 34). On the other hand, in the second experiment, fruits from plots treated with 300 kg ha<sup>-1</sup> NPK 15-15-15 attained first spoilage significantly earlier (day 7) than those from plots treated with complementary fertilizer but were similar to those from 10 t ha<sup>-1</sup> poultry manure and those from control plots.

As storage progressed, fruits from control plots attained 50% spoilage earlier than those from the complementary fertilizer plots but similar to 10 t ha<sup>-1</sup> poultry manure and 300 kg ha<sup>-1</sup> NPK 15-15-15. All fruits from the different fertilizer treatments attained 100% spoilage earlier than those from 10 t ha<sup>-1</sup> poultry manure.

#### **Effect of ethylene remediation substance on days to spoilage of stored tomato fruits**

There was significant difference ( $p < 0.05$ ) in days to spoilage of tomato fruits treated with the different ripening remediation agents (**Table 6**). In the first experiment, fruits kept in the open shelf (control treatment) attained first spoilage, 50 and 100% spoilage earlier (6, 14 and 18 days respectively). However, fruits exposed to 0.1 $\mu$ L/L 1-MCP conc. and those stored with 5% KMnO<sub>4</sub> solution both attained first spoilage later at day 13 than those exposed to 0.3 $\mu$ L/L, 0.5 $\mu$ L/L 1-MCP while those stored in 10 and 20g of zeolite and 10% KMnO<sub>4</sub> solution media attained first spoilage earlier (9, 8 and 9 days respectively). As storage time progressed, it was observed that fruits exposed to 0.1 $\mu$ L/L, 0.3 $\mu$ L/L and 0.5 $\mu$ L/L 1-MCP and those stored with 5% KMnO<sub>4</sub> solution attained 50% spoilage later at Days 24, 26, 26 and 26 respectively, however, only 0.3 $\mu$ L/L and 0.5 $\mu$ L/L 1-MCP and those stored with 5% KMnO<sub>4</sub> solution attained 100% spoilage later at Days 43, 42 and 45 respectively than those stored with 10 and 20 g of zeolite and 10% KMnO<sub>4</sub> solution media. Fruits kept in the open shelf attained first, 50% and 100% spoilage earliest (6, 14 and 18 days, respectively).

For the second experiment, only fruits stored with 5% KMnO<sub>4</sub> solution commenced spoilage later at day 14 than those exposed to 0.1 $\mu$ L/L, 0.3 $\mu$ L/L 1-MCP and those in 10% KMnO<sub>4</sub> solution. As storage progressed, same fruits stored with 5% KMnO<sub>4</sub> solution attained 50% spoilage later at day 35 and 100% spoilage later at day 47 than those exposed to other remediation agents. However, fruits kept in the open shelf attained first, 50 and 100% spoilage earliest (5, 12 and 18 days, respectively).

#### **Effect of fertilizer type on shelf life of tomato fruits**

Results showed that fertilizer type had significant effect ( $p < 0.05$ ) on shelf-life of tomato fruits in both experiments (**Table 7**). In both experiments, fruits harvested from plots treated with 10 t/ha poultry manure had longer shelf-life of 37 days and 40 days in experiments 1 and 2 respectively, longer than observed in other fertilizer treatments. Fruits from 300 kg ha<sup>-1</sup> NPK 15-15-15 and complementary fertilizer plots had similar shelf life (35 days and 36 days, respectively) while those from the control plots in both trials had the shortest shelf life.

**Table 7.** Effect of fertilizer type on shelf-life of stored tomato fruits.

Fertilizer type	Shelf life (days)	
	1 <sup>st</sup> exp	2 <sup>nd</sup> exp
F1	35.13	35.79
F2	37.19	40.44
F3	35.06	34.88
F4	34.15	33.15
LSD (0.05)	2.03	6.77

F1- NPK 15-15-15, F2- Poultry manure, F3- NPK 15-15-15 + Poultry manure, F4- Control

### **Effect of ethylene remediation agents on shelf life of tomato fruits**

In both experiments, ripening remediation treatments had a considerable impact on tomato fruit shelf life (**Table 8**). Fruits exposed to 0.3µL/L and 0.5µL/L 1-MCP and stored with 5% KMnO<sub>4</sub> solution had the longest shelf life in the first experiment (45, 43, and 42 days, respectively), followed by those subjected to 0.1µL/L 1-MCP (37 days). The shelf life of fruits kept with 20 g of zeolite media and 10% KMnO<sub>4</sub> solution was the same. On the other hand, untreated fruits had the shortest shelf life. Fruits exposed to 0.3µL/L and 0.5µL/L 1-MCP, as well as those kept with 5% KMnO<sub>4</sub> solution, had the longest shelf life in the second experiment (46, 43, and 39 days, respectively), followed by 0.1µL/L 1-MCP. Fruits kept in an open shelf had the shortest shelf life, while those kept with 10% KMnO<sub>4</sub> solution and 20 g of zeolite medium had nearly similar shelf life.

**Table 8.** Effect of ripening remediation substance on shelf life of tomato fruits.

Ethylene remediation agent	Shelf life (Days)	
	2018	2019
P1	36.63 <sup>b</sup>	36.75 <sup>ab</sup>
P2	43.25 <sup>a</sup>	42.75 <sup>ab</sup>
P3	41.88 <sup>a</sup>	37.88 <sup>ab</sup>
P4	44.63 <sup>a</sup>	45.74 <sup>a</sup>
P5	36.38 <sup>b</sup>	32.10 <sup>b</sup>
P6	27.75 <sup>c</sup>	30.25 <sup>cb</sup>
P7	35.50 <sup>b</sup>	32.40 <sup>b</sup>
P8	18.25 <sup>d</sup>	17.88 <sup>c</sup>
LSD (0.05)	2.89	3.25

P1- 0.1µL/L 1-MCP, P2- 0.3µL/L 1-MCP, P3- 0.5µL/L 1-MCP, P4- 5% KMnO<sub>4</sub>, P5- 10% KMnO<sub>4</sub>, P6- 10g of Zeolite, P7- 20g of Zeolite, P8-Open shelf.

Means followed by the same alphabet in the same column are not significantly different at 5% probability level.

### **Interaction of fertilizer type and ethylene remediation substances on weight loss in stored tomato fruits**

The interaction of fertilizer type and ethylene remediation treatments had significant ( $p < 0.05$ ) effect on weight loss of tomato fruits in experiment I and II (**Tables 9-10**). For the first experiment, fruits from plots treated with 300 kg/ha NPK 15-15-15 and stored with the ethylene remediation agents had reduced weight loss when compared to those left in open shelf. At day 22 of storage, fruits exposed to 0.1 µL/L, 0.3µL/L and 0.5µL/L of 1-MCP and those stored with 5% KMnO<sub>4</sub> solution significantly ( $p < 0.05$ ) showed minimum (59.9%, 50.6%, 58.8%

and 50.4% respectively) weight loss when compared to others. As storage period progressed, most of the fruits had attained maximum weight loss (100%) except for fruits exposed to 0.3µL/L of 1-MCP (96.5%), 0.5µL/L of 1-MCP (90.9%) and those stored with 5% KMnO<sub>4</sub> solution (94.9%) which attained its maximum weight loss at 46 days.

Fruits harvested from plots treated with 10 t/ha poultry manure also recorded reduced weight loss compared to those from open shelf. At day 22 of storage, those fruits exposed to by 0.3µL/L of 1-MCP significantly ( $p < 0.05$ ) showed a minimum (28.4%) weight loss followed by 5% KMnO<sub>4</sub> solution which showed minimum (22.5%) weight. As storage period progressed, most of the fruits attained maximum weight loss except for fruits exposed 0.1µL/L of 1-MCP (95.8%) and 0.3µL/L of 1-MCP (96.7%) at 46 days.

Those fruits from plots treated with complementary fertilizer (150 kg ha<sup>-1</sup> NPK 15-15-15 + 5 t ha<sup>-1</sup> + 10t/ha poultry manure) which were exposed to by 0.3µL/L and 0.5µL/L of 1-MCP significantly ( $p < 0.05$ ) showed a minimum (34.7% and 44.5% respectively) weight loss followed by 5% KMnO<sub>4</sub> which showed minimum (46.8%) weight at day 22 of storage. As storage period progressed, most of the fruits attained maximum weight loss (100%) except for fruits exposed to 0.1µL/L of 1-MCP (95.8%), 0.3µL/L of 1-MCP (96.7%) at 46<sup>th</sup> day.

On the other hand, at day 22 of storage, only fruits from the control plots which were exposed to 5% KMnO<sub>4</sub> solution significantly ( $p < 0.05$ ) showed a minimum (26.1%) weight loss when compared to other storage treatments. As storage period advanced, most of the fruits attained maximum weight loss (100%) except for those fruits exposed to 5% KMnO<sub>4</sub> solution (95.8%) at 46<sup>th</sup> day of storage.

The second experiment had fruits from plots treated with 300kg/ha NPK 15-15-15 having a reduced weight loss when compared to those from open shelf. At day 22<sup>nd</sup> of storage, fruits exposed to 0.1µL/L and 0.3µL/L of 1-MCP and those exposed to 5% KMnO<sub>4</sub> solution showed significantly ( $p < 0.05$ ) minimum (38.3%, 35.3% and 39.2% respectively) when compared to other remediation treatments. As storage period progressed, most of the fruits attained maximum weight loss (100%) except for fruits 0.3µL/L of 1-MCP and those exposed to 5% KMnO<sub>4</sub> solution which showed minimum weight loss (89.2% and 88.0%) at day 46 the storage period.

Fruits harvested from plots treated with 10 t/ha poultry manure had a reduced weight loss for all the storage treatment when compared to those from open shelf. At day 22<sup>nd</sup> of storage, fruits exposed to 0.1µL/L, 0.3µL/L of 1-MCP and 10 g of zeolite showed significantly ( $p < 0.05$ ) minimum weight loss (33.3%, 37.6% and 37.6% respectively) and as storage period progressed, most of the fruits have attained maximum weight loss (100%) except for those exposed to 0.3µL/L 1-MCP and those exposed to 5% KMnO<sub>4</sub> solution which showed minimum weight loss (93.2% and 90.6%) at day 46 of the storage period.

Fruits from plots treated with complementary fertilizer also had reduced weight loss for the storage treatments when compared to those from open shelf. At day 22<sup>nd</sup> of storage, fruits exposed to 0.5µL/L of 1-MCP and 10% KMnO<sub>4</sub> showed significantly ( $p < 0.05$ ) minimum weight loss (38.0% and 39.4% respectively) and as storage period progressed, most of the fruits attained maximum weight loss (100%) except for only fruits exposed to 0.3µL/L 1-MCP which showed minimum weight loss of 95.3% at day 49 of the storage period.

Fruits harvested from control plots had reduced weight loss for the storage treatments when compared to those from open shelf. At day 22<sup>nd</sup> of storage, fruits exposed to 0.1µL/L and

0.3µl/L of 1-MCP and those stored with 5% and 10% KMnO<sub>4</sub> solution media showed significantly ( $p < 0.05$ ) minimum weight loss (36.8%, 39.4% and 38.7% respectively) and as storage period progressed, most of the fruits have attained maximum weight loss (100%) except for fruits stored with 5% KMnO<sub>4</sub> medium which showed minimum weight loss (85.4%) at day 46 of the storage period. Interaction of fertilizer type and ethylene remediation agent on days to spoilage of tomato fruits. The effect of the interactions between fertilizer type and ethylene remediation agent type on days to spoilage of tomato fruits are shown in **Table 11**. The two experiments conducted showed significant difference ( $p < 0.05$ ) at the onset of spoilage. For the first experiment, fruits from plots treated with 300 kg ha<sup>-1</sup> NPK 15-15-15 with exposure to 10 g of zeolite and those left in the open shelf commenced spoilage before others, at day 7 of storage as storage progressed, attained a 50% spoilage earlier at day 13 and 100% spoilage at 24 and 18 days of storage respectively. On the other hand, those with 0.1µl/L of 1-MCP showed their first sign later at 22<sup>nd</sup> day of storage and as storage progressed, while 5% KMnO<sub>4</sub> solution attained 50% later than other treatment at 42<sup>nd</sup> day of storage and 0.3µl/L of 1-MCP attained 100% later than other treatment at 48<sup>th</sup> day of storage.

Those from plots treated with 10 t/ha poultry manure which were left in the open shelf and those exposed to 10 and 20g of zeolite showed first sign of spoilage at day 7 while those with 0.3µl/L of 1-MCP showed the first sign of spoilage later at day 18. As storage progressed, fruit left in the open shelf attained 50% spoilage earlier than others at day 13 of storage and 100% at day 19. At the end of the storage period, fruits with 5% KMnO<sub>4</sub> solution attained 100% spoilage later than other treatments at day 48.

Fruits harvested from with complementary fertilizer plots which were exposed to 0.3µl/L of 1-MCP and those left in the open shelf in storage showed their first sign of spoilage at day 4 while those exposed to 5% KMnO<sub>4</sub> solution showed sign of spoilage later at day 18. As storage advanced, those left in the open shelf attained 50% spoilage at day 13 followed by those exposed to 0.1µl/L of 1-MCP and those in 20g of zeolite medium which attained 50% spoilage at day 15. At the end of the storage, fruits exposed to 0.3µl/L of 1-MCP attained 100% later than the other treatment at day 49.

Fruits harvested from control plots and were exposed to 0.3µl/L of 1-MCP and those left in open shelf also showed the first sign of spoilage at day 4 followed by those exposed to 10 g of zeolite. As storage progressed, those left in open shelf those attained 50% spoilage earlier at day 13 followed by those exposed to 0.1µl/L of 1-MCP and 20 g of zeolite at day 15 while those exposed to 0.3µl/L of 1-MCP attained 50 and 100% spoilage later at day 39 and day 49 respectively. Those left in the open shelf attained 100% spoilage earlier than other treatment at day 19.

For the second experiment, fruits harvested from plots treated with 300 kg ha<sup>-1</sup> NPK 15-15-15 which were exposed to 0.1µl/L & 0.5µl/L of 1-MCP, 10 and 20 g of zeolite showed their first sign of spoilage at day 9 of storage and as storage progressed, those exposed to 10 g of zeolite attained a 50% spoilage earlier at day 25 and 100% spoilage at day 28. On the other hand, those exposed to 0.3µl/L of 1-MCP attained 50% later than other treatments at day 34 while exposed to 0.3µl/L of 1-MCP and 5% KMnO<sub>4</sub> attained 100% later than other treatment at the same day 43.

Those fruits which were harvested from plots treated with 10t/ha poultry manure and left in the open shelf in storage

showed first sign of spoilage at day 6 of storage, followed by those exposed to 20 g of zeolite, followed by those exposed to 0.1µl/L of 1-MCP and 10 g of zeolite medium which showed first sign of spoilage at day 9 and 10 respectively. As storage progressed, those exposed to 10 g of zeolite medium attained a 50% spoilage earlier at day 19 and 100% spoilage at day 27. Those exposed to 0.1µl/L of 1-MCP attained 50% spoilage later than other treatments at day 33 and 100% spoilage at day 40.

Fruits that were harvested from with complementary fertilizer (150 Kg ha<sup>-1</sup> NPK 15-15-15 + 5 Kg ha<sup>-1</sup> poultry manure) plots and exposed to 10% KMnO<sub>4</sub> solution showed first sign of spoilage at day 7 and as storage progressed, fruits exposed to 10 g of zeolite medium attained 50% and 100% earlier spoilage at day 20 and 28 respectively while those at 5% KMnO<sub>4</sub> solution attained 50% later at day 34 and 0.3µl/L of 1-MCP and 10% KMnO<sub>4</sub> solution attained 100% spoilage later at day 49 and 42 respectively.

Fruits harvested from control plots which were left in open shelf in storage showed the first sign of spoilage at day 6, followed by those exposed to 0.1µl/L of 1-MCP. As storage progressed, those left in open shelf those attained 50% spoilage earlier at day 13 followed by those in 10 g of zeolite medium at day 21 while those stored in 5% KMnO<sub>4</sub> solution attained 50 and 100% spoilage later at day 40 and day 43 respectively. Those left in the open shelf attained 100% spoilage earlier than other treatment at day 15.

#### ***Interaction of fertilizer type and ethylene remediation substances on shelf-life of stored tomato fruits***

In the initial experiment, fruit harvested from plots fertilized with 300 kg/ha NPK 15-15-15 and treated with 0.3µl/L of 1-MCP exhibited the longest shelf life, lasting 48 days. This was followed by fruit treated with 0.5 µl/L of 1-MCP and 5% KMnO<sub>4</sub> solution, which maintained quality for 46 days. The subsequent experiment revealed that fruit from plots treated with 300 kg/ha NPK 15-15-15 and exposed to both 0.3 µl/L and 0.5 µl/L of 1-MCP displayed an equivalent and extended shelf life of 43 days followed by those exposed to 0.1µl/L with a shelf life of 40 days.

For fruits harvested from plots treated with 10ton/ha poultry manure in the first experiment, fruits exposed to 5% KMnO<sub>4</sub> had the longest shelf life of 48 days followed by those 0.5µl/L of 1-MCP at 43 days. Fruits kept in the open shelf had the least shelf life with the various fertilizer types. The second experiment had fruits exposed to 0.1µl/L of 1-MCP having the longest shelf life of 40 days followed by those exposed to 0.5µl/L of 1-MCP and 5% KMnO<sub>4</sub> solution at 39 days. Fruits in the open shelf had the shortest shelf life of 19 days.

Fruits harvested from plots treated with complementary fertilizer (150 kg/ha NPK 15-15-15 + 5 kg/ha poultry manure) and exposed to 10% KMnO<sub>4</sub> solution had the highest shelf life of 42 days followed by those 5% KMnO<sub>4</sub> solution at 40 days for the first experiment however those exposed to 0.3µl/L of 1-MCP had the longest shelf life of 49 days, followed by those 5% KMnO<sub>4</sub> solution at 42 days for the second experiment. Fruits from control plots which were exposed to 0.3µl/L of 1-MCP had the highest shelf life of 49 days followed by 0.5µl/L of 1-MCP and those in 5% KMnO<sub>4</sub> solution at 45days for the first experiment while those exposed to 0.3µl/L of 1-MCP had longest shelf life at 45 days followed by those in 5% KMnO<sub>4</sub> solution having same shelf life of 43 days for the second experiment.

Table 9. Interaction of NPK 15-15-15 fertilizer and ripening remediation treatments on percentage weight loss of tomato fruits in experiment 1.

Fertilizer type	E.R.A.	Days															
		4	7	10	13	16	19	22	25	28	31	34	37	40	43	46	49
F1	P1	2.2d	3.5cd	6.6d	22.4b	30.0c	51.4abc	59.9abc	69.7b	70.3b	79.8b	89.2ab	92.2a	94.5a	97.8a	100.0a	
	P2	4.4c	8.7c	13.6c	23.2b	25.8c	38.3c	50.6abc	61.9b	66.1b	83.3ab	92.1a	92.3a	92.4a	93.2a	96.5a	100.0a
	P3	2.1d	10.2c	21.3b	30.2b	42.5bc	49.0bc	58.8abc	84.7ab	84.8ab	89.8ab	90.1a	90.3a	90.6a	90.7a	90.9a	100.0a
	P4	4.9bc	10.4c	24.0b	34.6ab	35.8c	46.1bc	50.4abc	68.5b	69.3b	75.0b	75.4b	88.8ab	89.9ab	94.2a	94.9a	100.0a
	P5	5.6bc	17.0b	31.3ab	44.4b	53.8abc	63.5b	65.8b	84.7ab	97.2a	97.3a	100.0a	-	-	-	-	-
	P6	4.4c	11.4b	25.7b	38.9abc	47.3bc	55.9abc	72.3b	75.4b	83.6ab	100.0a	-	-	-	-	-	-
	P7	6.7bc	12.0b	19.0bc	37.7abc	42.7bc	58.8abc	69.5b	80.9ab	87.2ab	92.4a	100.0a	-	-	-	-	-
	P8	12.9a	17.8ab	23.7bc	38.9abc	42.2bc	79.6b	85.8ab	94.2a	94.7a	95.3a	100.0a	-	-	-	-	-
F2	P1	2.8d	8.0d	11.0c	19.0c	48.1bc	50.6abc	57.1abc	81.4ab	86.1ab	94.0a	94.3a	94.5a	95.2a	95.7a	95.8a	100a
	P2	2.9d	9.0d	14.3c	16.5c	20.8c	26.9c	28.4c	74.5b	76.2b	92.9a	93.3a	93.4a	87.8ab	89.0ab	96.7a	100a
	P3	2.4d	25.3ab	27.5b	53.0ab	65.7b	65.7b	72.2b	73.7b	78.0b	85.8ab	88.5ab	90.3a	92.6a	96.0a	100a	-
	P4	1.3d	1.5d	3.0d	3.6d	8.30d	21.8c	22.5c	23.6c	51.7abc	52.1abc	52.9abc	67.7b	76.8b	92.2ab	100a	-
	P5	2.7b	11.0abc	22.4b	29.5bc	40.0bc	40.5bc	47.8bc	49.3bc	66.9b	67.4b	71.4b	73.6b	90.7a	100a	-	-
	P6	8.9b	39.3a	50.8a	53.2a	53.9abc	54.3abc	77.0b	83.6ab	89.6ab	100a	-	-	-	-	-	-
	P7	5.9bc	11.4abc	21.6b	30.4bc	39.9c	40.6bc	49.3bc	50.3abc	56.8abc	58.8abc	66.4b	79.7b	100a	-	-	-
	P8	6.7bc	10.6abc	21.1b	32.9bc	56.6abc	100a	-	-	-	-	-	-	-	-	-	-
F3	P1	11.2ab	17.7b	21.3b	23.9bc	37.9c	46.6c	51.0bc	69.7b	70.1b	94.0a	94.3a	94.5a	95.2a	95.70a	95.80a	100a
	P2	8.3b	17.3b	18.5bc	21.2bc	27.4c	28.7cd	34.7cd	48.8c	52.6bc	92.9a	93.3a	93.4a	87.8ab	89.0ab	96.7a	100a
	P3	11.0ab	13.0c	15.0bc	18.8c	29.2c	30.2cd	44.5c	67.3b	74.3b	85.8ab	88.5ab	90.3a	92.6a	96.0a	100a	-
	P4	12.5ab	13.5c	18.5bc	24.5bc	28.5c	32.9cd	46.8c	47.4c	61.1b	52.1bc	52.9bc	67.7b	76.8b	92.2a	100a	-
	P5	15.3a	12.2c	38.3ab	49.4b	64.7b	66.6b	67.8b	72.3b	79.9b	82.2ab	84.6ab	89.4ab	100a	-	-	-
	P6	15.2a	14.5c	29.5b	53.3ab	63.9b	64.4b	81.0a	81.4ab	96.0a	100a	-	-	-	-	-	-
	P7	13.4ab	19.4ab	19.8bc	32.0bc	47.9bc	56.7bc	57.4bc	68.9b	70.3b	74.6b	81.0ab	100a	-	-	-	-
	P8	18.2a	28.3b	32.6ab	37.6bc	54.5abc	100a	-	-	-	-	-	-	-	-	-	-
F4	P1	5.7c	16.7a	27.8b	33.4bc	38.0c	42.9bc	59.6abc	71.0b	71.4b	77.6b	85.2ab	86.6ab	88.0ab	98.4a	100a	-
	P2	1.8d	7.0b	8.6d	16.3c	18.6cd	19.9cd	26.1c	30.9c	51.5abc	72.8b	73.8b	74.2b	82.5ab	84.0ab	100a	-
	P3	2.5d	19.3a	27.7b	41.2b	51.9abc	52.7abc	57.1abc	72.6b	73.1b	76.4b	79.7b	83.9ab	87.1ab	93.0a	100a	-
	P4	3.2c	10.5ab	29.0b	31.4bc	48.5bc	58.9abc	60.0b	60.3b	66.7b	69.7b	71.0b	79.0b	92.3a	93.2a	95.8a	100a
	P5	5.0c	12.5ab	30.4ab	34.7bc	53.0abc	57.1abc	63.5b	64.3b	71.9b	78.2b	82.9ab	88.2ab	100a	-	-	-
	P6	4.8c	15.5ab	55.7a	66.9a	82.7ab	83.7ab	85.2ab	86.8ab	100a	-	-	-	-	-	-	-
	P7	5.0c	12.1ab	27.6b	36.3abc	43.3bc	43.9bc	59.0abc	60.1b	71.5b	71.9b	72.4b	77.1b	100a	-	-	-
	P8	7.8b	25.2a	35.4ab	41.1b	52.7abc	95.1a	100a	-	-	-	-	-	-	-	-	-
LSD (0.05)		6.06	9.72	13.39	15.32	16.86	16.20	16.55	17.38	13.22	11.64	10.04	9.01	6.44	4.82	3.86	

E.R.A- Ethylene Remediation Agent, P1, 0.1µL/L 1-MCP, P2- 0.3µL/L 1-MCP, P3- 0.5µL/L 1-MCP, P4- 5% KMnO<sub>4</sub>, P5- 10% KMnO<sub>4</sub>, P6- 10 g of Zeolite, P7- 20 g of Zeolite, P8-Open shelf, F1- NPK 15-15-15, F2- Poultry manure, F3- NPK 15-15-15 + Poultry manure, F4- Control.

Means followed by the same alphabet in the same column are not significantly different at 5% probability level.

Table 10. Effect of NPK 15-15-15 fertilizer and ethylene remediation treatments on % weight loss of tomato fruits in experiment 2.

Fertilizer type	E.R.A.	Days															
		4	7	10	13	16	19	22	25	28	31	34	37	40	43	46	49
F1	P1	3.3c	8.8d	19.4bc	26.0b	33.9bc	36.0c	38.3c	43.4bc	59.0abc	67.4b	73.4b	85.8ab	93.2a	95.7a	96.4a	100a
	P2	2.7d	8.3d	14.1c	24.9bc	28.8c	32.7c	35.3c	39.8c	43.6bc	48.2bc	52.0b	55.9abc	61.8b	73.5b	89.2b	100a
	P3	4.7c	9.3d	16.6bc	29.8bc	34.7abc	38.6c	44.2bc	47.5bc	56.0abc	65.3b	69.9b	81.7ab	88.8ab	92.3a	100a	-
	P4	5.1bc	8.9d	14.4c	18.7c	27.8bc	33.8c	39.2c	44.1bc	48.2bc	56.3abc	63.6b	66.3b	71.3b	86.5ab	88.0b	100a
	P5	4.7c	8.1d	11.9c	18.3c	25.7bc	31.4c	44.7bc	50.1abc	59.3abc	63.4b	69.5b	74.5b	100a	-	-	-
	P6	5.6bc	10.3d	15.5bc	22.8bc	29.5bc	42.2bc	52.3abc	57.3abc	61.4b	73.0b	100a	-	-	-	-	-
	P7	2.5d	9.7d	21.8b	27.6bc	41.3abc	46.6bc	50.3abc	57.2abc	60.6b	66.3b	72.0b	90.2b	100a	-	-	-
	P8	11.9ab	18.8bc	25.2b	41.2b	75.5a	80.2ab	100a	-	-	-	-	-	-	-	-	-
F2	P1	5.1bc	8.3d	14.0c	38.4c	41.6bc	43.8bc	33.3abc	59.8abc	40.7bc	73.8b	100a	-	-	-	-	-
	P2	4.0bc	9.5d	15.2c	28.4c	36.4c	39.4c	53.6abc	50.2abc	65.3b	68.7b	71.2b	75.7b	87.6ab	90.0a	93.2a	-
	P3	5.0bc	11.1c	15.4c	24.4c	35.4c	44.7bc	49.5bc	54.4abc	59.9abc	65.5b	79.1b	90.6a	-	-	-	-
	P4	4.2c	7.5d	12.3c	17.0cd	24.4c	30.0c	37.6c	37.7c	56.3abc	49.0bc	55.0abc	58.2abc	62.1b	68.8b	90.6a	-
	P5	5.1bc	9.9d	25.4bc	31.6c	39.3c	48.0bc	60.5b	59.0abc	78.4b	70.9b	83.6ab	89.4ab	-	-	-	-
	P6	3.7c	9.7d	22.4bc	32.2c	38.0c	44.5bc	37.6c	53.9abc	52.8abc	75.6b	81.1ab	90.8a	-	-	-	-
	P7	3.5c	6.9d	14.3c	23.0c	30.3c	34.3c	47.0bc	41.3bc	58.3abc	61.1b	80.7ab	94.8a	-	-	-	-
	P8	9.8ab	50.2a	55.6ab	73.0a	87.9a	92.8a	100a	-	-	-	-	-	-	-	-	-
F3	P1	4.3c	9.7d	21.8bc	27.6bc	41.7bc	46.6bc	49.0bc	57.2abc	64.2b	65.2b	71.3b	78.5b	91.8a	93.0a	-	-
	P2	3.6c	9.8d	14.2c	25.6bc	29.1c	32.0c	48.6bc	53.0abc	59.5abc	73.3b	74.2b	74.6b	83.0ab	84.4ab	95.3a	-
	P3	7.3b	12.1c	15.7c	23.6bc	38.7c	41.3bc	38.0c	59.5abc	65.2	67.0b	70.8b	75.6b	87.0ab	100a	-	-
	P4	2.7d	6.8d	10.6c	14.0c	22.1c	28.1c	41.0bc	41.0bc	53.8abc	52.6abc	56.4abc	65.7b	68.8b	85.4ab	-	-
	P5	2.6d	5.4d	9.4d	22.5bc	29.0c	34.2c	39.4c	47.0bc	50.8abc	64.9b	72.1b	78.6b	-	-	-	-
	P6	4.7c	8.1d	11.9c	18.3c	25.7c	31.4c	51.7abc	60.1b	63.6b	67.4b	69.5b	74.5b	-	-	-	-
	P7	4.9c	9.1d	16.5c	23.2bc	31.4c	33.7c	49.5bc	51.4abc	66.3b	54.8abc	64.8b	86.4ab	-	-	-	-
	P8	15.3a	54.3a	59.6a	71.0b	76.5b	81.6ab	100a	-	-	-	-	-	-	-	-	-
F4	P1	3.5c	6.9d	14.3c	25.9bc	30.3bc	34.3c	36.8c	41.3bc	56.3abc	72.4b	86.3ab	89.7ab	92.7a	94.7a	-	-
	P2	3.0c	9.2d	13.9c	27.5bc	30.5bc	35.3c	43.1bc	50.7abc	56.5abc	60.4b	65.4b	80.8ab	83.4ab	88.0ab	91.7a	-
	P3	3.3c	8.3d	14.6c	23.0bc	27.5bc	33.5c	39.4c	42.9bc	46.7bc	56.6abc	65.9b	75.5b	81.4ab	92.0b	100a	-
	P4	4.5c	10.1c	15.8c	21.3bc	31.5bc	33.8c	38.7c	40.8bc	47.7bc	53.1abc	58.7abc	62.7b	71.1b	76.9b	85.4b	-
	P5	3.7c	9.7d	22.4bc	32.2bc	38.0bc	44.5bc	56.8abc	53.9abc	59.9abc	75.6b	81.1ab	90.8a	-	-	-	-
	P6	3.6c	9.8d	18.7c	36.4bc	41.1b	51.4abc	59.9abc	65.8b	73.9b	89.7ab	-	-	-	-	-	-
	P7	6.1bc	11.0c	16.6c	40.3b	43.4b	45.4bc	52.7abc	54.3abc	57.8abc	63.0b	67.7b	88.1ab	-	-	-	-
	P8	10.1a	39.1ab	50.5ab	70.4a	79.8a	83.8ab	100a	-	-	-	-	-	-	-	-	-
LSD (0.05)		1.98	4.12	7.58	7.20	6.91	6.24	8.59	7.56	11.28	10.52	9.89	10.11	7.70	5.72	4.24	1.73

E.R.A. - Ethylene Remediation Agent, P1, 0.1µL/L 1-MCP, P2- 0.3µL/L 1-MCP, P3- 0.5µL/L 1-MCP, P4- 5% KMnO<sub>4</sub>, P5- 10% KMnO<sub>4</sub>, P6- 10 g of Zeolite, P7- 20 g of Zeolite, P8-Open shelf, F1- NPK 15-15-15, F2- Poultry manure, F3- NPK 15-15-15 + Poultry manure, F4- Control.

Means followed by the same alphabet in the same column are not significantly different at 5% probability level.

**Table 11.** Interaction of fertilizer types and ethylene remediation treatments on days to spoilage and shelf life of stored tomato fruits.

Fertilizer type	E.R.A.	Days to spoilage						Shelf life (days)	
		1 <sup>st</sup>		50%		100%		1 <sup>st</sup> exp	2 <sup>nd</sup> exp
		1 <sup>st</sup> exp	2 <sup>nd</sup> exp	1 <sup>st</sup> exp	2 <sup>nd</sup> exp	1 <sup>st</sup> exp	2 <sup>nd</sup> exp		
F1	P1	10bc	10bc	25b	31ab	43a	37ab	43a	37ab
	P2	13bc	13bc	37a	36a	48a	40a	48a	40a
	P3	10bc	13bc	27b	36a	46a	42a	46a	42a
	P4	10bc	9bc	42a	39a	45a	49a	45a	49a
	P5	9bc	10bc	24bc	31ab	40a	36ab	40a	36ab
	P6	12b	10bc	13cd	21bc	28b	30b	28b	30b
	P7	16ab	12bc	24bc	30b	40a	36ab	40a	36ab
	P8	4c	6c	19c	12cd	21bc	19c	21bc	19c
F2	P1	19a	10bc	22bc	37ab	39ab	42a	39ab	42a
	P2	22a	13b	37ab	36ab	40a	43a	40a	43a
	P3	7bc	12b	28b	28b	49a	40a	49a	40a
	P4	24a	18a	31ab	33ab	46a	46a	46a	46a
	P5	13b	16ab	22bc	28b	30b	37ab	30b	37ab
	P6	9bc	15ab	17c	25b	31ab	31ab	31ab	31ab
	P7	12b	9bc	22bc	28b	30b	31ab	30b	31ab
	P8	10bc	6c	13cd	12cd	19c	19c	19c	19c
F3	P1	10bc	12b	19c	22bc	37ab	31ab	37ab	31ab
	P2	6c	13b	42a	36ab	46a	42a	46a	42a
	P3	15ab	15ab	12cd	25b	37ab	36ab	37ab	36ab
	P4	19a	19a	25b	37ab	42a	45a	42a	45a
	P5	10bc	13b	25b	28b	42a	36ab	42a	36ab
	P6	10bc	10bc	25b	21bc	27b	36ab	27b	36ab
	P7	15ab	10bc	19c	20bc	40a	36ab	40a	36ab
	P8	7bc	6c	13cd	13cd	19c	18c	19c	18c
F4	P1	7bc	10bc	25b	22bc	31ab	40a	31ab	40a
	P2	10bc	7bc	31ab	27b	45a	45a	45a	45a
	P3	6c	15ab	31ab	31ab	45a	39a	45a	39a
	P4	10bc	16ab	35ab	39a	45a	43a	45a	43a
	P5	13b	15ab	22bc	31ab	39a	37ab	39ab	37ab
	P6	10bc	16ab	21bc	27b	28b	34ab	28b	34ab
	P7	10bc	10bc	22bc	27b	34ab	37ab	34ab	37ab
	P8	7bc	6c	16c	15c	19c	19c	19c	19c
LSD(0.05)		4.94	3.31	5.35	5.83	5.77	4.98	5.77	4.98

E.R.A- Ethylene Remediation Agent, P1- 0.1µL/L 1-MCP, P2- 0.3µL/L 1-MCP, P3- 0.5µL/L 1-MCP, P4- 5% KMnO<sub>4</sub>, P5- 10% KMnO<sub>4</sub>, P6- 10 g of Zeolite, P7- 20 g of Zeolite, P8-Open shelf, F1- NPK 15-15-15, F2- Poultry manure, F3- NPK 15-15-15 + Poultry manure, F4- Control.

Means followed by the same alphabet in the same column are not significantly different at 5% probability level.

## Discussion

### Weight loss

One of the main causes of fruit quality degradation during storage is weight loss and change in weight can be attributed to loss of carbohydrates through produce respiration which breaks down the organic substrate of the produce or moisture loss in the produce which also results in fruit shriveling (Parker & Maalekuu, 2013). In this study, weight loss of fruits derived from fertilizer treated plots, especially organic manure, or complemented with NPK 15-15-15, was minimal throughout the storage period. This might be due to availability of soil micronutrients required for strengthening the cellular makeup of the fruits, thus minimizing the physiological loss in weight as earlier presumed by Muthukumar et al. (2019).

Postharvest ethylene remediation treatments can reduce the effects of ethylene by delaying senescence, reducing weight loss, and extending the marketable life of horticultural crops

(Zakriya et al., 2023) Pre-storage application of the different ethylene remediation agents remarkably reduces the magnitude of weight loss of the fruits during storage when compared to those kept in open shelf. This could be as a result of the ability of these postharvest treatments in preventing the buildup of ethylene that could accelerate the breakdown of carbohydrates in the produce, thus conserving the organic content of the fruits as assumed by Hakimi et al. (2022). This work agrees with Zakriya et al. (2023) who reported that application of 1-MCP controlled the ripening process, along with changes in physicochemical profiles of tomato fruits.

The interaction of fertilizer types and ethylene remediation treatments revealed that across the different fertilizer types, that fruits exposed to 1-MCP at different concentrations or 5% KMnO<sub>4</sub> solution recorded reduced percentage weight loss when compared to those in the open field. Stored fruits continue to respire and carbohydrates are broken down into their essential parts to produce energy to keep the produce alive, with attendant loss of weight. From the result of this study, it could

be deduced that pre-storage application of the different ripening remediation agents remarkably reduce weight loss of fruits during storage when compared to those kept in open shelf. This could be as a result of the ability of these remediation treatments in preventing the buildup of ethylene that could accelerate the breakdown of carbohydrates in the produce, thus delaying the release of energy through the breakdown of carbon compounds. Win et al. (2019) and Win et al. (2021) have reported similar results in the activities of 1-MCP treatments in apple varieties.

### Days to spoilage

Tomato, generally are known to contain large amount of water which makes them susceptible to spoilage by the action of several microorganisms. Physiological disorder, transpiration and subsequent water loss can result to loss of quality and enhanced spoilage (Genanew & Ababa, 2013). This finding showed that spoilage of tomato fruits was delayed and reduced by the ethylene remediation treatments used. In both years, there was delay in spoilage of fruits from poultry manure or its combination with NPK 15-15-15 plots. Following exposure to different ethylene remediation treatments, 1-MCP at different concentrations or 5% KMnO<sub>4</sub>, were found to be more effective in reducing the extent of tomato fruit spoilage. From the results of this finding, it was observed that ethylene remediation treatments imposed on the fruits reduced the extent of spoilage when compared to those kept in the open shelf and it could be attributed to the efficacy of these treatments in their ability to bring down respiration rates in the fruits. This was similar to the findings of Win et al. (2021) who reported the effect of 1-MCP in reducing the effect of deterioration in some climacteric fruits.

The interaction of fertilizer types and ethylene remediation treatments revealed that fruits from different fertilizer applied plots NPK 15-15-15 and exposed to 1-MCP at different concentrations or 5% KMnO<sub>4</sub> solution had delayed spoilage when compared to those in the open field, indicating that these ethylene remediation agents were able to slow down the ripening process in the fruit thus reducing decay. This agrees with Mansourbahmani et al. (2018) who reported that similar results with the use of ethylene scavengers to remove or inhibit the action of ethylene in tomato fruits.

### Shelf life of tomato

According to Sharma et al. (1996), who reported the ability of calcium nutrients to extend fruit shelf life, the superior performance seen in fruits from plots treated with organic manure may be due to the readily available calcium levels that can extend fruit shelf life. They also suggested that desirable characteristics of calcium, such as its ability to delay ripening and senescence, reduce respiration, increase firmness, and reduce physiological disorders, may have affected the shelf life of stored tomato fruits. It was evident from the results that fruits treated with 0.3 µL/L1-MCP, 0.5µL/L1-MCP and 5% KMnO<sub>4</sub> solution had long shelf life of 43 days, 39 days and 45 days, respectively, when compared to other ripening remediation treatments and those kept in the control. The longer shelf life may have resulted from these treatments' ability to prevent starch from being converted to sugars, which would have decreased the fruits' peroxidase activity and ethylene production. According to Srividya et al. (2014), similar result of a delay in the conversion of starch to sugars

for an extended shelf life of tomatoes was evident when Gibberllic acid was used.

The interaction of fertilizer types and ethylene remediation treatments revealed that across the different fertilizer types, those exposed to 0.3 µL/L1-MCP, 0.5µL/L1-MCP and 5% KMnO<sub>4</sub> solution had longest shelf life. Their capacity to regulate respiratory metabolism may contribute to the fruits' increased shelf life as suggested by Guillen et al. (2007) and Nath et al. (2015).

### Conclusions

Ethylene remediation agents must have acted by either removing ethylene from the storage environment or inhibiting its action on the fruit thus delaying the ripening process and extending shelf life. Irrespective of the fertilizer types, pre-storage application of the different ripening remediation agents remarkably reduces weight loss of fruits during storage when compared to those kept in open shelf as a result of their ability in preventing the buildup of ethylene that could accelerate the breakdown of carbohydrates in the produce, thus delaying the energy released through the breakdown of carbon compounds. The findings of this study indicate that shelf life is not necessarily influenced by fertilizer type used in cultivation, however, controlling ethylene intensities with some remediation agents including KMnO<sub>4</sub> and 1-MCP at certain concentrations can be effective in extending the shelf life of tomato fruits by reducing respiration rates.

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