Knowex Food and Agriculture
Vol.3, No.1, 50-68, 2026, ISSN 2682-728X (Online)

DOI: https://doi.org/10.17501/2682728X.2026.3105

Impact of Ethylene Absorbents on Postharvest Quality and Shelf Life of Tomatoes at Different Maturity Stages under Cold Storage

Ranasinghe BVAM[1], Weerasinghe WMSSK[2], and Senevirathne M[1*]

[1]*Department of Food Science and Technology, Faculty of Applied Sciences, Sabaragamuwa University of Sri Lanka, Belihuloya*
[2]*National Institute of Post-Harvest Management, Research and Development Centre, Anuradhapura*

Abstract: Tomatoes (*Solanum lycopersicum)* are highly perishable climacteric fruits, leading to substantial losses during storage and distribution. This study investigated the effectiveness of ethylene absorbent sachets in extending the shelf life and preserving the quality of tomatoes at different maturity stages stored under cold conditions. Tomatoes of the "platinum" variety at five maturity stages (I–V: mature green, breaker, turning, pink, and light red) were treated with three ethylene scavenger sachets: potassium permanganate, activated carbon, and a combined treatment, alongside an untreated control. The mixed sachet was prepared by impregnating activated carbon with saturated potassium permanganate solution (0.04 M). Samples were stored at 12 °C and 95% relative humidity, and postharvest quality parameters including weight loss, firmness, skin color, pH, total soluble solids, lycopene, ascorbic acid, and shelf life were evaluated. Potassium permanganate demonstrated highest ethylene absorption capacity (539 ppm), indicating superior ethylene scavenging efficiency. All treated samples showed delayed ripening, reduced weight loss, improved firmness retention, and slower increases in pH and total soluble solids compared to control fruits. Treatment effectiveness varied with maturity stage: Potassium permanganate was most effective for mature green and turning stages, activated carbon for breaker stage, and the mixed sachet for pink and light red stages. The longest shelf life of (28 days) was recorded in mature green tomatoes treated with potassium permanganate, compared to 20 days in control. Ethylene absorbent sachets treated with potassium permanganate for stages I and III, activated carbon for stages II, and mix for stages IV and V can be recommended for extending the shelf life of tomato. The findings confirm that stage-specific application of ethylene absorbents is an effective and economical strategy for increasing tomato storage life and reducing postharvest losses

Keywords: cold storage, ethylene absorbent sachets, maturity stages, postharvest storage, shelf life extension, Tomato (*Solanum lycopersicum*)

1. Introduction

Vegetables, due to their perishable nature, process a short shelf life, leading to high post-harvest losses. Therefore, it is essential to adopt strategies to reduce the losses and extend the storage life of vegetables both at the marketplace and household levels. Tomato (Solanum lycopersicum) fruit is an important berry (vegetable or fruit) all over the world for culinary processing. Tomatoes are highly perishable fruits undergoing rapid ripening and deterioration, leading to heavy economic losses for farmers, distributors, and retailers (Gil et al., 2002). It is widely consumed agricultural crops, with 186,821,216 tons of worldwide production in 2020 (Alonso-Salinas et al., 2022). Although a large volume of tomatoes are produced annually, the World Processing Tomato Council (WPTC) estimated that

[*]Corresponding author's email: *msaraths@appsc.sab.ac.lk*

approximately eight million tons of tomatoes were wasted annually (Trombino et al., 2021; FAO, 2022).

Ripe tomatoes have a shelf life of 5-10 days depending on their ripeness at the time of purchase. Additionally, shelf life can vary based on several factors including ripeness, storage conditions, stage of harvest, and variety (Priyankara et al., 2017; Casals et al., 2021). Various methods are reported to increase the shelf life of tomatoes. Some of them include the use of modified packaging methods, providing good storage conditions, nanotechnology applications, ozone or ultraviolet (UV) light treatment, and the use of different ethylene scavengers. Tomatoes can be processed into products such as ketchup, sauce, juice, puree, pulp, and canned whole to increase their shelf life (Mujtaba and Masud, 2014; Chavan and Sakhale, 2020). However, many consumers prefer to consume tomatoes as fresh fruit rather than as a manufactured product.

When a tomato is ripening, six distinct stages of ripening maturity can be clearly identified. Those are mature green (stage I), color breaker (stage II), color turning (stage III), pink (stage IV), light red (stage V), and red (stage VI) stages (Thengane and Gawande, 2018). The maturity at which tomatoes are harvested significantly influences their post-harvest quality and longevity (Oduntan et al., 2022). Ethylene, a natural plant hormone, plays a key role in the ripening and softening of tomatoes, affecting the entire supply chain from farm to market. Managing ethylene levels is thus crucial to prolong shelf life and maintain quality. Ethylene scavengers or absorbents can be employed to limit ethylene accumulation in packaging environments, thereby slowing the ripening process (Sargent, 2000; Chudasama, 2021).

The common packaging forms of ethylene scavengers are sachets, films, and corrugated boxes which are generally employed to maintain ethylene gas concentration inside the package (Frígola, 2016; Mariah et al., 2022). The use of a sachet is an easy-to-use and cost-effective method (Zakriya et al., 2023). Ethylene absorbent sachets containing scavengers such as potassium permanganate ($KMnO_4$), activated carbon (AC), zeolite, alumina, and silicon dioxide have been used as cost-effective solutions to extend the shelf life of perishable produce. These chemicals oxidize or absorb ethylene, reducing its concentration and extending the storage life of perishable produce. Currently, ethylene absorbent sachets have been developed for various vegetables and fruits (Frígola, 2016; Prasetyo et al., 2018; Chudasama, 2021). The effect of ethylene absorption on tomato has also been done by using potassium permanganate in previous studies (Nath et al., 2015; Frígola, 2016; Dobrucka et al., 2017). Moreover, several studies have been done on identifying the mature ripening stages of tomatoes (Thengane and Gawande, 2018).

Temperature has a strong effect on the perishable food materials, and temperature can also affect other properties. Previous studies confirmed that storage temperature directly affects the shelf life and ripening of tomatoes (Cantwell, 2015). Cantwell (2015) conducted a study to evaluate the impact of temperature on respiration, ethylene production, and color during tomato ripening. In the study, a comparison was made with different temperatures of 12.5, 20, and 30 ℃. Ethylene production and color alteration were higher at 20 ℃, while 12.5 ℃ exhibited relatively lower levels of respiration and ethylene production in tomatoes. Cold storage is commonly used to prolong the shelf life of fresh produce, but its interaction with ethylene management strategies across various maturity stages of tomatoes remains underexplored. Relative humidity (RH %) can affect water exchange, physiological disorders, decay development, and uniformity of fruit ripening. While vegetables are typically suitable in a RH% range of 90% to 100%, fruits should be stored in a suitable range of 85% to 95% (Keller et al., 2013). In this study, tomatoes were stored at temperature 12 °C and 95% RH.

Three ethylene absorbent sachets were developed using $KMnO_4$, activated carbon (AC), and a mixture of them, to evaluate the effectiveness in extending the storage life of tomatoes at different maturity stages. KMnO4 is an ethylene absorbent and ethylene catalytic oxidant, AC is an ethylene adsorbent (Chaemsanit et al., 2018; Hu et al., 2019). Tomatoes at various ripening stages were stored under cold conditions, and key quality parameters weight loss, color development, total soluble solids (TSS), pH, firmness, Ascorbic acid and Lycopene content were monitored. The aim of the research was to determine the effect of KMnO4, AC, and a mixture of them to extend the storage life of tomatoes. Further, the shelf life of tomatoes stored under cold conditions (12 °C and 95% (RH)) was determined and the most suitable ethylene scavenging treatment for the corresponding maturity stage was identified.

2. Materials and Methods

2.1 Sample preparation

Fresh tomatoes (Solanum lycopersicum L. cv. platinum) at the five maturity stages (mature green (I), color breaker (II), color turning (III), pink (IV), and light red (V)) were harvested from a local farm. Selected fruits were washed with tap water and kept under ambient temperature conditions (29 °C to 32 °C) to remove surface moisture. Tomatoes were packed (40 bags) in non-porous polypropylene (LDPE 150 gauge) bags as postharvest treatment (with sachets containing 3 g active ingredient) and control samples (without sachets) according to maturity stages. The bags were sealed and kept at cold storage (12 °C and 95% RH).

Impregnated KMnO4 and AC mix substance were prepared using the method described by Aprilliani et al. (2018). Activated carbon was washed with distilled water and dried overnight at 105 °C using conventional oven. Activated carbon (25 g) was dipped in the saturated solution of potassium permanganate (6.4 g/100 mL). This mixture was shaken for 2-3 min, left for 120 min, and then centrifuged for 45 min at 2000 rpm. The solid materials were separated and dried at room temperature for 16 h and then dried at 50 °C for 24 h using conventional oven. The impregnated substance was used as mix treatment (M) sachets.

2.2 Analysis of ethylene absorbent ability of prepared sachets

Four containers of the same volume were taken and the lids were pierced and covered with a piece of rubber. One half test tube and a relevant sachet were placed into each container. One mL of ethephon (2-chloroethylphosphonic acid) solution (Ethephon: water – 5 mL :100 mL) and 1 mL of limewater (Calcium hydroxide) solution (lime – 10 g/ water – 100 mL) were added into test tubes and mixed well. The containers were covered with lids quickly and were allowed at 48 h. The remaining ethylene concentration in the headspace was determined according to the method described by Hu et al., (2019) using a gas chromatograph (Model: GC-2014, SHIMADZU) equipped with a dual thermal conductivity detector (DTCD). One µL headspace gas sample was withdrawn from each container using a gas-tight microsyringe and injected into the GC. The column oven, injector, and detector temperatures were maintained at 70 °C, 100 °C, and 120 °C, respectively. Nitrogen was used as the carrier gas at a flow rate of 30 mL min^{-1}. Ethylene was identified by comparing its retention time with that of an ethylene standard, and the concentrations were quantified based on the corresponding peak areas.

2.3 Experimental design

This study was conducted as five separate experiments to represent five maturity stages of tomato. These five maturity stages were treated with ethylene scavenger separately [Control (C), 100% KMnO4 sachet (K), 100% Activated carbon sachet (AC), and Impregnated KMnO4 and AC (Mix) sachet (M)]. Each experiment was conducted as a Complete Randomized Design (CRD) with three replicates per treatment. Observations and data during the storage period for required parameters were recorded at the intervals of 4 days for mature green, color breaker, color turning stages, and daily for the pink and light red maturity stages.

2.4 Evaluation of postharvest parameters of Tomato

Weight loss was evaluated as the percentage loss of the initial weight of tomatoes (Priyankara et al., 2017). A Minolta colorimeter (Model: Minolta Camera, Osaka, Japan, CR-400) was used to determine the skin color of tomatoes. The pH was measured using digital pH meter (Model – ST-300 Ohaus Corporation, USA). Total soluble solid content (TSS) was assessed using a digital refractometer

(Model - ATAGO PAL-1) at 24 °C and a penetrometer (Model – BISHOP, Italy) was used for measuring the firmness of tomatoes (Priyankara et al., 2017). The lycopene content (LC) was estimated according to the method reported by Anthon and Barrett (2007). It was determined by extracting 0.2 g of tomato juice with a hexane:ethanol:acetone (2:1:1) solvent mixture, followed by phase separation with distilled water, spectrophotometric measurement at 444 and 503 nm, and calculation using the equation:

Lycopene content (mg/100 g) = (6.95A503- 1.59A444) (0.55) (537) (V/W)/10 [where 0.55 is the ratio of the final hexane layer volume to the volume of mixed solvents added, 537 is the molecular weights of lycopene (g/mol), W (mg) is the weight of tomato juice analyzed, V (mL) is the volume of mixed solvents added.]

The ascorbic acid content was measured using ultra high performance liquid chromatography (Model: Ultimate 3000, DIONEX) described by Gîrd et al., (2018); Mahmood and Ahmad, (2018). The mobile phase consisted of 95% 0.05 M sodium dihydrogen phosphate (NaH_2PO_4, pH 3.6) and 5% methanol. Standard solutions (10–100 ppm) were prepared from 100 ppm L-ascorbic acid stock solution using the mobile phase. Tomato juice samples were mixed with an equal volume of the mobile phase, centrifuged at 5000 rpm for 5 min, filtered through a 0.45 μm PVDF membrane filter, and analyzed by UHPLC at a flow rate of 0.7 mL min^{-1} with an injection volume of 20 μL. Ascorbic acid was identified based on its retention time and UV absorbance. The absorbance was measured at 242 nm and run time was 20 minutes. The shelf life of a tomato was calculated by counting the days required to attain the last stage (dark red color) of ripening, to the stage when fruits remained still acceptable for marketing (Moneruzzaman et al., 2008). Marketability was determined through visual observation of external appearance, ripening color, firmness, and the absence of visible spoilage or fungal growth. Fruits exhibiting severe deterioration, visible fungal growth, or unacceptable softening were considered to have reached the end of their marketable life.

2.5 Statistical analysis

Each experiment was conducted in three replicates and the values were expressed as the mean ± standard deviation. Data were analyzed using the analysis of variance (ANOVA). Mean separation was done with $p<0.05$ significant level. All the data were analyzed using Minitab statistical software version 17.0.

3. Results and Discussion

3.1 Ethylene absorbent ability of each sachet

The remaining ethylene gas in the control, KMnO4, AC, and mix treatment samples were 2923 ppm, 539 ppm, 605 ppm, and 887 ppm, respectively. The corresponding ethylene peak area values were 4680576 uV, 865151 uV, 971495 uV, and 1422526 uV, respectively. Residual ethylene concentration was highest in control and substantially lower in all ethylene absorbent treatments (Figure 1), confirming that the sachets effectively removed ethylene from the storage environment. Potassium permanganate exhibited the highest ethylene absorption, followed by activated carbon and the mixed treatment. Lower residual ethylene delays ripening and senescence, thereby helping to maintain postharvest quality and extend the shelf life of tomatoes.

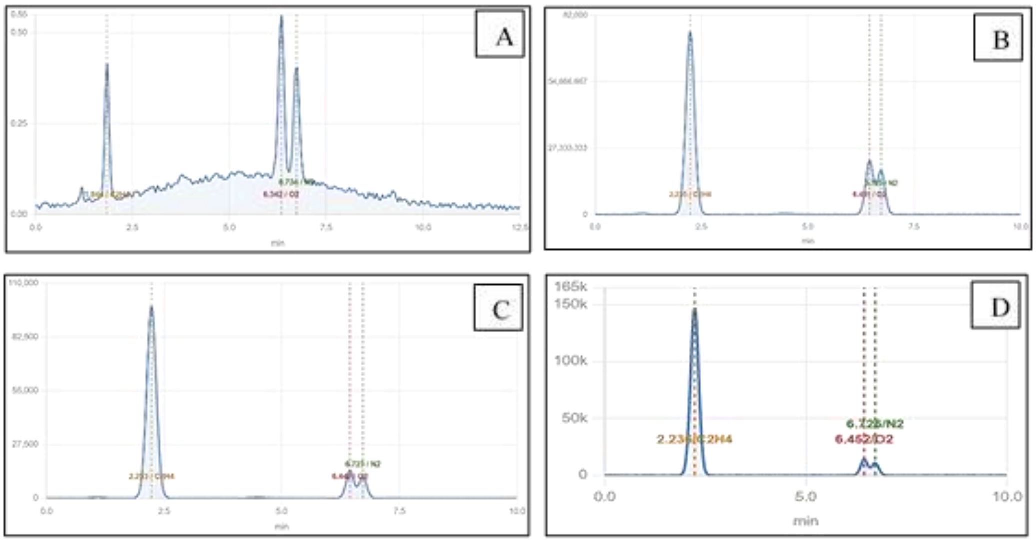

Figure 1: Gas chromatograms of residual ethylene (C_2H_4) following treatment with different ethylene absorbent sachets. The peak at approximately 2.2 min represents ethylene (C_2H_4), while the peak at approximately 6.7 min represents nitrogen (N_2). (A) Control, (B) Potassium permanganate, (C) Activated carbon, and (D) Mix

3.2 pH, Total soluble solid, and firmness of tomatoes during storage

Figures 2, 3, and 4 show the changes in pH, TSS, and firmness of treated and untreated tomatoes at all stages with storage time, respectively. Tomatoes at mature green stage showed the highest firmness, pH value and lowest TSS value on the initial day. According to the graphs, treated samples showed reduced ripening compared to the control sample in all pH, TSS, and firmness values.

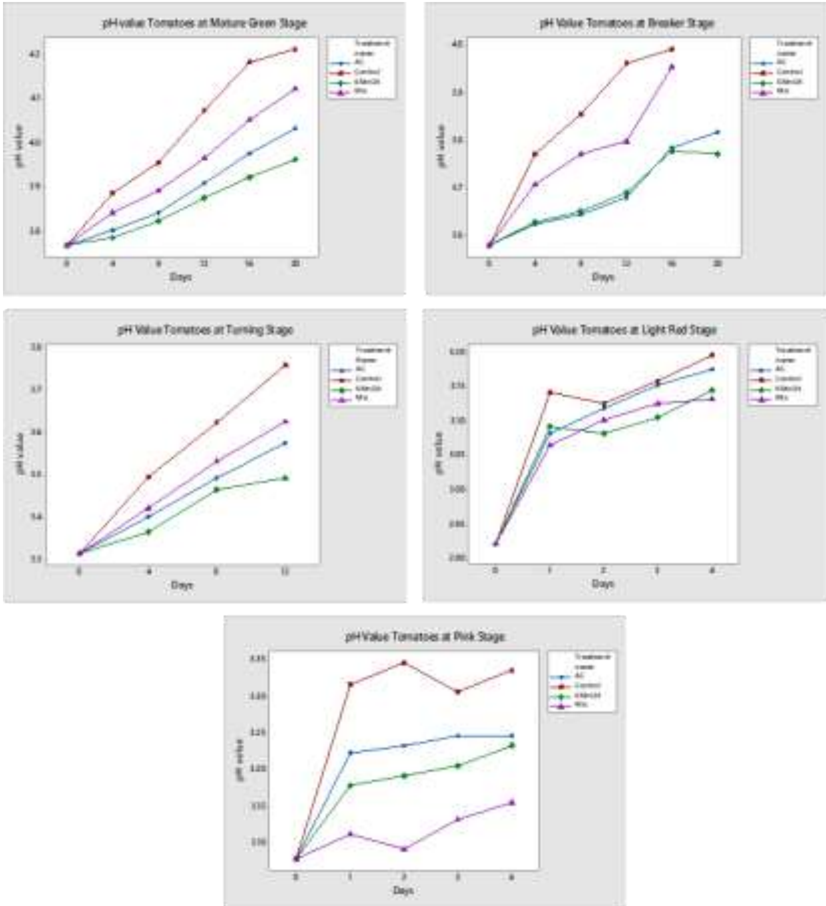

Figure 2 :Effect of different treatments on pH of five maturity stages with storage time (Mature green=Stage I, Breaker= Stage II, Turning=Stage III, Pink=Stage IV, Light Red= Stage V, AC=Activated Carbon, $KMnO_4$=Potassium permanganate)

3.2.1. Change in pH: In day 0 (initial day), the pH values of mature green, breaker, turner, pink, and light red stages were 3.8, 3.6, 3.3, 3.1 and 3.0 respectively. The pH values of all treated and untreated samples generally increased throughout storage time, being affected by the presence of ethylene absorbance sachet (Figure 2). The increase in pH during ripening may be attributed to the gradual reduction of organic acids through the respiration and their conversion into sugars and other metabolic products, resulting in a decrease in titratable acidity and a corresponding increase in pH. This result corroborated with the findings of Moniruzzaman et al. (2013) and Alonso-Salinas et al. (2022). According to the results in Figure 2, no clear significantly different pH values were observed among the four treatments at stages I, II, and III. The potassium permanganate treatment showed a positive significant difference (low mean) for stage I and III. The activated carbon treatment showed a positive significant difference (low mean) for stage II. In considering the stage IV and V, mix treatment showed notable difference over other treatments in early storage days but not in latter days. This was because by now the tomatoes were fully ripe. Based on the pH values, potassium permanganate resulted in the lowest pH for Stage I and Stage III tomatoes, activated carbon resulted in the lowest pH for Stage II, while the mixed treatment resulted in the lowest pH for Stage IV and Stage V tomatoes.

3.2.2. Change in TSS: In day 0 (initial day), the TSS value of mature green, breaker, turner, pink, and light red stages were 3.4, 3.9, 4.4, 4.3, and 4.4 brix^{o} respectively. The TSS values of all tomato samples increased throughout the storage time, being affected by the presence of ethylene absorbance sachet (Figure 3). This result corroborated the results of Chavan and Sakhale, (2020) and Poudel et al. (2022). The hydrolysis of cell wall polysaccharides or the breakdown of starch into sugars may be the cause of the rise in TSS (Priyankara et al., 2017). According to the mean TSS values for each groups, activated carbon resulted in the lowest mean TSS value for Stage II, while potassium permanganate resulted in the lowest mean TSS values for Stages III and IV, and the mixed treatment resulted in the lowest mean TSS value for Stage V.

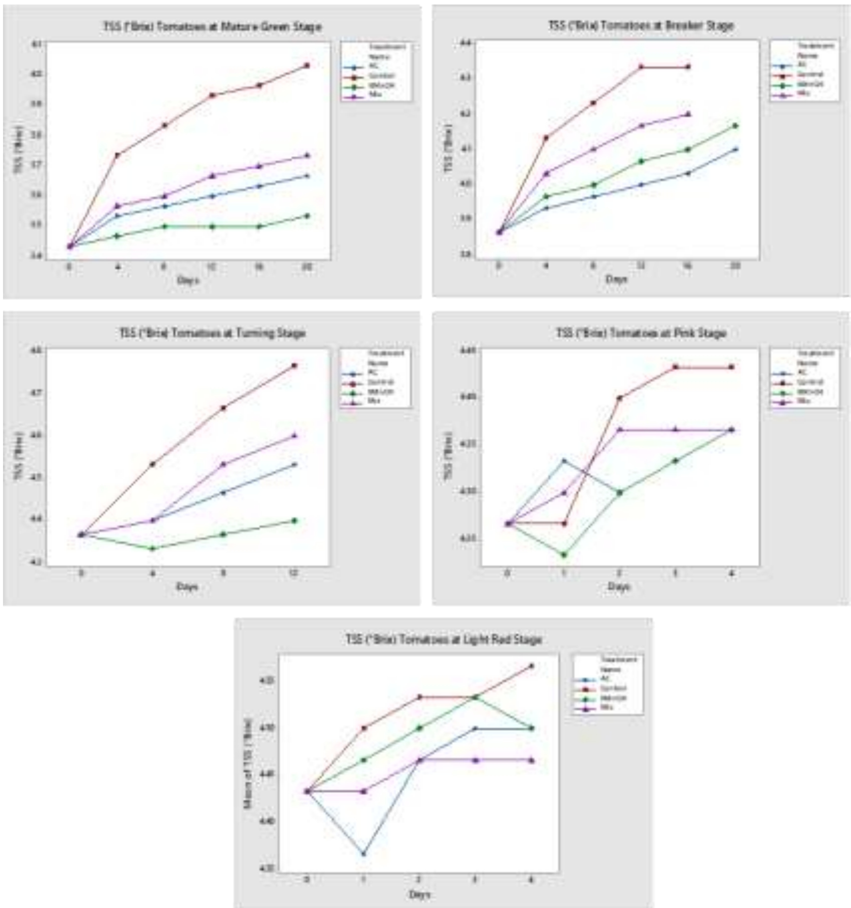

Figure 3 :Effect of different treatments on TSS of five maturity stages with storage time (Mature green=Stage I, Breaker= Stage II, Turning=Stage III, Pink=Stage IV, Light Red= Stage V, AC=Activated Carbon, $KMnO_4$=Potassium permanganate)

Change in firmness: Firmness depends on the stages of tomato fruit maturity, variety of tomato, manuring practices and environmental factors (Moneruzzaman et al., 2008). Softening can be defined as a response to ripening induced by ethylene synthesis. According to the results in this study, the highest firmness (4.66± 0.13) was shown in the stage I and the lowest firmness (3.15±0.13) in the stage V. The results of this study confirmed the results obtained by Chavan and Sakhale (2020) and Oduntan et al. (2022). The firmness of all treatment generally decreased throughout the storage time, being affected by the presence of ethylene absorbance sachet (Figure 4). Firmness loss occurs due to the biochemical degradation of cell wall components during fruit ripening. Ethylene stimulates cell wall-degrading enzymes, such as polygalacturonase and pectin methylesterase, which breaks down pectin and other structural polysaccharides, weakening cell-to-cell adhesion and resulting in fruit softening. There were no statistically significant differences in firmness among the treatments over the storage period ($p > 0.05$); however, slight differences in mean firmness values were observed. Based on the mean firmness values, potassium permanganate treatment showed relatively better firmness retention at maturity stage I, while activated carbon was comparatively more effective at stage II. Potassium permanganate provided relatively higher firmness retention at stage III, whereas the mixed treatment performed comparatively better at stages IV and V. These differences indicate that the effectiveness of the ethylene absorbent treatments in maintaining firmness varied with the maturity stage of the tomatoes.

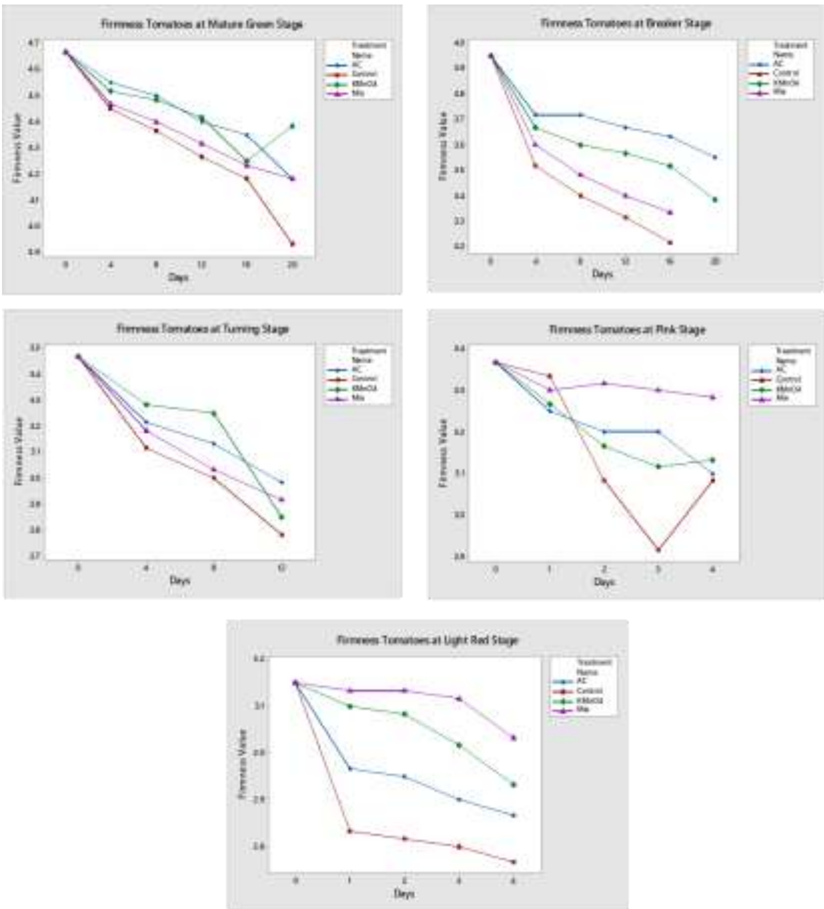

Figure 4 :*Effect of different treatments on firmness of five maturity stages with storage time (Mature green=Stage I, Breaker= Stage II, Turning=Stage III, Pink=Stage IV, Light Red= Stage V, AC=Activated Carbon,* $KMnO_4$*=Potassium permanganate)*

3.3 Ascorbic acid and Lycopene content of tomatoes during storage

3.3.1. Change in lycopene content: When tomatoes ripen, lycopene is produced in the fruit giving a red color. The lycopene contents of mature green, breaker, turner, pink, and light red stages were 0.03, 0.27, 0.79, 2.26, and 7.82 mg/ 100 g, respectively, on the initial day. All the treated and untreated tomatoes showed increase in lycopene content during ripening (Table 1). However, tomatoes treated with potassium permanganate, activated carbon, and the mixed ethylene absorbent generally showed a slower increase in lycopene content than the control, indicating delayed ripening. In this study, range of lycopene content of all tomato samples changed from 0.03 ± 0.01 to 10.43 ± 0.05 mg/100 g. Treatments 'potassium permanganate' at mature green (0.08 ± 0.01) mg/100 g and turner (5.19 ± 0.04) mg/100 g, 'Activated carbon' at breaker (2.48 ± 0.01) mg/100 g showed the lowest lycopene contents after 7 days, whereas 'Mix' at pink (7.37 ± 0.03) mg/100 g and light red (8.61 ± 0.03) mg/100 g showed the lowest lycopene contents after 3 days. Alda et al. (2009) reported that lycopene content of fresh tomato was approximately 12 mg/100 g, and Carolina (2013) reported that lycopene content of fresh tomato was 0.88–7.74 mg/100 g. The color changes were more evident in the earlier maturity stages, suggesting that ethylene removal slowed lycopene biosynthesis and helped maintain marketable visual quality for a longer period.

Table 1. Effect on lycopene content (mg/ 100 g) of treated and untreated tomatoes

T	Stage I	Stage II	Stage III	Stage IV	Stage V
C	0.16 ± 0.01^{d}	3.16 ± 0.03^{a}	5.19 ± 0.04^{a}	7.53 ± 0.02^{c}	8.81 ± 0.02^{c}
K	0.08 ± 0.01^{b}	2.84 ± 0.04^{b}	5.75 ± 0.06^{d}	8.18 ± 0.02^{b}	10.43 ± 0.05^{b}
A	0.09 ± 0.01^{c}	2.48 ± 0.01^{d}	5.98 ± 0.11^{c}	7.37 ± 0.03^{a}	8.61 ± 0.03^{a}
M	0.13 ± 0.01^{a}	2.66 ± 0.02^{c}	6.51 ± 0.03^{b}	7.61 ± 0.01^{d}	9.60 ± 0.02^{d}

(T: Treatment, C: control, K: $KMnO_4$, A: activated carbon, M: mix, n.a.: not available; (Stage I= Mature green, Stage II = Breaker, Stage III= Turning, Stage IV= Pink, Stage V= Light Red; Values expressed are mean ± standard deviation. Means in the same column with different letters were significantly different at $P < 0.05$)

3.3.2. Change in ascorbic acid: Tomato has a high content of ascorbic acid. The content of ascorbic acid vary with tomato cultivar, species, harvested time, climate, and maturity stage (Gîrd et al., 2018). The ascorbic acid contents of mature green, breaker, turner, pink, and light red stages were 1.7 ppm, 2.4 ppm, 5.0 ppm, 6.0 ppm, and 12.0 ppm, respectively, on the initial day. Ascorbic acid content generally increased during storage as ripening progressed, although slight reductions were observed at the advanced maturity stages due to oxidative degradation during senescence. Except for the pink, and light red stages, all treated and untreated tomatoes showed an increase in ascorbic acid content during ripening (Table 2). Mujtaba and Masud (2014) reported that ascorbic acid content of tomatoes during storage increased continuously with a slight fall during 20 days of storage. After seven days, the highest concentration of ascorbic acid was observed with by the treatment ‘Mix’ (145 ppm). These findings demonstrate that ethylene absorbent sachets effectively retained both nutritional quality and postharvest freshness, thereby contributing to an extended shelf life.

Table 2. Effect on ascorbic acid content (ppm) of treated and untreated tomatoes

T	Stage I	Stage II	Stage III	Stage IV	Stage V
C	72.8	136.94	75.46	10.42	8.60
K	93.8	89.00	63.52	3.55	7.68
A	n.a.	53.56	60.79	4.53	5.88
M	145.76	45.19	24.02	9.84	4.51

(T: Treatment, C: control, K: $KMnO_4$, A: activated carbon, M: mix, n.a.: not available; (Stage I= Mature green, Stage II = Breaker, Stage III= Turning, Stage IV= Pink, Stage V= Light Red; Values expressed are mean ± standard deviation. Means in the same column with different letters were significantly different at $P < 0.05$)

3.4 Weight loss

Weight loss during storage could occur due to water loss through transpiration and respiration, as well as decay and microbial activity. In this study, five tomato fruits per treatment were used to calculate the weight loss and the weight loss of all five fruits was calculated separately and their mean was taken as the final weight loss. In early three stages, weight loss decreased over time with treatment ‘potassium permanganate’, while it increased in the control samples compared to other treatments. Weight loss in treatment ‘Mix’ was less compared to other treatments in pink and light red stages.

Moneruzzaman et al. (2008) reported that the weight loss of mature green tomatoes increased with storage time due to the higher rate of dehydration in the tender tissues. Weight loss reduction is important because it helps to maintain fruit firmness, and visual appearance, thereby preserving market quality and consumer acceptance while reducing economic losses during storage and marketing. The delayed ripening caused by ethylene removal reduced respiration and moisture loss, contributing to the extended shelf life of treated tomatoes.

3.5 Skin Color

Fruit color is used as a quality indicator to describe consumer attraction (Moniruzzaman et al., 2013). Changes in visual color development on peel of tomato occurs during ripening of different types of matured fruits are shown in Plate 1. The International Commission on Illumination (CIE) uses the color qualities of L*, a*, and b*, which may be determined with a chromo meter. In this study, color change values (L, a, b) of each treatment were obtained at specified intervals along with storage time. Table 3 illustrated the "L" value, "a" value and "b" value of the color change of tomato samples. These values represented the mean value of individual color values obtained on different dates during the storage period. Accordingly, the "L" value decreased in all five stages and "a" value showed negative value first and then positive values. Conversely, the "b" value decreased initially and then increased. Dobrucka et al. (2017) reported similar trends.

Table 3. Skin color changes (L, a, and b value) of tomato with treatments and maturity stages

	T	Stage I (Mature green)	Stage II (Breaker)	Stage III (Turning)	Stage IV (Pink)	Stage V (Light Red)
L value	C	50.50±5.96	43.16±5.42	41.61±5.40	40.86±3.94	40.17±2.76
	K	52.85±4.92	44.76±4.64	45.84±3.72	41.77±3.78	40.95±2.61
	A	50.80±5.81	45.49±4.30	45.56±3.92	41.34±3.82	40.65±2.91
	M	51.82±5.78	44.72±4.62	42.21±5.34	42.36±3.64	41.29±2.51
a* value	C	-4.78±6.21	5.81±8.64	10.45±6.85	13.39±4.50	16.35±2.75
	K	-9.60±3.33	6.06±9.06	8.04±6.23	12.66±4.32	15.60±2.47
	A	-8.76±3.47	5.57±8.57	8.83±6.48	12.81±4.07	15.74±2.34
	M	-8.21±4.07	4.64±8.61	9.43±6.70	12.13±3.40	15.48±2.18
b* value	C	28.15±4.68	23.84±3.40	21.78±3.39	18.54±4.13	15.34±3.39
	K	28.45±4.09	24.25±3.33	22.68±3.14	18.50±3.36	16.80±2.76
	A	28.38±4.04	23.96±3.06	22.38±3.36	18.52±3.80	16.11±2.93
	M	28.07±4.34	27.98±2.63	21.99±3.54	18.75±3.00	16.95±2.54

(T: Treatment, C: control, K: $KMnO_4$, A: activated carbon, M: mix; Values expressed are mean ± standard deviation. Means in the same column with different letters were significantly different at P < 0.05)

In this study, the highest 'L' and 'b' values and lowest "a" value was shown in mature green stage in all treatments. Comparing the L* values among the treatments, the highest mean L* values were observed for the potassium permanganate treatment at stage I, activated carbon at stage II, potassium permanganate at stage III, and the mixed treatment at stages IV and V, indicating relative differences in lightness among treatments across the maturity stages. The "a" value is the most important value for monitoring ripening of tomatoes. As the fruit ripens, the a value increases from negative toward positive values, indicating an increase in red coloration (Camelo and Gomez, 2004). Considering the average "a" value during the storage period, the lowest "a" values were shown with treatment 'potassium permanganate' at mature green (-9.60±3.33) and turning (8.04±6.22) stages. With treatment 'mix' at breaker (4.64±8.60), pink (12.13±3.99), and light red (15.48±2.17) stages. Accordingly, tomatoes treated with ethylene absorbent sachets, particularly potassium permanganate and the mixed treatment, exhibited a slower increase in redness than the control, demonstrating delayed ripening. Maintaining greener and brighter fruit for a longer period is advantageous because it preserves visual quality, extends the marketable period, and provides higher flexibility during transport and retail display. These findings suggest that ethylene removal effectively slowed color development, thereby improving postharvest quality and shelf life.

The changes in tomato color during ripening were closely associated with the accumulation of lycopene (Table 1). As ripening progressed from stage I to stage V, the "a" value increased from negative to positive values, indicating a gradual transition from green to red color. This color development corresponds to the increasing lycopene content, which is a major carotenoid responsible for the characteristic red color of ripe tomatoes. Lycopene is also an important antioxidant with potential health-promoting properties. The development of an attractive red color together with increased lycopene accumulation enhances both the nutritional quality and consumer acceptability of tomatoes, enhancing their market value. The treatments differed in their ability to maintain these quality characteristics during storage, indicating their potential to preserve the visual and nutritional quality of tomatoes up to the market stage.

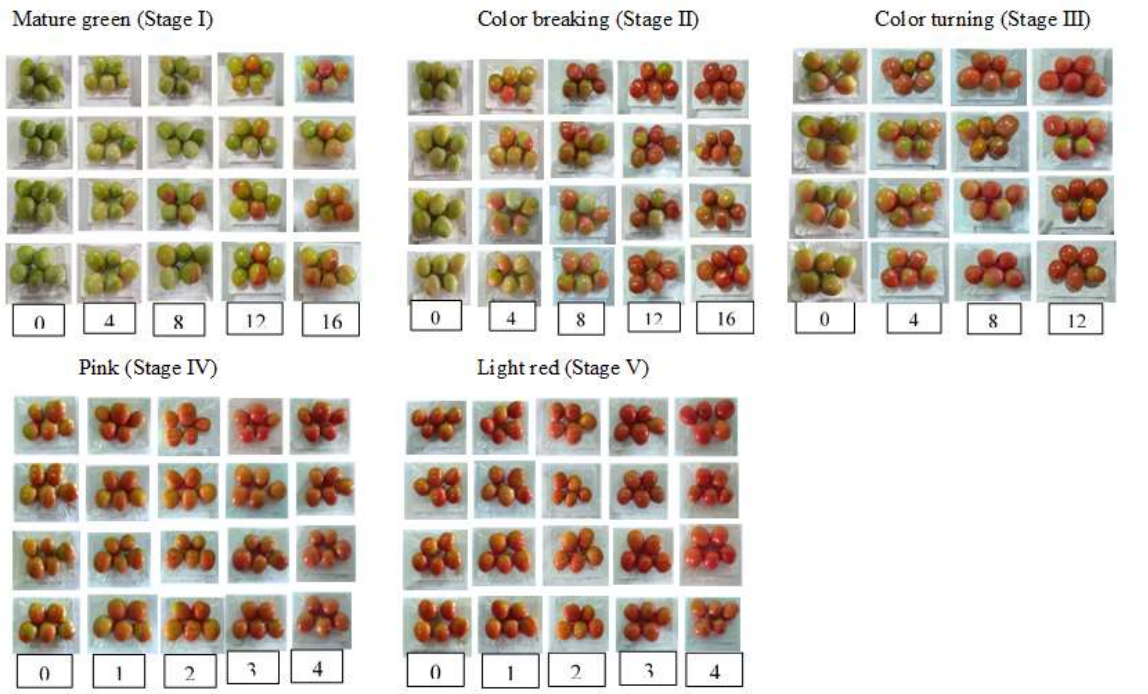

Plate 1: Visual color changes of treated tomatoes with storage time at early five maturity stages (C: Control, K: $KMnO_4$, A: Activated carbon, M: Mix)

3.6 Shelf life

The shelf life of fruits is the duration after harvest, with no quality deterioration remaining suitable for consumption. The majority of preservative treatments are evaluated based on the shelf life of fruits, which ultimately is the most crucial quality for fruit storage (Ahmed et al., 2021). Table 4 shows increased storability of tomatoes treated with potassium permanganate. Ahmed et al. (2021) reported that the maximum shelf life of 14 days in banana fruits treated with 1% potassium permanganate concentration against 7 days for untreated.

Table 4: Effect of treatments on days of shelf life for treated and control tomatoes

T	Shelf life (for reach full ripen stage) (Days)				
	Stage I (Mature green)	Stage II (Breaker)	Stage III (Turning)	Stage IV (Pink)	Stage V (Light Red)
C	20	16	12	6	5
K	28	20	15	8	6
A	27	22	13	7	6
M	25	18	14	9	7

(T: Treatment, C: Control, K: $KMnO_4$, A: Activated carbon, M: Mix)

Potassium permanganate was particularly effective at the early maturity stages in delaying ripening, while the mixed treatment showed higher benefits at later stages, suggesting that the performance of the absorbents varied with the physiological condition of the fruit. Moneruzzaman et al. (2008) reported the maximum shelf life of tomatoes for mature green (13 days), followed by half ripe (12 days) and minimum was for full ripen tomatoes (10 days). Compared with the findings of Moneruzzaman et al. (2008), the present study achieved a considerably longer shelf life of tomato fruits. In their study, tomatoes were stored under ambient conditions, with an average maximum and minimum temperature of 30.70 and 18.8 °C, respectively, and 75% RH, whereas the present study was conducted at 12 °C and 95% RH using ethylene-absorbing sachets. The extended shelf life observed in the present study may be attributed primarily to the lower storage temperature, which slows respiration and ripening, together with the removal of ethylene from the storage environment. Differences in tomato cultivar and maturity stage may also have contributed to the variation in shelf life between the two studies. These findings demonstrate the potential of combining appropriate low-temperature storage with ethylene management to delay ripening and maintain postharvest quality. Extending shelf life is commercially important because it helps preserve fruit quality during storage, transportation, and retail display, thereby reducing postharvest losses and improving the marketability and economic value of tomatoes.

4 Conclusions and Future Prospects

This study demonstrated that the application of ethylene absorbent sachets effectively extended the shelf life and maintained the postharvest quality of tomatoes stored under cold conditions (12 °C and 95% RH). The effectiveness of the reagents in the sachets depended on the maturity stage of the tomatoes. Among the tested treatments, $KMnO_4$ sachets showed superior performance in mature green (Stage I) and turning (Stage III) tomatoes, while activated carbon performed better in breaker stage (Stage II). The mixed sachet ($KMnO_4$ + activated carbon) was more effective for pink (Stage IV) and light red (Stage V) tomatoes. Treated tomatoes exhibited reduced weight loss, delayed color development, slower changes in pH and TSS, better firmness retention, and extended shelf life compared to untreated control samples. Considering the overall quality parameters and shelf-life performance, $KMnO_4$-based sachets showed the most consistent potential for practical application, particularly in delaying ripening and maintaining postharvest quality. Although the activated carbon and mixed constituent sachets also improved selected quality attributes at specific maturity stages, the use of a single $KMnO_4$-based sachet may be more practical for commercial application because it provides a relatively simple approach to ethylene management across different maturity stages. Therefore, $KMnO_4$ sachets are recommended as a practical postharvest technology for reducing ethylene accumulation, delaying ripening, extending shelf life, and maintaining the marketability of tomatoes during cold storage, transportation, and retail distribution. However, the present study did not determine the optimum quantity of ethylene absorbent or the number of sachets required for a typical commercial plastic container based on the mass of tomatoes. Further studies should determine the optimum sachet size, absorbent quantity per sachet, and sachet-to-tomato ratio under realistic commercial packaging and transportation conditions to establish an appropriate application rate for practical use.

Declaration of Generative AI and AI-Assisted Technologies

The authors declare that no generative AI or AI-assisted technologies were used in the preparation, writing, or editing of this manuscript. The authors maintained complete responsibility and oversight throughout the research and writing process, and assume full accountability for the content of the published work.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Ahmed, Z., M.F. Tanveer, and M.F. Tahseen, 2021. "Potassium permanganate (kmno4) in relation to temperatures alters shelf life and quality of banana (*Musa paradisiaca L.*)". *International Journal of Food Science and Agriculture*, 5 no (1), 41–51. https://doi.org/10.26855/ijfsa.2021.03.007.

Alda, L.M., I. Gogoasal, D.M. Bordean, C. Moldovan, and L. Nita, 2009. "Lycopene content of tomatoes and tomato products". *Journal of Agroalimentary Process and Technologies*, 15 no (4), 540–542.

Alonso-Salinas, R., S. Lopez-Miranda, A.J. Perez-Lopez, A.A. Carbonell-Barrachina, E.Nunez-Delicado, and J.R. Acosta-Motos, 2022. "Novel combination of ethylene oxidisers to delay losses on postharvestquality, volatile compounds and sensorial analysis of tomato fruit". *Lwt*, 170, 2-8. https://doi.org/10.1016/j.lwt.2022.114054.

Anthon, G., and D.M. Barrett, 2007. "Standardization of a rapid spectrophotometric method for lycopene analysis". *Acta Horticulturae*, 758, 111–128. https://doi.org/10.17660/ActaHortic.2007.758.12.

Aprilliani, F., E. Warsiki and A. Iskandar, 2018. "Kinetic studies of potassium permanganate adsorption by activated carbon and its ability as ethylene oxidation material". *IOP Conference Series: Earth and Environmental Science*, 141 no (1). https://doi.org/10.1088/1755-1315/141/1/012003.

Camelo, A.F.L., and P.A. Gomez, 2004. "Comparison of color indexes for tomato ripening". *Horticultura Brasileira*, 22 no (3), 534–537. https://doi.org/10.1590/S0102-05362004000300006.

Cantwell, M. 2015. "Ripening tomatoes". *Postharves technologyt*, 1–13. http://ucanr.edu/datastoreFiles/234-2818.pdf.

Carolina, N. 2013. "An update on the health effects of tomato lycopene". *The Annual Review of Food Science and Technology*, 2010 no (1), 1–24. https://doi.org/10.1146/annurev.food.102308.124120.An.

Casals, J., A. Rull, and J. Giné-Bordonaba, 2021. "Changes in ripening-related quality traits of long shelf life tomatoes as influenced by water deficit and short-term postharvest storage". *Agronomy*, 11 no (11), 2304-2317. https://doi.org/10.3390/agronomy11112304.

Chaemsanit, S., M. Narumol, and M. Nirundorn, 2018. "Activated carbon for food packaging application: Review".*Walailak Journal of Science and Technology*, 15 no (4), 255–271. https://doi.org/10.48048/wjst.2018.4185.

Chavan, R.F., and B.K. Sakhale, 2020. "Studies on the effect of exogenous application of salicylic acid on post-harvest quality and shelf life of tomato fruit *Cv. Abhinav". Food Research*, 4 no (5), 1444–1450. https://doi.org/10.26656/fr.2017.4(5).131.

Chudasama, M. 2021. "Ethylene scavengers in food packaging technology: A review". *Food Chemistry*, 337, 1–25.

Dobrucka, R., A. Leonowicz, and R. Cierpiszewski, 2017. "Preparation of ethylene scavenger based on kmno$_4$ to the extension of the storage time of tomatoes". *Studia Oeconomica Posnaniensia*, 5 no (7), 7–18. https://doi.org/10.18559/soep.2017.7.1.

FAO. 2022. "World Food and Agriculture". *Statistical Yearbook 2022*. https://doi.org/10.4060/cc2211en.

Frígola, A. 2016. "Role of potassium permanganate ethylene on physicochemical properties, during storage of five different tomato cultivars". *MOJ Food Processing and Technology*, 3 no (2), 1-8. https://doi.org/10.15406/mojfpt.2016.03.00069.

Gil, M.I., M.A. Conesa, and F. Artés, 2002 "Quality changes in fresh cut tomato as affected by modified atmosphere packaging". *Postharvest Biology and Technology*, 25 no (2), 199–207. https://doi.org/10.1016/S0925-5214(01)00166-1.

Gîrd, C.E., I. Nencu, L.E. Dutu, M.E. Poopescu, and T. Costea, 2018. "HPLC evaluation of the ascorbic acid content of Romanian fruits and vegetables from retail markets". *Farmacia*, 66 no (5), 894–898. https://doi.org/10.31925/farmacia.2018.5.21.

Hu, B., D. Sun, H. Pu, and Q. Wei, 2019. "Recent advances in detecting and regulating ethylene concentrations for shelf-life extension and maturity control of fruit: A review". *Trends in Food Science and Technology*, 91, 66–82. https://doi.org/10.1016/j.tifs.2019.06.010.

Iamjud, K., S. Srimat, P. Sangwanangkulb, S. Wasee, and K. Thaipong, 2016. "Antioxidant properties and fruit quality of selected papaya breeding lines". *ScienceAsia*, 42 no (5), 332–339. https://doi.org/10.2306/scienceasia1513-1874.2016.42.332.

Keller, N., M.N. Ducamp, D. Robert, and V. Keller, 2013. "Ethylene removal and fresh product storage: A challenge at the frontiers of chemistry. Toward an approach by photocatalytic oxidation". *Chemical Reviews*, 113 no (7), 5029–5070. https://doi.org/10.1021/cr900398v.

Mahmood, H., and R. Ahmad, 2018. "High perfarmance liquid chromatographic determination of ascorbic acid in pharmaceutical preparations, fruit juices and human serum". *Rafidain Journal of Science*, 27 no (2), 79–92. https://doi.org/10.33899/rjs.2018.145393.

Mariah, M.A.A., J.M. Vonnie, K.H. Erna, N.M.N. Aqilah, N. Huda, R.A. Wahab and K. Rovina, 2022. "The emergence and impact of ethylene scavengers techniques in delaying the ripening of fruits and vegetables". *Membranes*, 12 no (2), 1–19. https://doi.org/10.3390/membranes12020117.

Moneruzzaman, K.M., A.B.M.S. Hossain, W. Sani, and M. Saifuddin, 2008. "Effect of stages of maturity and ripening conditions on the physical characteristics of tomato". *American Journal of Biochemistry and Biotechnology*, 4 no (4), 329–335. https://doi.org/10.3844/ajbbsp.2008.329.335.

Moniruzzaman, K.M., M.F.B Hossain, R. Khatoon, and M.M. Rashid, 2013. "Ripening of tomato at different stages of maturity influenced by the post harvest application of ethrel". *Bulletin of the Institute of Tropical Agriculture, Kyushu University*, 36 no (1), 17–30. https://www.jstage.jst.go.jp/article/bita/36/1/36_017/_article/-char/ja/.

Mujtaba, A., and T. Masud, 2014. "Enhancing post harvest storage life of tomato (*Lycopersicon esculentum Mill.) Cv*. Rio grandi using calcium chloride". *Journal Agricultural and Environmental Science*, 14 no (2), 143–149. https://doi.org/10.5829/idosi.aejaes.2014.14.02.12269.

Nath, A., B. Bagchi, V. K. Verma, H. Rymbai, A.K. Jha, and B.C. Deka, 2015. "Extension of shelf life of tomato using $kmno_4$ as ethylene absorbent". *Indian Journal of Hill Farming*, 28 no (1), 77–80.

Oduntan, A.O., O.A. Oyetunde, B.A. Shobo, and J.G. Bodunde, 2022. "Effect of harvest maturity stage and ripening remediation agents on the shelf life and biochemical quality attributes of tomato (*Solanum lycopersicum L.*) fruits". *Advances in Horticultural Science*, 36 no (4), 255–263. https://doi.org/10.36253/ahsc12934.

Poudel, S., P. Aryal, and M. Basnet, 2022. "Effect of different packaging materials on shelf life and postharvest quality of tomato (*Lycopersicum esculentum var. Srijana*)". *Advances in Horticultural Science*, 36 no (2), 127–134. https://doi.org/10.36253/ahsc-12801.

Prasetyo, I., N.I.F. Mukti, M. Fahrurrozi, and T. Ariyanto, 2018. "Removing ethylene by adsorption using cobalt oxide-loaded nanoporous carbon". *ASEAN Journal of Chemical Engineering*, 18 no (1), 9–16. https://doi.org/10.22146/ajche.49542.

Priyankara, G.G.D.S., C.L.S.M. Karunarathne, K.H. Sarananda, and M. Ariyaratne, 2017. "Effect of maturity stage on ripening and quality characters of four tomato (*Solanum lycopersicum* L.) varieties of Sri Lanka". *Tropical Agricultural Research*, 28 no (4), 496. https://doi.org/10.4038/tar.v28i4.8249.

Sargent, S. 2000. "Ripening tomatoes with ethylene 1 ethylene-a natural plant hormone". *Intitute of Food and Agricultural Science*, 1–3. http://edis.ifas.ufl.edu.

Thengane, V., and M. Gawande, 2018. "Arduino based tomato ripening stages monitoring system". *International Journal of Innovative Research in Science, Engineering and Technology*, 7 no (1), 530-536. https://doi.org/10.15680/IJIRSET.2017.0701013.

Trombino, S., R. Cassan, D. Procopio, M.L.D. Gioia, and E. Barone, 2021. "Valorization of tomato waste as a source of carotenoids". *Molecules*, 26 no (16), 3-15. https://doi.org/10.3390/molecules26165062.

Yimmongkol, S., P. Pratumpong, S. Boonyuen, and C. Pechyen, 2018. "Preparation and evaluati on of ethylene absorbers from zeolite a/kmno$_4$ composite for monitoring of silk banana (*Musa sapientum L.*) ripening". *Chiang Mai Journal of Science*, 45 no (5), 2152–2167.

Zakriya, M., A. Hussain, A. Mahdi, F. Yasmeen, T. Kausar, A. Rehman, S. Yaqub, P. Fatima, S. Noreen, K. Kabir, R. Nisar, F.I. Gorsi, H. Fatima, and S.A. Korma, 2023. "Effect of different types of ethylene scavengers used in different combinations, on the post-harvest quality and phytochemicals retention of tomatoes (*Solanum lycopersicum L.*)", *Chemical and Biological Technologies in Agriculture*, 10 no (1), 1–16. https://doi.org/10.1186/s40538-023-004.