Chemical and Biological Technologies in Agriculture

RESEARCH

Open Access

Effect of different types of ethylene scavengers used in different combinations, on the post-harvest quality and phytochemicals retention of tomatoes (*Solanum lycopersicum* L.)

Muhammad Zakriya[1], Ashiq Hussain[2,3*], Amer Ali Mahdi[4*], Farhat Yasmeen[1], Tusneem Kausar[2], Abdul Rehman[2], Shazia Yaqub[3], Pinky Fatima[2], Saima Noreen[2], Khurram Kabir[5], Rizwan Nisar[2], Faiza Iftikhar Gorsi[2], Haya Fatima[5] and Sameh A. Korma[6]

Abstract

Background Ripening of climacteric vegetable, tomato, is a complicated process that results in numerous physiological and biochemical changes, and role of ethylene in this phenomenon is very crucial. Use of different ethylene scavengers can control the post-harvest ripening and quality of tomatoes. In current study, combinations of chemicals as 2% $CaCl_2$ and $KMnO_4$ (T_1), 1 mM salicylic acid and $KMnO_4$ (T_2), 2% $CaCl_2$ and $K_2Cr_2O_7$ (T_3) and 1 mM salicylic acid and $K_2Cr_2O_7$ (T_4), were tested to study their effect on pH, acidity, total soluble solids (TSS), vitamin C, lycopene, phenolics, flavonoids and antioxidant activity of treated tomatoes, after 30 and 40 days of storage.

Results Weight loss and titratable acidity were significantly reduced in treated tomatoes, even after 40 days, which were high in untreated tomatoes. Total phenolic contents (TPC), total flavonoid contents (TFC) and vitamin C, were significantly lesser in untreated tomatoes after 30 and 40 days of storage, but use of ethylene scavengers caused increment in these phytochemicals during post-harvest storage, with more prominent results of T_1. Highest lycopene was found in T_0 (9.76 ± 0.2 mg/100 g), due to fully ripened and spoiled tomatoes, as compared to treated samples, while the lowest value was found in T_1 (4.82 ± 0.20 mg/100 g). Highest antioxidant activity was detected in T_1 (33.80 ± 0.52%), whereas the lowest antioxidant activity was noticed in T_0 (22.00 ± 0.2%).

Conclusion Findings revealed that during the storage period, the 50 g $KMnO_4$ sachet + 2% $CaCl_2$ exerted most superior effects than the other treatments, and extended the shelf-life of tomato fruits for up to 40 days, with no quality and phytochemicals deterioration. Therefore, tomatoes could be harvested at breaker stage, to optimize the ripening process during storage, through application of ethylene scavengers.

Highlights

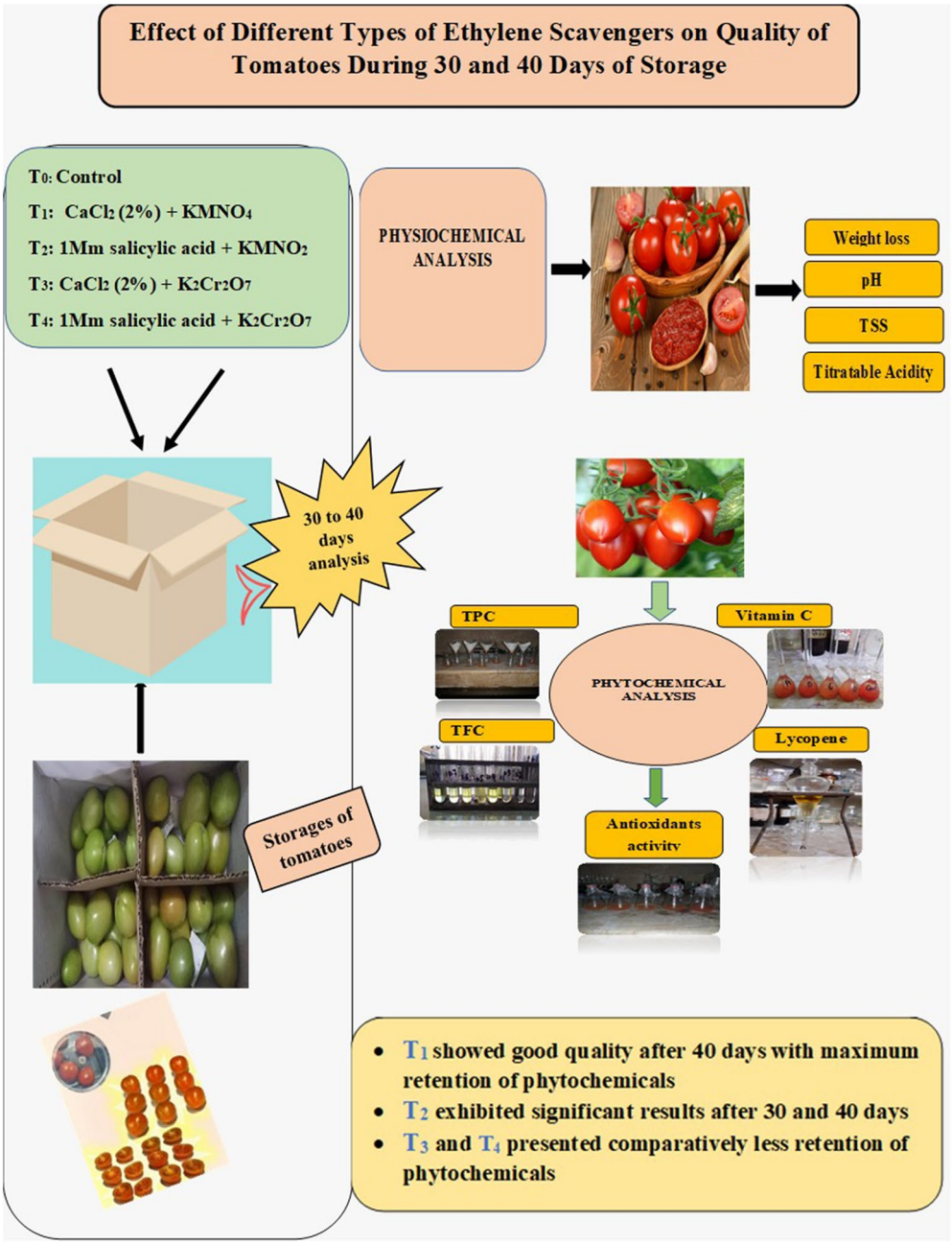
- Tomatoes, climacteric fruits loaded with phytochemicals.
- Controlling production and retention of ethylene, a tool to manage post-harvest quality.
- Tomatoes treated with 2% $CaCl_2$ + $KMnO_4$ sachet exhibited excellent quality after 40 days.

*Correspondence:
Ashiq Hussain
ashiqft@gmail.com
Amer Ali Mahdi
amer.alimahdi@yahoo.com
Full list of author information is available at the end of the article

- Treatment with 2% $CaCl_2$ solution and $K_2Cr_2O_7$ sachet preserved tomatoes for 30 days.
- High retention of phenolics, flavonoids, vitamin C, lycopene in treated tomatoes.

Keywords Tomato, Storage, Post-harvest, Salicylic acid, $CaCl_2$, $KMnO_4$, Polyphenols

Graphical abstract



Introduction

Consumers like to prefer fruit and vegetables for their high nutritional contents and health-promoting potential. However, in addition to temperature and relative humidity, ethylene, even at low concentrations, is a significant element that affects the post-harvest life of these perishable commodities. The creation of efficient tools to eliminate ethylene from the air neighboring these goods, while in storage or transit has therefore received a lot of attention [1]. Horticultural products undergo a complex and genetically designed process called ripening, that leads to a variety of physiologic, biochemical, and structural changes. These changes result from the coordinated activation of various biochemical and transcriptional regulatory mechanisms, which are influenced by endogenous and external factors. Fruits and vegetables are classified as climacteric or non-climacteric based on their ripening pattern, the presence of a burst in respiration, and the generation of ethylene during post-harvest. The ripening process in climacteric produce is linked to an increase in ethylene generation and respiration [2].

One of the most popular commercial vegetable crops, is the tomato (*Solanum lycopersicum* L.), which is a member of the *Solanaceae* family, and has about 2800 species, with an annual production of about 161 million tonnes in the world [3, 4]. Due to a variety of advantages for human health, including their antioxidant and antimicrobial properties, tomatoes are frequently used as fresh fruit, cooked food, and processed products having antioxidant compounds [5, 6]. This vegetable has protective effects against cardiovascular disease and cancer [7]. But, post-harvest quality deterioration of tomato has always been remained a challenge for food processors, as loss of certain phytochemicals might disturb the pharmacological potential of this vegetable.

With improved living standards and an emphasis put on health, the demand for high-quality fruits and vegetables has also been significantly expanded. Soluble sugars, organic acids, and amino acids, as well as secondary metabolites, like flavonoids and phenolic acids, are often indicators of the flavor and quality of tomato fruit [8]. Phenolic compounds, lycopene, vitamin C and pro-vitamin A contents, which are regarded as naturally occurring antioxidants and anti-carcinogenic substances, are just a few of the bioactive components of tomatoes, that have pharmacological and nutritional benefits [9]. Fruits and vegetables are normally considered as good source of phytochemicals, which can be used in the form of extracts, purified bioactives and isolates, with their potential role in promoting human health in different forms [10, 11]. Tomatoes are mostly popular, and are abundantly used world-over, as this vegetable is available throughout the year for table purpose, as well as for processing. Tomatoes are consumed in diverse ways. In raw form, as an ingredient in many dishes, salads, sandwiches and as salsa. Ketchup, pastes, preserves, soups, sauces, and juices are consumed as processed products of tomato [12]. Tomatoes are also a fantastic source of beneficial compounds, known as secondary metabolites, the quantities of which are linked to preventing human chronic degenerative diseases like cardiovascular disease (CVD), neurological diseases and cancer [13].

Significant amounts of tomatoes overripen or deteriorate before being consumed, due to high-volume production, and improper post-harvest management in underdeveloped and even developing nations [14]. Combination of intrinsic and extrinsic factors links with food quality, where aroma, acidity, flavor, sweetness, texture, nutritional contents and total soluble solids are intrinsic characteristics, while color, defect-free fruit, shape, and peel are external attributes. Fruits and vegetable's processors have always been involved in the attempts to keep these intrinsic and extrinsic factors at optimized levels, throughout the post-harvest handling and storage, through implementation of different technologies [15].

The quality of tomatoes, throughout their post-harvest shelf life, is improved by unique practices, including chemical treatments and edible coatings [16]. Natural zeolite doped with cations of copper and zinc were found good ethylene gas removal agents, and delayed the tomato ripening. As reduced post-harvest life is the outcome of ethylene-induced ripening acceleration [16]. Application of chlorine dioxide during post-harvest storage of tomatoes was found helpful in maintaining quality of tomatoes, by controlling ethylene production [17]. Edible films of gum arabic were proved useful in extending shelf life of tomatoes [18]. Aloe vera gel and chitosan treatments have also been tested on tomatoes, to preserve their shelf life [19]. Application of different calcium-based external treatments have been successfully experimented to observe tomatoes storage quality [20]. Some more experiments on tomatoes, by application of calcium chloride have been reported in previous studies [21, 22].

Customers now give harvested horticultural goods' nutritional content and original quality, more consideration. Technology used to preserve horticultural products is primarily responsible for their eating superiority or ornamental worth. Therefore, it is vitally necessary to apply new practices, to enhance the quality of vegetables, fresh-cut flowers and fruits, after harvest. Some of the typical signs of degrading horticultural goods, include browning and such other discolorations, surface dehydration, tissue softening, progress of off-odors, water loss, as well as microbial degeneration [23]. Recent research has demonstrated that certain low molecular

mass compounds can be used to treat horticultural crops to prolong their post-harvest lives, by controlling a range of growing and evolving processes, and by enhancing their resilience to abiotic and biotic stressful factors [17]. Although several researches have been carried out on packaging of tomatoes for longer storage, storage conditions for delayed ripening and coatings from different sources, to delay the ripening process, but a combination of pretreatment from different chemicals, and then application of some other ethylene scavengers, for controlling the ripening process, along with changes in physicochemical profiles and effects on retention of important phytochemicals in tomatoes during at 30 and 40 days of storage, has been experimented first time. So, this study was conducted in new fashion, by keeping in view the previous experiments upon tomatoes post-harvest treatments, through application of external chemicals in different combinations, to study their impact not only on post-harvest shelf life, but also on the preservation and enhancement of bioactives in tomato fruits.

Materials and methods

Procurement of fresh materials and chemicals for research work

Fresh and of good-quality fully mature green tomatoes (Breaker stage, Roma verity), freshly harvested, were obtained from the local market of Lahore, Pakistan (Sigh pura fruits and vegetables market). Sorting the yellowish, ripe, and damaged fruits from green ones, for best results was performed. Tomatoes with uniform color, shape, size and maturity were considered for study. Reagents and chemicals for different analysis were purchased from Sigma scientific store, Islamabad, Pakistan. Same trade reagents (Sigma Aldrich, Germany) were used for each analysis.

Treatment plan of study

The total tomato fruits were weighed as 60 kg, for experimental analysis, and were sorted carefully. First of all, 10 kg tomatoes were characterized, just after purchase, without any treatment or storage. Control group (untreated tomatoes) was washed with distilled water, and other two treatment groups of tomato fruits were prepared with 2% $CaCl_2$ solution, and two further treatment groups of tomatoes were prepared with 1 mM salicylic solution. First of all, the weighed samples (10 kg tomatoes in each group) were taken and properly washed with prepared 2% $CaCl_2$ solution. The other two weighed samples were properly washed with 1 mM salicylic solution. Tomatoes were kept in each solution for 2–3 min for better results. After that fruits were air dried for 10–15 min and packed in corrugated cartons, with two sachets of $KMnO_4$ in two treatments, and two sachets of $K_2Cr_2O_7$ in two treatments, as treatment plan of the study is presented in Table 1.

Storage period for experimental study

Mature green tomato fruits were stored at ambient temperature, for 30 and 40 days in card board boxes, as presented in Fig. 1. Stored tomatoes were taken for analysis at two time periods, as first experimental analyses of all treatments were performed after 30 days storage by taking half of the packed tomatoes, whereas remaining half tomatoes of each treatment were then taken after 40 days of storage, for analyses. For physicochemical analyses, the samples were subjected to grinding in juicer blender (PS-104, Panasonic, Japan), for juice preparation, which was further used for physical and chemical analyses.

Determination of weight loss percentage in treated tomatoes

The tomato fruits after 30 and 40 days of storage period were checked for weight loss that occurred as a result of application of different chemicals, making comparison with control. The physical mass loss (%) was found using the designated method by Workneh et al. [24]. The percentage weight loss was determined by following the below given formula:

$$\begin{aligned}&\text{Physiological weight loss}(\%)\\&= \text{Wt. of initial} - \text{Wt. of final}\\&\quad/\text{Wt. of initial} \times 100.\end{aligned}$$

Determination of pH

Tomatoes pH was determined by using an alphanumeric pH meter (AH 1264 Benchtop pH meter, Adwa, Hungary) according to method 981.12 of AOAC [25]. First of all, distilled water was used to wash the rod of pH meter, after drying with the tissue papers then immersed in sample for 30–40 s. All the calculations were passed out in triplicates to find out the mean values.

Determination of titratable acidity

Amount of titratable acidity in the samples was measured according to the method no 942.15 of AOAC [25]. Briefly explaining, 1 mL of sample from each treatment was taken in 10 mL measuring glass and diluted with 9 mL distilled water in the wake of including the phenolphthalein marker. It was titrated against 0.1 N sodium hydroxide arrangements till pink end point, and titratable acidity was determined by following formula. Each computation was done three times, and the findings were calculated as means.

Table 1 Treatment plan of the experimental study

Treatments	Chemicals applied	
T_0 (Control)	–	–
T_1	2% $CaCl_2$	$KMnO_4$ sachet
T_2	1 mM salicylic acid	$KMnO_4$ sachet
T_3	2% $CaCl_2$	$K_2Cr_2O_7$ sachet
T_4	1 mM salicylic acid	$K_2Cr_2O_7$ sachet

$$\text{Titratable acidity}(\%) = \text{mL .of titrant used} \times \text{N .of titrant} \times 0.064/\text{sample wt.} \times 100.$$

Determination of total soluble solids (TSS) (Brix)

Total soluble solids (Degree brix) were measured using a digital refractometer (Atago, Japan) under method 932.12 of AOAC [25]. First of all, blank run was done by taking distilled water. After that 2–3 drops of tomato puree samples were dropped in the refractometer hole (brix reading compartment) and clicked the 'Start' button and obtained the sample brix reading. All the calculations were done out in triplicates and the values were acquired.

Estimation of total antioxidant activity (TAA)

Antioxidant activity of mature green, untreated but stored for 30 and 40 days, and all treated tomato samples, was measured spectrophotometrically by following the technique described by Cheng et al. [26], with required changes. Briefly describing, 5 g of prepared juice sample was taken and mixed with 20 mL ethanol in flask. Then shaking process of the mixture for overnight in the shaker was performed, and then the mixture was filtered with filter paper (Whatman No.1). After that, 0.5 mL of filtrate was taken and was added 2.5 mL DPPH in the test tube and placed in the dark for 2 h at ambient temperature. The UV absorbance was measured at 517 nm. The following formula was used to calculate successive antioxidant capacity expressed as (%):

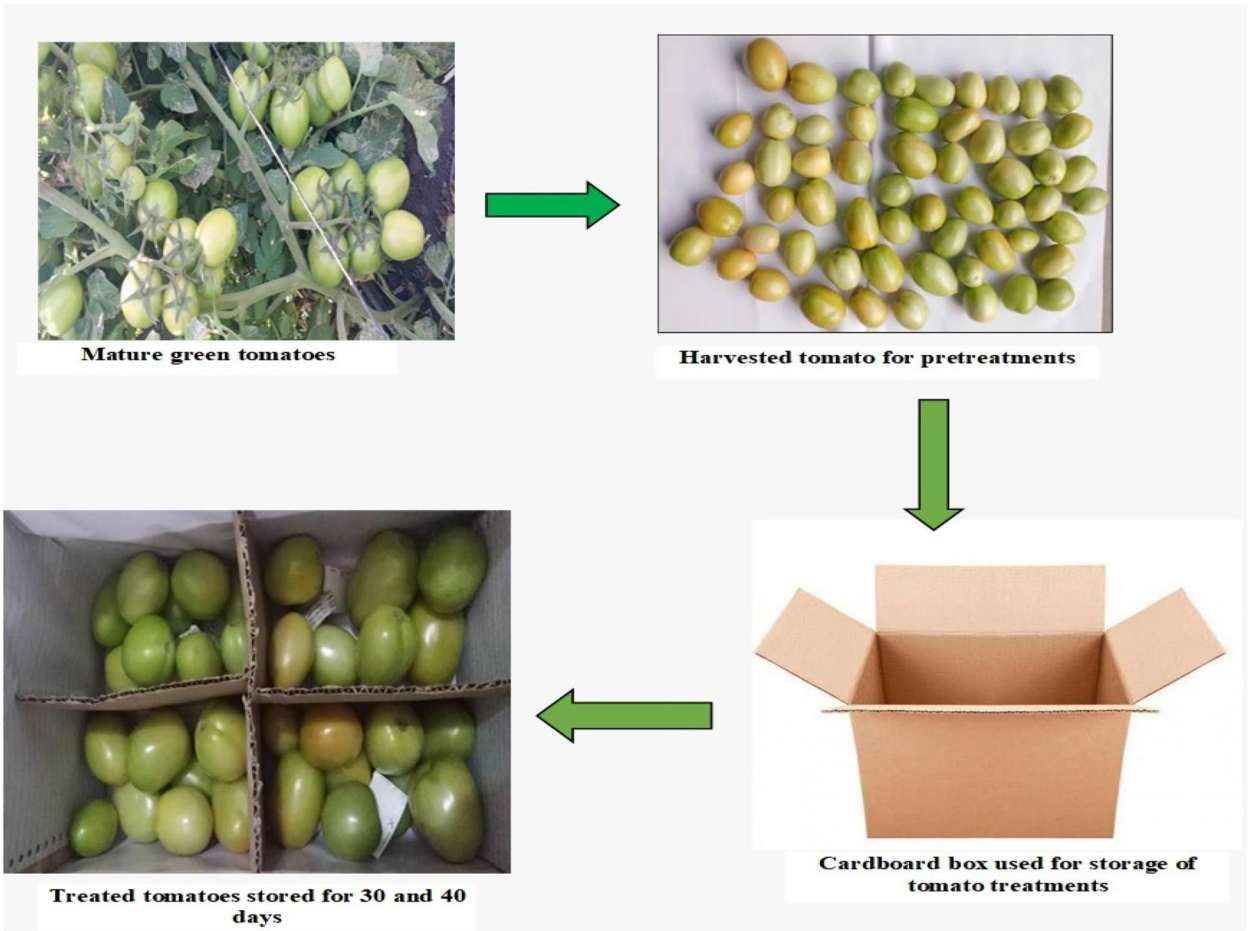


Fig. 1 Mature green tomatoes harvested and stored in card board boxes after treatments

$$\text{Total antioxidant activity}(\%) = \text{Blank abs} - \text{Sample abs} / \text{Blank abs} \times 100.$$

Determination of total phenolic contents (TPC)

The Folin–Ciocalteu reagent-based assay was employed as was described by Molan et al. [27], with minor changes, to estimate the TPC of tomatoes, spectrophotometrically. Gallic acid (in water) was taken for creation of normal calibration curves. Briefly describing, 5 g of sample juice was taken and mixed with 20 mL ethanol in flask. Shaking the mixture overnight in the shaker and then filtered the mixture with filter paper (Whatman No.1). Then 3 mL filtrate was taken and added 1 mL saturated sodium carbonate and 0.5 mL Folin–Ciocalteu reagent in 10 mL volumetric flask and the UV absorbance at 760 nm. The following formula was used to calculate the total phenolic content, and results were articulated as mg of (±) GAE per sample's 100 g:

$$(C \times V/D) \times 100/W,$$

where V is the value calculated from standard calibration curves; D, mL of filtrated used; and W, Wt. of sample.

Determination of total flavonoids contents (TFC)

The aluminum chloride colorimetric technique was used to calculate the TFC of different tomato treatments, as was described by Marinova et al. [28], with some necessary modifications. Starting with 5 g sample dissolving in water in the flask of 25 mL, then was added distilled water up to mark and shaken well. Then the mixture was filtered with paper and 3 mL filtrate was taken and added 1.3 mL methanol, 0.1 mL 10% $AlCl_3$ and 0.1 mL potassium acetate in 10 mL flask. Again, was added distilled water up to mark and again was filtered the mixture with filter paper. The absorbance was determined at 417 nm. Quercetin (in water) was used for making standard calibration curves. The following formula was used to calculate the total flavonoids content and results were articulated as mg of (±) QE per sample's 100 g:

$$(C \times V/D) \times 100/W,$$

where V is the value calculated from standard calibration curves; D, mL of filtrated used; and W, Wt. of sample.

Quantification of vitamin C content

Vitamin C content was measured by spectrophotometrically, adopting the methodology given by Majidi and Al Qubury [29], with required changes. From each treatment of tomato, 3 g of prepared juice samples was dissolved in 25 mL EDTA in a flask. Shaking for 3 h in shaker and then was filtered with Whatman No.1 filter paper. Then 5 mL filtered was taken and then added 1 mL 5% H_2SO_4, 0.5 mL 3% metaphosphoric acid + acetic acid and 2 mL 5% ammonium molybdate in a 25-mL flask. At the end, the absorbance was measured at 760 nm. Ascorbic acid was taken for making standardization curves. The following formula was used to calculate the total vitamin C content and result was articulated as mg of ascorbic acid equivalent (AAE) per 100 mg of sample:

$$X = c \times V \times f/m \times 100/1000,$$

where X is the content of the vitamin C in the specimen, mg/100 g; V, volume of specimen solution used in the fluorescent, mL; C, mass cons. of vitamin C of the specimen solution from standard curve, µg / mL; m, specimen mass, g; and f, specimen dilution factor.

Determination of lycopene contents

All fresh mature green, stored without any treatment, and treated samples, were tested by using the acetone petroleum ether extraction method, as was earlier described by Szabo et al. [5]. Briefly describing, 5 g samples was taken in the flask with 10 mL acetone. After shaking the mixture for 30 min in the shaker and transferred the extract to a funnel enclosing 15 mL petroleum ether and assorted gently. Two phases were formed in the mixture, transferred the lower phase (acetone + sample) to another funnel and the upper phase (petroleum ether) extract containing the carotenoid pigments to a yellowish-brown colored bottle. The lower phase mashed in pestle and mortar until the residue was colorless. The lower phase was discarded and petroleum ether extract filter with filter paper-added with small quantity of anhydrous sodium sulfate (Na_2SO_4). Then transferred the filtered to a 50-mL volumetric flask and diluted up to mark with petroleum ether. At the end diluted an aliquot 1 mL to 10 mL with petroleum ether and the absorbance was measured at 503 nm. The lycopene contents of the samples were calculated as mg of lycopene per 100 g of sample using following formula:

$$\begin{aligned}\text{mg of lycopene per100g} &= 3.1206 \times \text{OD of sample} \\ &\times \text{volume made up(50ml)} \\ &\times \text{Dilution(50ml)} \times 100/1 \\ &\times \text{Wt. of sample} \times 1000.\end{aligned}$$

Statistical analyses of the results

All analyses were performed in triplicate to obtain triplicate results, and the results were reported as means and standard deviations. The one-way ANOVA and completely randomized design (CRD) with 2-factorial design was used for the statistical analysis. Means were separated by

least significant difference (LSD) at $p \leq 0.05$ using Statistix 8.1® software, Tallahassee, U.S. State of Florida. Guidelines from the procedures of Steel et al. [31] were taken for statistical analyses.

Results and discussion

Characterization of mature green tomatoes, before chemical treatments and storage

Physicochemical and phytochemical characterization of mature green (breaker stage) tomatoes, which was performed just after acquiring the tomatoes from the market, is presented in Table 2, from where it can be seen that at this stage tomatoes were good source of phenolic and flavonoid contents, vitamin C and antioxidant activity, as values of these important parameters are shown in Table 2. Titratable acidity, pH and TSS of tomatoes were recorded as 0.68 ± 0.02%, 3.85 ± 0.03 and 4.03 ± 0.50, respectively. Presence of recognizable amounts of phenolic and flavonoid compounds, and vitamin C, in tomatoes, might have contributed towards total high antioxidant activity of this fruit. As climacteric fruits, tomatoes reach their maximal respiration and ethylene production during the beginning of ripening. Tomato fruits go through ripening, a complicated developmental process involving the coordinated regulation of various physiological and biochemical changes that define flavor, color, texture, and scent, towards the conclusion of fruit development, when seeds are mature and ready for dispersal. The beginning and development of tomato ripening are often accompanied by changes in the pericarp's outer color, which are a result of the buildup of carotenoid and flavonoid pigments [8]. The total phenolic and flavonoid content in mature green and fully ripened tomatoes can differ during storage depending on many factors, such as the fruit species and cultivar, and temperature, climatic, and environmental conditions throughout the growth period [19].

These results of characterization of mature green tomatoes were in line with the findings of Mun et al. [61], when metabolites and phytochemicals of different varieties of tomatoes were analyzed. As tomatoes turn from mature green to ripen red stage, lycopene contents and pH increases, whereas, titratable acidity and TSS decreases, but cultivars used, cultivation conditions and atmospheric factors strongly influence these parameters [3]. Findings of Mishra and Prakash [21] were also found closely related with current ones, as they characterized different varieties of tomatoes at different maturity stages, for their chemical composition. Although processing tomatoes may reduce their vitamin C concentration, fresh tomatoes are still a significant source of the vitamin. While tomato fruit developing from green to red seems to boost vitamin C concentration, once tomatoes are harvested and kept, more maturity and light exposure have been linked to a reduction in vitamin C level [7]. Lycopene is a carotenoid responsible for giving tomatoes their red pigmentation, whereas, phenolic compounds are important phytochemicals with powerful antioxidant activity present in most fruits and vegetables. In tomatoes, some of the phenolic compounds are flavonoids, phenolic acids, and tannins. Phenolic contents and lycopene in tomatoes is significantly conditioned by farming techniques, genotype, and storage [5, 7] In addition to the non-edible green tissues of this plant, which have been found to contain significant bioactives, the mature green tomato fruit is a well-documented source of dietary antioxidants like carotenoids, vitamins, and phenolic compounds [6]. The post-harvest survivability of fruits, with intact phytochemicals and optimum physicochemical characteristics for a longer period during transportation and storage, gives a boost to farmers. Therefore, harvesting at mature green stage and then controlled ripening through application of different chemical and biological technologies could prove beneficial for tomatoes [19].

Weight loss, pH and titratable acidity of different treatments of tomatoes

The ethylene scavengers were studied for delaying the ripening processes and retaining the post-harvest quality of tomato fruits. Different analyses were done to analyze the samples or to ensure the correct direction. When storage time extended, weight loss percentage rose. One of the main reasons, why fruit quality degrades is weight loss. It was observed that one of the most important causes of weight loss was water loss, due to respiration and evaporation. It was seen that weight loss occurred steadily regardless of the effects of ethylene scavengers,

Table 2 Characterization of mature green tomatoes, before chemical treatments and storage

Physicochemical and phytochemical characters	Values
pH	3.85 ± 0.03
Titratable acidity	0.68 ± 0.02%
Total soluble solids (TSS)	4.03 ± 0.50
Total antioxidant activity (TAA)	47.49 ± 0.35%
Lycopene content	3.13 ± 0.02 mg/100 g
Total phenolic content (TPC)	42.56 ± 0.42 mg GAE/100 g
Total flavonoid content (TFC)	11.23 ± 0.10 mg QE/100 g
Vitamin C	32 ± 0.35 mg/100 g

Values are presented as means ± standard deviations, where, GAE; gallic acid equivalent, QE; quercetin equivalent

and it was further assumed that weight loss increased with time for all control as well as treated samples. As presented in Table 3, when compared to treated individuals, T_0 showed the highest estimation of weight loss% (17.93 ± 0.20%), while T_1 showed the lowest estimation (6.86 ± 0.14%), after 40 days storage.

The pH of all treated samples significantly decreased from 30 to 40 days. The lowest value of pH was observed in T_4 (4.73 ± 0.17), while the highest pH value was found in T_0 (4.85 ± 0.13) after 40 days of storage; whereas, after 30 days, change in pH of all treatments was neglectable. The effect of storage period on the pH of tomato described that, pH value gradually decreased with the passage of time as shown in Table 3. The titratable acidity of all treated samples significantly decreased, whereas, highest decrease was observed in control tomatoes. On the other hand, application of ethylene scavengers slowed down the decrease in titratable acidity, during 30 and 40 days of storage. The influence of storage time on the tomato's titratable acidity showed that, highly significant decrease in acidity was seen in tomatoes without any treatment, and then with time, the acidity slowly decreased, due to the chemical preservatives applied. In fruit and vegetables, the titratable acidity and pH are important organoleptic components [32]. Sourness of tomato fruits is because of acids like maleic acid and citric acid presence [33]. Treatments of harvested tomatoes, have proved useful in controlling the ripening process, by mediating the ethylene production, due to which pH and acidity were maintained by the earlier experiments of Asiamah et al. [30].

Total soluble solids and titratable acidity contributes fruit sweetness and acidity, and thus they give fruit, flavor and quality characteristics [34]. Higher concentration of organic acids caused lower pH value; however, the environmental factors significantly change these parameters to prevent pathogenic development, hence minimizing post-harvest loss [35]. In the fruit, the acid concentrations decline with maturity, due to rise in pH and decrease in titratable acidity. Ripening of tomato fruit is associated with change in color and flavor factors, such as acidity, aroma, and soluble solid concentrations. Use of different chemical-based coatings, films, sheets and layers of fruits have been proved useful in maintaining the quality of fruits in terms of preservation of phytochemicals and bioactives [36].

Potassium permanganate scrubbers in most cultivation items are one of the most generally utilized advances to evacuate the ethylene. Need is to give a layout of the most widely recognized materials utilized as $KMnO_4$ bolsters on post-harvest treatment and their impacts on quality attributes during the capacity of different new produce. Activated carbon, initiated alumina, silica gel, vermiculite, zeolite and mud are the most widely recognized ingredients, that have been as a help of $KMnO_4$-based ethylene scrubbers [1].

Reduced post-harvest life is the outcome of ethylene-induced ripening acceleration. The innovative copper–zinc based ethylene scavenger adsorption capability supported by natural zeolite and its scavenging effects on tomato quality over their post-harvest shelf life were studied in an experiment. For both zeolite treatments at 9.5 days major concentration peaks appeared. Modified zeolite during the first 6 days delayed tomato respiration, and adsorbent was able to shift the peak respiration compared to control treatment in time [16], just as was observed in current experiments. The edible coating on fruits and vegetables including tomatoes maintains the activity of organic acids and reduce the respiration rate [37]. The fact that weight loss had a consistent slope independent of the impact of the ethylene scavenger and that the weight loss percentage increased during storage were both noted by the experiments of Guillen et al. [38]. However, 1-MCP reportedly decreased the rate of weight loss during shipment times, according to Cliff et al. [39]. In the current investigation, the weight loss of the control samples was substantially greater than that of the other treated fruits during each storage period. As a result, in terms of long-term economic effects, KMnO4 storage periods may have a greater positive extra effect.

Table 3 Weight loss, pH and titratable acidity of different treatments of tomatoes

Treatment	Weight loss (%)		pH		Titratable acidity	
Storage (days)	30	40	30	40	30	40
T_0	7.06 ± 0.16^{df}	17.93 ± 0.20^{a}	4.15 ± 0.13^{a}	4.85 ± 0.13^{b}	0.33 ± 0.10^{bc}	0.21 ± 0.1^{c}
T_1	3.76 ± 0.15^{h}	6.86 ± 0.14^{e}	4.13 ± 0.13^{a}	4.78 ± 0.16^{b}	0.53 ± 0.1^{ab}	0.38 ± 0.1^{b}
T_2	3.90 ± 0.15^{h}	7.29 ± 0.14^{d}	4.12 ± 0.13^{a}	4.75 ± 0.16^{b}	0.49 ± 0.14^{abc}	0.49 ± 0.05^{a}
T_3	4.63 ± 0.14^{g}	8.66 ± 0.15^{c}	4.15 ± 013^{a}	4.75 ± 0.14^{b}	0.45 ± 0.16^{bc}	0.36 ± 0.08^{b}
T_4	4.96 ± 0.15^{f}	9.15 ± 0.14^{b}	4.15 ± 0.13^{a}	4.73 ± 0.17^{b}	0.41 ± 0.18^{bc}	0.32 ± 014^{b}

Different letters indicated significant differences between treatments ($p < 0.05$). Treatments: T_0, Control; T_1, treated with 2% $CaCl_2 + KMnO_4$ sachet; T_2, treated with 1 mM salicylic acid solution and $KMnO_4$ sachet; T_3, treated with 2% $CaCl_2$ solution and $K_2Cr_2O_7$ sachet; T_4, treated with 1 mM salicylic acid solution and $K_2Cr_2O_7$ sachet

Application of 1-MCP delayed the onset of ripening, without affecting the firmness, weight loss and color of the tomatoes stored at different temperatures for different time period [40].

For validation of current findings some other relevant examples of controlling the ripening process of tomatoes have also been observed and discussed, as, Fashanu et al. [18] performed experiments to expand shelf life of tomato with gum arabic as a non-toxic coating, and results indicated that the control had faster rate of softening and rapid weight loss, while tomatoes coated with gum arabic slowed down the ripening process and maintained their nutritional quality up to 20 days. Their results showed that gum arabic is an eatable coating of tomatoes may be utilized. Khatri et al. [19] used aloe vera and chitosan to coat tomatoes, coated tomatoes were additionally indicated the high cell reinforcement exercises during cold stockpiling contrasted than control one. Aloe vera and chitosan covering showed the best productivity in deferring maturing process and expand the time span of usability of tomatoes, by minimizing weight loss, as long as, 42 days. Another study proved the role of active coatings and packaging's on post-harvest quality of fruits when compared to tomatoes packed in chitosan film and the control, tomatoes packaged in titanium dioxide film underwent fewer quality changes. According to the findings, when exposed to UV light, the titanium dioxide film showed ethylene photodegradation activity, which delayed the ripening process and quality changes in the tomatoes [41].

Conducting similar fashion experiments with supportive findings, Barua et al. [33] after experimental results reported that the ripening process of tomatoes was inhibited, treated with gibberellin acid and ethanol, and also retained the food quality. On the other hand, salicylic acid and maleic acid were unsuccessful to postpone the tomatoes maturing. Most effectual delaying in the process of ripening was linked with handling of tomatoes with one methyl cyclopropene. Haleema and Rab [20] have reported that post-harvest treatments of tomatoes, included calcium sources (calcium chloride, calcium gluconate, calcium lactate, and calcium sulphate) in two storing conditions: 32 ± 2 °C and 10 ± 2 °C, with varying Ca concentrations (0, 0.25, 0.5, and 0.75%). The findings showed that fruits stored at room temperature had a greater incidence of soft rot and black rot. Low temperature storing increased cell wall ion leakage, cell membrane ion leakage, and green mold incidence. Calcium chloride also had a greater Ca content than calcium carbonate. However, calcium chloride had reduced levels of ion leakage through cell walls and membranes, thus minimizing the weight loss and decaying of tomatoes.

According to the reports of Mohammed et al. [42], the pH of ripe tomato fruits may be greater than 4.6. The quality and storing life of tomato fruits were found to be extended by guar gum-based coatings, combined with extracts from various condiments. When tomato fruits were covered with guar gum + ethanolic extracts, the rate of change in total soluble solids, titratable acidity, and pH was found to be less than that of uncoated and treated control, as well as coatings enhanced with methanolic extracts [43]. Hakimi et al. [22] made experiments to understand the effect of post-harvest treatments and harvesting stages on the shelf life and sensory quality of tomato fruits and reported that dipping in 6% $CaCl_2$ was useful in extending the shelf life of tomatoes for many days, which probably was due to minute variations in pH and acidity of fruits, the factors responsible for happening of various biochemical reactions in fruit, which ultimately decide the ripening and shelf life of fruits.

The fact that the acidity of the treated tomato fruits in this study was reduced more slowly, than that of the control tomatoes, suggests that the ethylene scavenger materials, which are in charge of reducing respiration rate and regulating pH, play a key part in the process. This result may be attributable to the ethylene scavengers' impact on the biochemical state of tomato fruit, where they decreased metabolic activity and respiration rate [44, 45]. Reduction in weight loss and acidity for even 92 days with the application of calcium chloride and potassium permanganate, experimented by Sammi and Masud [46] was also found supporting results for current investigations. Similar experimental results showed that 2% calcium chloride and 800 ppm boric acid were efficient in preserving the pH and titratable acidity of preserved tomatoes, according to Mujtaba et al. [47]. Use of potassium permanganate along with hypobaric pressure was also tested on tomatoes, stored for 21 days, by Muhammad et al. [48], with optimum retention of quality, which was credited to maintained pH and acidity.

TPC, TFC and vitamin C of different treatments of tomatoes

Table 4 presents the results of the mean values for the tomato's total phenolic contents (TPC). Under storage conditions, there was a significant difference between the treatments. After 30 and 40 storage days of treatments, the TPC of every sample significantly rose, except control. In terms of TPC, T_1 had the highest concentration (41.30 ± 0.58 mg GAE/100 g), whereas T_0 had the lowest concentration (17.11 ± 0.09 mg GAE/100 g), after 40 days storage. According to the research on the impact of storage time on tomato fruits TPC, treated samples' TPC steadily rose with time, except in the control

samples, in which TPC were decreased from 33.42 ± 0.2 to 17.11 ± 0.09 mg GAE/100 g. From the values presented in Table 4 it was evident that application of ethylene scavengers not only preserved tomatoes, but also caused increment in TPC of tomatoes.

From Table 4, it was evident that the total flavonoid contents (TFC) of all treated samples significantly increased, except the control, from days 30 to days 40. The TFC ranged from 3.11 ± 0.1 to 5.60 ± 0.2 mg QE/100 g, after 40 days study. The highest mean value of TFC was noticed in T_1 (5.90 ± 0.20 mg QE/100 g). Meanwhile, the lowest mean value was detected in T_0 (3.11 ± 0.1 mg QE/100 g). However, the treated samples concentrations of TFC were increased frequently during storage time, from 30 to 40 days, due to attaining the ripened stage, and in T_0 concentration of TFC decreased frequently, which might be due to spoilage. From day 30 to day 40, the vitamin C level of all treated samples was significantly rose, as was evident from the values given in Table 4, but in control tomatoes, this level was decreased with storage. From the results it was evident that T_1 had the highest concentration (18.27 ± 0.2 mg/100 g) of vitamin C, followed by T_2 (18.03 ± 0.15 mg/100 g), and T_0 had the lowest concentration (13.70 ± 0.2 mg/100 g). The effect of storage time on tomatoes vitamin C concentration revealed that, in the case of treated samples, vitamin C steadily rose with time. Natural loss of vitamin C during storage of non-treated tomatoes was controlled by application of tomato nutrients, which are aided by the phytochemical compositions. Tomatoes are a component of a balanced diet because they include a variety of macronutrients, including vitamins, minerals, amino acids, and lipids. Tomatoes have lower concentrations of phytosterols than other fruits and vegetables, which may help prevent heart disease and colon cancer. Presence of phenolics, flavonoids and their capacity to act as antioxidants make tomatoes a trustworthy fruit [45, 46].

Use of low molecular mass compounds and gaseous has been proved best way to expand shelf life, and maintain quality attributes during storage of rapidly deteriorating horticultural products. The compounds including carbon monoxide, carbon dioxide, and chlorine dioxide, calcium chloride and salicylic acid could delay senescence process in agricultural items through various components, for example, repressing ethylene biosynthesis, managing action of cancer prevention agent chemicals, delaying browning and suppressing respiration rate. During the senescence these compounds regulate the expression of genes, including ethylene biosynthesis related genes, cysteine protease gene, chlorophyll degradation-related genes and lipoxygenase genes [23]. The treatments of tomatoes with 2% calcium chloride and 800 ppm boric acid, as tested by Mujtaba et al. [47] also resulted in higher values for total phenolic content, ascorbic acid, and total antioxidant content. According to the findings, tomatoes can be treated post-harvest with 2% calcium chloride to maintain their functional qualities and increase their shelf lives.

Extending storage life with delayed ripening was also observed, when apple pomace was added to a polyvinyl alcohol matrix with a concentration of 1, 5, 10, and 30% (w/w) to create active antioxidant food packaging sheets. Thermodynamic, structural, mechanical, and functional analysis in its entirety was performed. The research's results demonstrated that adding apple pomace to polyvinyl alcohol films increased the overall phenolic content and antioxidant properties of fruit, also delaying the decaying process [49]. The mean value of total phenolic content in tomatoes was found to be at its lowest point after 30 days of storage and its highest point after 40 days of storage, with a value of 22.14 mg GAE/100 g [50]. Studies have revealed that all the treated tomato fruits showed increment in total phenolic content due to controlled ripening process [51].

Conducting experiments just in line to our research, Toor and Savage et al. [52] concluded that the total flavonoids contents and the soluble antioxidant activity of tomato showed slight increases during storage time.

Table 4 TPC, TFC and vitamin C of different treatment tomatoes

Treatment	TPC (mg GAE/100 g)		TFC (mg QE/100 g)		Vitamin C (mg/100 g)	
Storage (days)	30	40	30	40	30	40
T_0	33.42 ± 0.20^{d}	17.11 ± 0.09^{i}	5.19 ± 0.20^{cd}	3.11 ± 0.10^{h}	17.90 ± 0.20^{b}	13.70 ± 0.20^{f}
T_1	21.80 ± 0.53^{h}	41.30 ± 0.58^{a}	4.10 ± 0.20^{g}	5.90 ± 0.20^{a}	16.03 ± 0.20^{d}	18.27 ± 0.20^{a}
T_2	22.95 ± 0.02^{g}	37.50 ± 0.017^{b}	4.21 ± 0.20^{g}	5.60 ± 0.20^{b}	15.80 ± 0.20^{d}	18.03 ± 0.15^{ab}
T_3	24.09 ± 0.02^{f}	35.17 ± 0.02^{c}	4.40 ± 0.20^{fg}	5.40 ± 0.20^{bc}	15.37 ± 0.20^{e}	17.43 ± 0.10^{c}
T_4	25.00 ± 0.20^{e}	33.85 ± 0.12^{d}	4.71 ± 0.20^{ef}	4.91 ± 0.20^{df}	15.07 ± 0.20^{e}	17.27 ± 0.20^{c}

Different letters indicated significant differences between treatments ($p < 0.05$). Treatments: T_0, Control; T_1, treated with 2% $CaCl_2 + KMnO_4$ sachet; T_2, treated with 1 mM salicylic acid solution and $KMnO_4$ sachet; T_3, treated with 2% $CaCl_2$ solution and $K_2Cr_2O_7$ sachet; T_4, treated with 1 mM salicylic acid solution and $K_2Cr_2O_7$ sachet. TPC; total phenolic content, TFC; total flavonoid content, GAE; gallic acid equivalent, QE; quercetin equivalent

However, ethylene scavengers led to significant increase in total flavonoids contents and antioxidant activity in each treated samples, during storage relative to the control tomato fruits, which was due to reduced loss of bioactives. Similar findings were also present in the work of Kaewklin et al. [41], when they monitored phytochemicals loss in chitosan and titanium dioxide coated tomatoes. Results of Naeem et al. [43] also witnessed the increment of bioactive compounds in tomatoes protected with active coatings, as these protective films also control the gasses entry and exit from the fruits, thus controlling metabolic reactions, responsible for ripening and decay of fruits.

Vitamin C is water soluble vitamin and was 1st known to prevent scurvy disease and it is largely used in therapy as an anti-infection of cells. Vitamin C has to be supplemented mainly through fruits, vegetables and vitamin C tablets. Many health benefits such as antioxidant, anticarcinogenic, anti-atherogenic and prevent cold, etc., has been ascribed to vitamin C [53]. Vitamin C is a heat and light sensitive molecule, it may be lost during cooking, processing and even at long-term storage of foods [54]. Active packaging of fruits has proved useful in protecting vitamin C loss [41]. According to the experimental results of Lee and Kader [55], vitamin C contents of tomato fruits showed significant decrease during storage. But vitamin C value of the treated tomatoes was higher than that of the control fruits. Watkins [56] concluded that ethylene scavenger (1-MCP) led to decreased ethylene content and increased vitamin C content, validating the outcomes of current study, as heat, light and temperature sensitive vitamin C, degrades rapidly with increased respiration and decaying of untreated tomatoes during storage.

TSS (°Brix), TAA and lycopene contents of different treatments of tomatoes

The effect of different treatments on TSS (°Brix) showed that TSS of all treated samples significantly increased, while of non-treated samples, decreased. Highest °Brix was found in T_4 (4.93 ± 0.10), followed by T_3 (4.87 ± 0.2), while the lowest value was noticed in T_1 (4.43 ± 0.2), after 40 days. The impact of storage on °Brix of treated tomatoes indicated that the TSS increased as storage days increased, as presented in Table 5.

The total antioxidant activity (TAA) of all treated samples increased from days 30 to days 40, as compared to control. The TAA ranged from 22.00 ± 0.2 to 33.80 ± 0.52%, as is shown in Table 5. The highest mean value of TAA was detected in T_1 (33.80 ± 0.52%). Meanwhile the lowest mean value of TAA was noticed in T_0 (22.00 ± 0.2%), during 40 days storage. However, in T_0, concentration of antioxidant compounds was also decreased frequently due to spoilage during longer storage, and in treated samples, antioxidant activity increased significantly during storage time from 30 to 40 days, due to attaining the ripening stage, as shown in Table 5. On the other hand, lycopene contents of all treated and control samples significantly increased from day 30 to day 40 during storage, as can be seen from Table 5. The highest value of lycopene content was noticed in T_0 (9.76 ± 0.2 mg/100 g) after 40 days, due to fully ripened and spoiled tomatoes as compared to treated samples, while the lowest value was found in T_1 (4.82 ± 0.20 mg/100 g) after 30 days storage. Effect of storage period on the lycopene content of tomatoes revealed that, in the start, decrease in lycopene content was due to slight ripening or under ripening conditions, and then it increased with the passage of time, however, lowest lycopene contents exhibited by T_1 even after 40 days, showed that use of these ethylene scavengers moderated the tomato ripening very well during storage. Lycopene content increased as fruit got matures, whereas, uncontrolled ripening cause robust increase in carotenoid contents.

In fruits and vegetables, the total soluble solids are considered a useful index of fruit maturity and quality, and generally increase with the ripening stage [57]. Total soluble solid contents also play a part to the aroma, taste and quality of the food [58].

Our findings of present study correspond with a previous report, which also showed a gradual reduction in the total acidity and a gradual increase in total soluble solids, emphasizing that a slower ripening process had occurred in our experiment with the ethylene scavengers [59]. In their experiments, Melin et al. [16] observed the greatest delay of color development in tomatoes induced by modified zeolite, while natural zeolite promoted the red color. Furthermore, lycopene synthesis was significantly higher by the use of natural zeolite, as compared to modified zeolite in stored tomatoes. Natural zeolite doped with cations of copper and zinc can also be applied as ethylene gas removal agents, delaying the tomato ripening.

Use of some other natural and chemical compounds had also been reported involved in controlling the ripening process of tomatoes, as was experimented in our study. Fashanu et al. [18] coated tomatoes with gum arabic at different concentrations, and compared with non-treated ones, and reported antioxidant activities ranged from 66.26–192.1 µg/mg, contents of β carotene were 1.78–23.8 mg/g and the lycopene content ranged from 0.77–17.6 mg/g. These variation in results was due to controlled and uncontrolled ripening of tomatoes, during storage. Discussing one more relevant experimental research with in line findings, it was observed that,

Table 5 TSS, TAA and lycopene contents of different treatment tomatoes

Treatment	TSS (°Brix)		TAA (%)		Lycopene contents (mg/100 g)	
Storage (days)	30	40	30	40	30	40
T_0	4.60 ± 0.20^{bc}	4.43 ± 0.20^{cd}	32.00 ± 0.20^{c}	22.00 ± 0.20^{h}	7.06 ± 0.20^{b}	9.76 ± 0.20^{a}
T_1	4.07 ± 0.20^{e}	4.60 ± 0.14^{bc}	29.97 ± 0.15^{d}	33.80 ± 0.52^{a}	4.82 ± 0.20^{g}	6.11 ± 0.12^{e}
T_2	4.27 ± 0.20^{de}	4.70 ± 0.10^{abc}	29.00 ± 0.10^{e}	33.00 ± 0.10^{b}	5.15 ± 0.12^{f}	$6.33 \pm 0.20d^{e}$
T_3	4.43 ± 0.20^{cd}	4.87 ± 0.20^{ab}	29.00 ± 0.20^{e}	28.00 ± 0.10^{f}	5.31 ± 0.10^{f}	6.59 ± 0.20^{cd}
T_4	4.50 ± 0.10^{cd}	4.93 ± 0.10^{a}	28.00 ± 0.10^{F}	26.97 ± 0.06^{g}	5.45 ± 0.22^{f}	6.86 ± 0.20^{bc}

Different letters indicated significant differences between treatments ($p < 0.05$). Treatments: T_0, Control; T_1, treated with 2% $CaCl_2 + KMnO_4$ sachet; T_2, treated with 1 mM salicylic acid solution and $KMnO_4$ sachet; T_3, treated with 2% $CaCl_2$ solution and $K_2Cr_2O_7$ sachet; T_4, treated with 1 mM salicylic acid solution and $K_2Cr_2O_7$ sachet. TSS; total soluble solids, TAA; total antioxidant activity\

Khatri et al. [19] used aloe vera and chitosan-based coating of tomatoes, and reported increment in TPC, antioxidant activity and lycopene contents of stored tomatoes, with applied coatings. Increment in lycopene contents of coated tomatoes, a contradictory result to our study, was possibly due the difference in the ethylene scavenging capacities of the components applied in both studies.

Ali et al. [60] concluded that the post-harvest ripening process and the DPPH radical-scavenging activity have a positive correlation. According to their results there was a premature increase in the DPPH radical-scavenging activity in the treated tomato fruits, which may have been due to the fact that treated tomatoes ripened more slowly than the untreated tomato fruits. This was corroborated that, tomatoes coated with gum arabic exhibited a delay in the physiological and biochemical changes related to storage, just as in current experimental design, same was done by the applied chemicals.

According to the findings of present study, ethylene scavenger's treatments reduced lycopene content during storage, as $KMnO_4$ and $K_2Cr_2O_7$ delayed the onset of lycopene increase and fruit softening. Similar delayed ripening, as was measured by lycopene contents, was observed in tomatoes applied with 1 MCP and stored up to 24 days [40]. Cliff et al. [39] reported that 1-MCP resulted in delayed lycopene accumulation in tomato fruits. Results of the present study confirmed that $KMnO_4$ was far superior to $K_2Cr_2O_7$ in delaying lycopene accumulation. However, it was reported that ethylene gas had no significant effect on total lycopene content in tomato fruit.

In order to extend their shelf life, two well-known tomato cultivars from India, that were in the mature green, breaker, and mature red stages were treated with 1, 2, and 5% calcium chloride, and kept at 5, 10 and 15℃. The progressions in non-enzymatic cell reinforcements (ascorbic corrosive, carotenoids, lycopene and all out phenolic substance) were recorded as long as 21 days of capacity. Results indicated a direct expanded in the ascorbic corrosive substance when treated with $CaCl_2$ (~ 40%) at 5℃, while carotenoids (25%) and lycopene content (45%) have indicated similar moderation when treated with 1% calcium chloride fixation [21]. Experiments of Asiamah et al. [30] also provided findings in line with the current ones, as lycopene contents, ascorbic acid, TSS and antioxidant activity were maintained during storage of treated tomatoes, as compared to untreated ones, which possibly was due to controlled ripening process provided by coatings applied.

Melin et al. [16] investigated the impact of ethylene scavenging on tomato quality during post-harvest shelf life, using a novel copper–zinc based ethylene scavenger adsorption capacity supported by natural zeolite. Due to the increased respiration and rate of ethylene formation, both zeolites after 1 week of storage of tomatoes, increased the decomposition of organic acids and the portion of soluble solids. The greatest delay of color development in tomatoes was induced by modified zeolite, while natural zeolite promoted the red color. They recorded lycopene synthesis significantly higher by the use of natural zeolite, as compared to modified zeolite in stored tomatoes. Reduced post-harvest life is the outcome of ethylene-induced ripening acceleration. Sugars are an important constitute of tomato fruit. This important component determines the sweetness and influence the overall tomato flavor. Tomato sugars mostly comprised glucose, fructose and sucrose in trace amount. In fruits, organic, amino acids, and soluble pectin are the soluble materials also found in tomato fruit juice. The lengthier the time fruit respiration, the greater the rate of acid and sugar consumption because both attributes are the respiration substrate [16]. Similar to our study, experiments by Sammi and Masud, [46] provided in line findings for TSS of tomatoes, applied with calcium chloride and potassium permanganate as ethylene scavengers for extending the shelf life of tomatoes.

Conclusion

Tomatoes are an excellent source of nutrients that promote health, including the vitamins C, lycopene, phenolics and flavonoids, thanks to their widespread intake. According to this study, post-harvest treatments had a substantial impact on the following factors; pH, titratable acidity, TSS, vitamin C content, total flavonoids, total lycopene, total phenolic content, weight loss, and shelf life. Our findings showed that during the storage period, the 50 g $KMnO_4$ sachet + 2% $CaCl_2$ exerted more superior effects, than the other treatments, and extended the shelf-life of tomato fruits up to 40 days. Phytochemical analysis revealed that TPC, TFC and vitamin C in T_1 were found highest (41.30 ± 0.58 mg GAE/100 g, 5.90 ± 0.20 mg CE/100 g, and 18.27 ± 0.20 mg/100 g, respectively) after 40 days storage. Lycopene contents were observed highest (9.76 ± 0.2 mg/100 g) in T_0, due to uncontrolled over ripening, whereas T_1 presented lowest lycopene contents (6.11 ± 0.12 mg/100 g), due to fully controlled ripening during 40 days. After 40 days, TAA was found highest (33.80 ± 0.52%) in T_1. It may be inferred that the study's findings will be helpful, particularly with regard to medium- and long-term storage, quality control, transportation, and marketing. The majority of fresh horticultural products are extremely perishable, and ethylene frequently contributes significantly to the ripening and senescence process. The shelf life of these commodities may be increased by lowering the ethylene concentrations in the area by slowing down metabolic activities. To preserve tomatoes, particularly to keep these fruits in the same stage of maturity during storage without going bad, the application of the suggested chemicals could be used in safe manners. The impact of further promising ethylene scavenger therapies on the shelf life, quality, and safety of tomatoes in the agricultural supply chain is also recommended for future research.

Recommendations

There is a rising demand for high-quality products in both forms of consumption, including those with organoleptic and functional quality, the latter of which is defined as the ability of a product's consumption to avoid specific diseases. Studies on toxicological effects produced as a result of chemical agents' application on fruits, should be conducted on laboratory scale, before commercialization of such implementations, as product safety must be the first priority of the food processor. Further industrial application of these experiments can be demonstrated for the wellness of food producers, sellers, stockers and processors.

Acknowledgements

This research paper is a part of MPhil dissertation of Muhammad Zakriya, submitted to Higher Education Commission (HEC) of Pakistan under title "Effect of Different Types of Ethylene Scavengers on the Post-Harvest Quality of Tomatoes (*Solanum lycopersicum*)". This scientific research work was carried out in Post-harvest section of University of Engineering and Technology, Lahore, Pakistan. Some of the analyses were performed in Food science department, university of Sargodha, Pakistan. All authors participated scientifically in the preparation of this scientific paper and gave their consent for its publication.

Author contributions

AH, conceptualization; FY and AAM, data curation; MZ, formal analysis; FIG and HF, funding acquisition, investigation; RN and KK, methodology, project administration; MZ, resources; AR, software; TK, supervision; PF and SY, validation, visualization; AH and AAM, roles/writing—original draft; AH and SAK, writing—review and editing.

Funding

No funds in any form, from any source were availed for this research work.

Availability of data and materials

Data relevant to this study can be provided upon request.

Declarations

Ethics approval and consent to participate

This study does not involve any experiments on humans and animals.

Consent for publication

Not applicable.

Competing interests

The authors have declared no conflicts of interest for this article.

Author details

[1]Department of Chemistry, University of Engineering and Technology, Lahore, Pakistan. [2]Institute of Food Science and Nutrition, University of Sargodha, Sargodha, Pakistan. [3]Punjab Food Authority, Lahore, Pakistan. [4]Department of Food Science and Nutrition, Faculty of Agriculture, Food and Environment, Sana'a University, Sana'a, Yemen. [5]PMAS-Arid Agriculture University, Rawalpindi, Pakistan. [6]Department of Food Science, Faculty of Agriculture, Zagazig University, Zagazig, Egypt.

Received: 10 April 2023 Accepted: 30 August 2023
Published online: 12 September 2023

References

1. Alvarez-Hernández MH, Artés-Hernández F, Ávalos-Belmontes F, Castillo-Campohermoso MA, Contreras-Esquivel JC, Ventura-Sobrevilla JM, Martínez-Hernández GB. Current scenario of adsorbent materials used in ethylene scavenging systems to extend fruit and vegetable postharvest life. Food Bioprocess Technol. 2018;11:511–25.
2. Ghidelli C, Perez-Gago MB. Recent advances in modified atmosphere packaging and edible coatings to maintain quality of fresh-cut fruits and vegetables. Crit Rev Food Sci Nutr. 2018;58:662–79.
3. Lahoz I, Pérez-de-Castro A, Valcárcel M, Macua JI, Beltran J, Roselló S, Cebolla-Cornejo J. Effect of water deficit on the agronomical performance and quality of processing tomato. Scientia Hort. 2016;200:55–65.
4. Mesquitaa M, Machadob AL, dos Santosb AP, da Silvac MV, de Oliveirab HF, Battistia R, Nascimentoa AR. Assessing the effects of deficit irrigation techniques on yield and water productivity of processing tomato. Chem Eng. 2019;75:181–5.
5. Szabo K, Diaconeasa Z, Cătoi AF, Vodnar DC. Screening of ten tomato varieties processing waste for bioactive components and their related antioxidant and antimicrobial activities. Antioxidants. 2019;8:292.
6. Anibarro-Ortega M, Pinela J, Ćirić A, Martins V, Rocha F, Soković MD, Ferreira IC. Valorisation of table tomato crop by-products: Phenolic

profiles and in vitro antioxidant and antimicrobial activities. Food Bioprod Process. 2020;124:307–19.
7. Laranjeira T, Costa A, Faria-Silva C, Ribeiro D, de Oliveira JMPF, Simões S, Ascenso A. Sustainable valorization of tomato by-products to obtain bioactive compounds: Their potential in inflammation and cancer management. Molecules. 2022;27:1701.
8. Quinet M, Angosto T, Yuste-Lisbona FJ, Blanchard-Gros R, Bigot S, Martinez JP, Lutts S. Tomato fruit development and metabolism. Front Plant Sci. 2019;10:1554.
9. Vinha AF, Alves RC, Barreira SV, Castro A, Costa AS, Oliveira MBP. Effect of peel and seed removal on the nutritional value and antioxidant activity of tomato (*Lycopersicon esculentum* L.) fruits. LWT-Food Sci Technol. 2014;55:197–202.
10. Hussain A, Kausar T, Sehar S, Sarwar A, Ashraf AH, Jamil MA, Zerlasht M. Utilization of pumpkin, pumpkin powders, extracts, isolates, purified bioactives and pumpkin based functional food products; a key strategy to improve health in current post COVID 19 period; an updated review. Appl Food Res. 2022;34:100241.
11. Hussain A, Kausar T, Sehar S, Sarwar A, Quddoos MY, Aslam J, Nisar R. A review on biochemical constituents of pumpkin and their role as pharma foods; a key strategy to improve health in post COVID 19 period. Food Prod Process Nutr. 2023;5:1–14.
12. Kitinoja L, Saran S, Roy SK, Kader AA. Postharvest technology for developing countries: challenges and opportunities in research, outreach and advocacy. J Sci Food Agric. 2011;91:597–603.
13. Cheng HM, Koutsidis G, Lodge JK, Ashor AW, Siervo M, Lara J. Lycopene and tomato and risk of cardiovascular diseases: A systematic review and meta-analysis of epidemiological evidence. Crit Rev Food Sci Nutr. 2019;59:141–58.
14. Kader AA. Increasing food availability by reducing postharvest losses of fresh produce. In V Int Postharvest Symposium. 2004;682:2169–76.
15. Costa AIA, Dekker M, Jongen W. Quality function deployment in the food industry: a review. Trends Food Sci Technol. 2000;11:306–14.
16. Melin P, Gomez A, Loyola C, De Bruijn J, Valdes H, Solar V. Effect of doping natural zeolite with copper and zinc cations on ethylene removal and postharvest tomato fruit quality. Chem Eng Trans. 2019;75:265–78.
17. Guo Q, Wu B, Peng X, Wang J, Li Q, Jin J, Ha Y. Effects of chlorine dioxide treatment on respiration rate and ethylene synthesis of postharvest tomato fruit. Postharvest Biol Technol. 2014;93:9–14.
18. Fashanu TA, Oladiji AT, Peters OA. Efficacy of Gum Arabic as an esculent film on shelf-life extension of tomato (*Solanum lycopersicum* L.) fruit. Ruhuna J Sci. 2019;10:32–50.
19. Khatri D, Panigrahi J, Prajapati A, Bariya H. Attributes of Aloe vera gel and chitosan treatments on the quality and biochemical traits of post-harvest tomatoes. Scientia Hort. 2020;259:108837.
20. Haleema B, Rab A. Calcium sources and concentrations affecting tomato fruit quality stored in different storage conditions. J Animal Plant Sci. 2018;28:1049–61.
21. Mishra S, Prakash V. Biochemical changes in calcium chloride treated Hisar Arun (Local) and Kashi Vishesh (Hybrid) cultivars of Tomato fruit. Curr Agric Res J. 2018;6:395.
22. Hakimi SS, Raina R, Saharawat YS. Postharvest treatments and maturity stages impact sensory attributes and shelf life of tomato fruits var Pearson kept in Zero Energy Cool Chamber. Emirates J Food Agric. 2022;34:586–94.
23. Gong T, Li C, Bian B, Wu Y, Dawuda MM, Liao W. Advances in application of small molecule compounds for extending the shelf life of perishable horticultural products: A review. Scientia Horti. 2018;230:25–34.
24. Workneh TS, Osthoff G, Steyn MS. Influence of preharvest and postharvest treatments on stored tomato quality. Afr J Agric Res. 2011;6:2725–36.
25. AOAC (Association of Official Agricultural Chemists) In: Horwitz W, Latimer G (Eds.). The official methods of analysis of AOAC International (20th ed). Gaithersburg: AOAC International. 2016.
26. Cheng Z, Moore J, Yu L. High-throughput relative DPPH radical scavenging capacity assay. J Agric Food Chem. 2006;54:7429–36.
27. Molan AL, Flanagan J, Wei W, Moughan PJ. Selenium-containing green tea has higher antioxidant and prebiotic activities than regular green tea. Food Chem. 2009;114:829–35.
28. Marinova D, Ribarova F, Atanassova M. Total phenolics and total flavonoids in Bulgarian fruits and vegetables. J Uni Chem Technol Metall. 2005;40:255–60.
29. Majidi MI, Al Qubury HY. Determination of vitamin C (ascorbic acid) contents in various fruit and vegetable by UV-spectrophotometry and titration methods. J Chem Pharm Sci. 2016;9:2972–4.
30. Asiamah E, Arthur W, Kyei-Barfour V, Sarpong F, Ketemepi HK. Enhancing the functional and physicochemical properties of tomato (*Solanum lycopersicum* L.) fruit through polysaccharides edible dipping technique coating under various storage conditions. Bioactive Carb Dietary Fibre. 2023;89:100373.
31. Steel R, Torrie J, Dickey D. Principles and procedures of statistics A biometrical approach. 3rd ed. New York: McGraw Hill Book Company Inc; 1997. p. 334–81.
32. Bugaud C, Deverge E, Daribo MO, Ribeyre F, Fils-Lycaon B, Mbéguié-A-Mbéguié D. Sensory characterisation enabled the first classification of dessert bananas. J Sci Food Agric. 2011;91:992–1000.
33. Barua S, Rahi T, Hossain O, Mazumder A, Sharmin R, Zaman T, Ahmed S. Optimization of Ethylene inhibitor-mediated controlled ripening of tomato (*Solanum lycopersicum* L.). Adv Agric Sci. 2018;6:49–60.
34. Malundo TMM, Shewfelt RL, Ware GO, Baldwin EA. Sugars and acids influence flavor properties of mango (*Mangifera indica*). J Am Soc Hort Sci. 2001;126:115–21.
35. Anthon GE, LeStrange M. Barrett DM Changes in pH, acids, sugars and other quality parameters during extended vine holding of ripe processing tomatoes. J Sci Food Agric. 2011;91:1175–81.
36. Watkins CB. Overview of 1-methylcyclopropene trials and uses for edible horticultural crops. HortScience. 2008;43:86–94.
37. Li C, Tao J, Zhang H. Peach gum polysaccharides-based edible coatings extend shelf life of cherry tomatoes. Biotech. 2017;7:168.
38. Guillén F, Castillo S, Zapata PJ, Martínez-Romero D, Serrano M, Valero D. Efficacy of 1-MCP treatment in tomato fruit: 1. Duration and concentration of 1-MCP treatment to gain an effective delay of postharvest ripening. Postharvest Biol. Technol. 2007; 43: 23–27.
39. Cliff M, Lok S, Lu C, Toivonen PM. Effect of 1-methylcyclopropene on the sensory, visual, and analytical quality of greenhouse tomatoes. Postharvest Biol Technol. 2009;53:11–5.
40. Mostofi Y, Toivonen PM, Lessani H, Babalar M, Lu C. Effects of 1-methylcyclopropene on ripening of greenhouse tomatoes at three storage temperatures. Postharvest Biol Technol. 2003;27:285–92.
41. Kaewklin P, Siripatrawan U, Suwanagul A, Lee YS. Active packaging from chitosan-titanium dioxide nanocomposite film for prolonging storage life of tomato fruit. Int J Biol Macromol. 2018;112:523–9.
42. Mohammed M, Wilson LA, Gomes PI. Postharvest sensory and physiochemical attributes of processing and nonprocessing tomato cultivars. J Food Quality. 1999;22:167–82.
43. Naeem A, Abbas T, Ali TM, Hasnain A. Effect of antioxidant and antibacterial properties of guar gum coating containing spice extracts and its application on tomatoes (*Solanum lycopersicum* L.). J Food Measure Charact. 2018;12:2725–34.
44. Jitareerat P, Paumchai S, Kanlayanarat S, Sangchote S. Effect of chitosan on ripening, enzymatic activity, and disease development in mango (*Mangifera indica*) fruit. New Zealand J Crop Hort Sci. 2007;35:211–8.
45. Uddin MS, Ferdosh S, Akanda JH, Ghafoor K, Rukshana AH, Ali E, Kamaruzzaman BY, Fauzi MB, Hadijah S, Shaarani S. Techniques for the extraction of phytosterols and their benefits in human health: A review. Sep Sci Technol. 2018;53:2206–23.
46. Sammi S, Masud T. Effect of different packaging systems on the quality of tomato (*Lycopersicon esculentum* var. Rio Grande) fruits during storage. Int J Food Sci Technol. 2009;44:918–26.
47. Mujtaba A, Masud T, Butt SJ, Qazalbash MA, Fareed W, Shahid A. Potential role of calcium chloride, potassium permanganate and boric acid on quality maintenance of tomato cv. Rio grandi at ambient temperature. Int J Biosci. 2014;5:9–20.
48. Muhammad A, Dayisoylu KS, Khan H, Khan MR, Khan I, Hussain F, Idrees M. An integrated approach of hypobaric pressures and potassium permanganate to maintain quality and biochemical changes in tomato fruits. Horticulturae. 2022;9:9–28.
49. Gaikwad KK, Lee JY, Lee YS. Development of polyvinyl alcohol and apple pomace bio-composite film with antioxidant properties for active food packaging application. J Food Sci Technol. 2016;53:1608–19.
50. Li X, Li M, Wang L, Wang J, Jin P, Zheng Y. Methyl jasmonate primes defense responses against wounding stress and enhances phenolic

accumulation in fresh-cut pitaya fruit. Postharvest Biol Technol. 2018;145:101–7.
51. Azzini E, Maiani G, Turrini A, Intorre F, Lo FG, Capone R, Polito A. The health-nutrition dimension: a methodological approach to assess the nutritional sustainability of typical agro-food products and the Mediterranean diet. J Sci Food Agric. 2018;98:3684–705.
52. Toor RK, Savage GP. Changes in major antioxidant components of tomatoes during post-harvest storage. Food Chem. 2006;99:724–7.
53. Pullar JM, Carr AC, Vissers MC. The roles of vitamin C in skin health. Nutrients. 2017;9:866.
54. Giannakourou MC, Taoukis PS. Effect of alternative preservation steps and storage on vitamin C stability in fruit and vegetable products: critical review and kinetic modelling approaches. Foods. 2021;10:2630.
55. Lee SK, Kader AA. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol Technol. 2000;20:207–20.
56. Watkins CB. 1-Methylcyclopropene (1-MCP) based technologies for storage and shelf-life extension. Int J Postharvest Technol Innov. 2006;1:62–8.
57. Iqbal M, Khan MN, Zafar M, Munir M. Effect of harvesting date on fruit size, fruit weight and total soluble solids of feutrell's early and kinnow cultivars of Mardan (*Citrus reticulata*) on the economic conditions of farming community of Faisalabad. Sarhad J Agric. 2012;28:19–21.
58. Hernandez-Munoz P, Almenar E, Del Valle V, Velez D, Gavara R. Effect of chitosan coating combined with postharvest calcium treatment on strawberry *(Fragaria ananassa*) quality during refrigerated storage. Food Chem. 2008;110:428–35.
59. Ullah A, Abbasi NA, Shafique M, Qureshi AA. Influence of edible coatings on biochemical fruit quality and storage life of bell pepper cv. "Yolo Wonder." J Food Quality. 2017;2017:6.
60. Ali A, Maqbool M, Alderson PG, Zahid N. Effect of gum arabic as an edible coating on antioxidant capacity of tomato (*Solanum lycopersicum* L.) fruit during storage. Postharvest Biol Technol. 2013;76:119–24.
61. Mun HI, Kwon MC, Lee N, Son SY, Song DH, Lee CH. Comparing metabolites and functional properties of various tomatoes using mass spectrometry-based metabolomics approach. Front Nutr. 2021;8: 659646.

Publisher's Note