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Research article

Effects of preharvest applications of chemicals and storage conditions on the physico-chemical characteristics and shelf life of tomato (*Solanum lycopersicum L.)* fruit

Aleminew Tagele [a,*], Kebede Woldetsadik [a], Fikreyohannes Gedamu [a], Mokula Mohammed Rafi [b]

[a] School of Plant Sciences, College of Agriculture and Environmental Sciences, Haramaya University, Ethiopia
[b] Department of Natural Resource Management, College of Agricultural and Environmental Sciences, University of Gondar, Ethiopia

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ABSTRACT

The aim of this study was to investigate the influence of preharvest sprays of chemicals and evaporative cooling (ZECC) on the postharvest physico-chemical quality and shelf life of tomatoes. The experiment was conducted using a combination of ten preharvest sprays of chemicals (chitosan (0.1%), chitosan (0.3%), chitosan (0.5%), salicylic acid (SA) (0.015%), SA (0.03%), SA (0.045%), calcium chloride ($CaCl_2$) (1%), $CaCl_2$ (3%), $CaCl_2$ (5%) and control) and two storage conditions (ambient environment storage and ZECC). The design of the experiment was completely randomized design with three replications. Data were collected from tomato samples (*Solanum lycopersicum L.* cv. ARP tomato D2) on four days interval. The result showed that all physico-chemical quality indicators were significantly ($p \leq 0.05$) affected by both preharvest sprays and storage conditions. $CaCl_2$ (5%) sprays extended the shelf life of tomato by 6 days in ZECC and 11 days in ambient storage compared to the control. The highest concentration of $CaCl_2$ and SA sprays minimized PLW and maintained fruit marketability compared to the control. The firmness of tomatoes was better retained with the sprays of SA (0.045%) in both storage conditions. $CaCl_2$ (5%), SA (0.045%) and chitosan (0.5%) sprays retained the titratable acidity by 42.86%, 47.62% and 33.33%, respectively compared to the control inside ZECC storage. At the end of storage period, the highest TSS was observed on tomatoes sprayed with SA (0.03%) followed by *chitosan (0.1%) and chitosan (0.3%)*. The lycopene contents were lower with sprays of SA (0.045%), SA (0.03%), $CaCl_2$ (3%), $CaCl_2$ (5%) and chitosan (0.1%) stored inside ZECC indicating the effectiveness of preharvest sprays in delaying lycopene accumulation. Moreover, the AA contents of tomatoes sprayed with $CaCl_2$ (5%), SA (0.045%) and chitosan (0.1%) were higher by 34.10%, 38.19% and 23.84%, respectively compared to the control. The result indicated that combining preharvest chemical sprays and ZECC storage is important to maintain the physico-chemical quality and shelf life of tomatoes.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most popular vegetable worldwide and it is grown for its edible fruits (Beckles, 2017). Among vegetables, it is the third most important crop (FAOSTAT, 2019) and the world average consumption of fresh tomato fruits and its products in 2018/19 was 28.3 million mT (Branthome, 2020). Nutritionally, it is a rich source of minerals and vitamins such as lycopene, β-carotene, potassium, vitamin C, flavonoids, folate and vitamin E (Shidfar et al., 2011).

Being a climacteric fruit, its shelf life is relatively short and the ripening process is actually stimulated by ethylene (Razali et al., 2013). The global postharvest loss of tomatoes is estimated to be 25–42% (Rehman et al., 2007). The postharvest loss of tomato fruits in Ethiopia is also considerably large. Postharvest losses of tomatoes in Fogera was estimated to be 24.17% (Asrat et al., 2019) and where as in Dire Dawa the loss was 45.32% (Kasso and Bekele, 2018).

The postharvest physico-chemical quality of fruits can be affected by both preharvest and postharvest managements. Due to the public concerns about the harmful effects of synthetic fungicides on environment and health of human being, it is important to search new alternatives (Babalar et al., 2007). To extend the keeping quality, use of preharvest sprays of agro-chemical substances such as chitosan, salicylic acid and related substances can be considered (Zeraatgar et al., 2018).

* Corresponding author.
E-mail address: aleminew98@gmail.com (A. Tagele).

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Salicylic acid (SA), an endogenous plant growth regulator of phenolic nature, participates in different physiological activities such as in plant growth regulation, development and enhancement of plant vigor under abiotic and biotic stresses (Hayat et al., 2010). Preharvest application of salicylic acid is reported to maintain the postharvest quality of tomato (Sarinana-aldaco et al., 2020). SA reduces fruit decay, softening rate and loss in physiological weight during storage (Babalar et al., 2007) through its influence on respiration and ethylene biosynthesis (Kumar et al., 2018a,b; Srivastava and Dwivedi, 2000). According to Rao et al. (2011), treating fruits with SA reduces the activity of hydrolases which might have been associated with a high integrity of the cell membrane and contributed to retention of firmness and crispness of the fruits during storage.

Similarly chitosan, a natural carbohydrate polymer is known to induce the accumulation of ROS and pathogenesis-related proteins to protect plant tissues against pathogen infection (Ferrari et al., 2013; Pichyangkura and Chadchawan, 2015). To prevent postharvest deterioration, extend the shelf life and retain the physico-chemical quality of fruit and vegetable, pre-or postharvest application of chitosan can been considered as an option to the use of synthetic fungicides (Bautista-Baños et al., 2006). El Ghaouth et al. (2004) reported that pre-or postharvest treatments of fruits and vegetables with chitosan may lead to the development of enhanced resistance to infection caused by pathogens. Almunqedi et al. (2017) also indicated preharvest application of chitosan extended the shelf life and maintained the physico-chemical properties of tomatoes.

Calcium, as a constituent of the cell wall, plays an important role in forming cross-bridges, which influences the strength of cell wall and it can be considered as the last barrier before the separation of the cell (Fry, 2004). Among the determinants of fruit quality, calcium is considered to be one of the most important mineral element (El-Badawy, 2012). Both preharvest and postharvest applications of calcium on fruits and vegetables have been reported to play an important role in maintaining their quality (Daundasekera et al., 2015; Ozturk et al., 2019). Pre-harvest calcium applications increase cell wall's calcium content of fruits (Serrano et al., 2004). It also contributes to the retention of postharvest physico-chemical quality and storage life of fruits. Preharvest application of calcium may slow down the processes responsible for the reduction of fruit firmness during ripening (Passam et al., 2007). Because calcium uptake from the soil and its movement to aerial plant organs is limited, direct spray applications onto the plant are preferable, as they often allow effective increase of calcium content in the fruit (Ferguson and Boyd, 2001).

Optimum storage temperature and relative humidity are crucial to the marketable quality of vegetables and fruits and they have impact on the shelf life (Chilson et al., 2011). Use of refrigerators requires uninterrupted electricity and high initial capital for procurement and installation. However, evaporative cooling, which is premised on cooling by evaporation is a cheaper option for resource poor farmers to achieve low storage temperature and high relative humidity, thereby, reducing postharvest deterioration (Manyozo et al., 2018). Furthermore, it requires less or no energy consumption, easy to install and operate and uses locally available materials for construction (Ambuko et al., 2017). One of the techniques that utilizes the principles of evaporative cooling is zero energy cool chambers (ZECC) and it is reported to maintain relatively high relative humidity and low temperature compared to ambient conditions (Rayaguru et al., 2010). Mekbib (2016) and Manyozo et al. (2018) reported significant differences in temperature and relative humidity between the ambient and the inside environment of ZEEC storage giving better retention of the physico-chemical and extend shelf life of tomatoes.

Studies reported the positive role of preharvest spray of SA, calcium and chitosan on the postharvest quality of tomatoes. However, there has been limited information available on the influence of different concentrations of SA, calcium and chitosan on the physico-chemical postharvest quality and shelf life of tomatoes. Therefore, the aim of the present study was to investigate the effect of preharvest applications of different concentrations of salicylic acid, calcium and chitosan under ambient and ZECC storage condition on the physico-chemical changes and shelf life of tomato.

2. Materials and methods

2.1. Description of the study area

The experiment was performed during 2019/20 season at Teda Campus of University of Gondar, Central Gondar zone, Amhara National Regional State, Ethiopia. The experimental site is located at latitude of 12°28′N, longitude of 37°29′E and has an altitude of 1977 m above sea level. The mean annual total rainfall of the study area is 1843 mm, having maximum and minimum temperature of 27.3 and 12.7 °C, respectively (Ousman et al., 2018).

2.2. Tomato fruit production

Tomato sample fruits of "ARP tomato D2" cultivar were produced under open field condition during the dry season of 2019/20 at Megech area, near Teda Campus, University of Gondar under irrigated condition. Tomato seedlings were planted on the experimental field using randomized complete block design with three replications on a plot size of $20m^2$. Each plots were irrigated every other day for the first two weeks and then at weekly interval. Fertilizer was applied at a rate of 46 kg P_2O_5/ha and 64 kg N/ha in the form of NPSB blended fertilizer (Mulualem and Tekeste, 2014). Plots were kept free from weeds manually and other cultural practices such as disease and insect pest control were done as per the recommendation for tomato production.

2.3. Treatments

The treatments consisted of 9 preharvest sprays of chemicals (chitosan (0.1%), chitosan (0.3%), chitosan (0.5%), salicylic acid (0.015%), salicylic acid (0.03%), salicylic acid (0.045%), $CaCl_2$ (1%), $CaCl_2$ (3%), $CaCl_2$ (5%) and control (without spray) combined with two storage environments (ambient environment storage and zero energy cool chamber storage).

Applications of the treatments were done as per the recommendation provided by different authors. The applications of $CaCl_2$ were done in the morning following the method described by Abbasi et al. (2013). First foliar spray of $CaCl_2$ was done during the anthesis and the second spray was done a week later on the inflorescence of tomatoes. The applications of salicylic acid were done in the morning following the procedure described by Javanmardi and Akbari (2016). The first spray was done at fruit setting stage followed by the second spray three weeks later. Chitosan sprays were done four times following the procedure described by El-Tantawy (2009). The sprays were done at 10 days interval until run off starting from 20 days after transplanting of the seedlings.

2.4. Preparation of treatments

To prepare 1%, 3% and 5% $CaCl_2$, 10g, 30g and 50g of $CaCl_2$ were dissolved in 1 L of distilled water, respectively. Tween-80 (0.5%) was added into the solution as surfactant. The chitosan solutions were prepared by dissolving in 30 ml of acetic acid (5%) for every gram of chitosan, and then distilled water was added to complete the volume. For homogenization, the chitosan solutions were heated and stirred for 3 h, then neutralized to pH of 5.5 with 1.0 N NaOH. To improve the wetting properties of the solution, 0.05% (w/v) Tween-80 was added as a surfactant before filtration (Meng et al., 2008; Tezotto-Uliana et al., 2014). For the preparation of 0.015%, 0.03% and 0.045% salicylic acid solutions, 0.15g, 0.3g and 0.45g of salicylic acid were dissolved in 1 L of distilled water, respectively. Tween-80 (0.5%) of was added to the solutions as surfactant.

2.5. Construction of zero energy cooling chamber (ZECC)

ZECC was developed by the India Agricultural Research Institute in which it can be built using locally available materials (Roy and Pal, 1991). The basic structure of the chamber was built from bricks and sand, with a cover made from cane and sacks. First the floor was built from a single layer of bricks, and then a cavity wall was constructed with bricks around the outer edge of the floor with a gap of 75mm between the inner wall and the outer wall. This cavity was then filled with sand. A covering for the chamber was made with canes covered in sacks, all mounted in a eucalyptus frame. The whole structure was protected from sunlight by making a roof to provide shade.

2.6. Laboratory experimental design

The sample fruits were harvested at breaker stage and then brought to the Plant Science Department Laboratory of CAES, University of Gondar and precooled. Each treatment combinations consisted of forty fruits having approximately uniform maturity and size. The laboratory experiment was carried out using completely randomized design with three replications.

The tomato samples for physico-chemical and shelf life analysis were randomly selected for their uniformity of shape, color and visual absence of defects. On each sampling date, three tomato fruits were selected randomly from each treatment for the analysis. Fixed samples of ten fruits were used for physiological loss in weight, percentage marketability, and shelf life. Data were recorded on 4^{th}, 8^{th}, 12^{th}, 16^{th}, 20^{th}, 24^{th} and 28^{th} days of storage. The air temperature and relative humidity of the storage rooms were recorded throughout the storage period using hygrometer (Sunroad, China).

2.7. Physical and chemical quality analysis

Physiological loss in weight (PLW): It was determined as percent loss from initial weight as described by Kumar et al. (2018a,b). The weights of freshly harvested fruits were recorded at the time of harvesting. On each day of observation, the stored fruits were weighed and the weight losses on each sampling date were calculated using the following formula:

$$\text{PLW}\ (\%) = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100 \quad (1)$$

Percentage marketability: It was measured subjectively according to the method described by Mohammed et al. (1999). Samples of ten fruits from each treatment were taken and the marketability was determined subjectively by observing the level of visible mold growth, decay, shriveling and the surface appearance characteristics such as smoothness and shininess of the fruit. The percentage of marketable fruits during storage was calculated as:

$$\text{Marketablefruits}\ (\%) = \frac{\text{No of marketable fruits}}{\text{No of total fruits}} \times 100 \quad (2)$$

Firmness: For the determination of firmness, the method described by Javanmardi and Akbari (2016) was used. Firmness was measured as penetration force on the fruit flesh (over the fruit locules) using hand held pressure tester (Model: FHT-1122, China) with a probe diameter of 7.9 mm. The average values of three fruits were used and expressed as Newton.

pH: It was measured using AOAC (2005) method. Three fruits from each treatment were chopped and homogenized using blender. The homogenates were filtered through cloth and a pH meter (Model: AC-3118M, Abron Exports, India) that had been previously calibrated to pH 4 and pH 7 was used for the determination of the pH values.

Titratable acidity (TA): For the analysis of TA, the method described by Chilson et al. (2011) was used. Six gram of the juice was diluted in 50 ml of distilled water and 3–4 drops of 1% phenolphthalein in 95% ethanol was added. The TA was determined by titrating with 0.1 N NaOH to an end point of pH 8.1 using digital titrometer (Jencons Digitrate, UK). The results were converted to percent of citric acid, using the following formula:

$$[(\text{mL NaOH} \times 0.1\ \text{N} \times 0.064)/\ 6.0\ \text{g of juice})] \times 100 \quad (3)$$

Total Soluble Solids (TSS): For the determination of TSS, the procedures described by Mazumdar and Majumder (2003) were used. Three fruits from each treatment were blended and 2–3 drops of filtered juice was used. Average of two readings were used with handheld refractometer (model: ERB-32, India) ranging from 0 to 32%.

Ascorbic acid: It was estimated following the procedure described by Mazumdar and Majumder (2003) by indicator method. Five grams of the juice samples were taken and extracted with a known volume of 3% metaphosphoric acid. The extracts were filtered and the filtrates were made up to a known volume with 3% metaphosphoric acid. 10 ml of aliquot was taken in conical flask and titrated (Jencons Digitrate, UK) with 0.025% 2,6- dichlorophenol indophenols dye solution. The end point was determined with appearance of pink color which persisted for at least 15 s. The results were converted in to ascorbic acid using the following formula:

$$\text{Ascorbicacid}\ (\text{mg}\ /\ 100\text{g}) = \frac{e*d*b}{c*a} \quad (4)$$

Where: a: weight of sample in gram, b: volume made with 3% metaphosphoric acid in ml, c: volume of aliquot taken for estimation in ml, d: dye factor in mg/ml, e: average burette reading for the sample in ml.

Lycopene content: It is the carotenoid content expressed in lycopene equivalents. Its determination was made following the extraction method of Sharma and Le Maguer (1996) with hexane:ethanol:acetone (2:1:1) (v/v) mixture. Briefly, 1g of the homogenized samples were extracted using 25 ml of hexane:ethanol:acetone and then placed on the shaker for 30 min. 10 ml of deionized water was added with continuous agitation for another 2 min. The solutions were left to separate into distinct polar and non-polar layers. The absorbance was measured at 472 nm in spectrophotometer (Abron, India), using hexane as a blank. Specific extinction coefficient (E 1%, 1 cm) of 3470 in hexane at 472 nm was used to calculate the lycopene concentration (Zechmeister, 1944). The lycopene concentration was calculated using the following formula:

$$\text{Lycopene}\ (\text{mg}/100\text{g}) = A*V/_{3.470*W} \quad (5)$$

Where V is the amount of hexane (ml), W the weight of fruit sample (g), A the absorbance at 472 nm and 3.470 is the extinction coefficient.

Shelf life: It was calculated by counting the days required to attain the last stage of ripening, but up to the stage when fruit remained still acceptable for marketing as described by Moneruzzaman et al. (2009).

2.8. Statistical analysis

The mean values of all the collected data were analyzed using SAS 9.4 (SAS Institute Inc, 2013) statistical software. Two way analysis of variance (ANOVA) was performed using generalized linear model to determine the effects of preharvest treatments, storage conditions and their interaction on physico-chemical parameters at 5% significance level. Duncan's Multiple Range Test (DMRT) was used to determine the significance between treatment means.

3. Results and discussion

3.1. Temperature and relative humidity of the storage environment

During the storage period, the ambient dry bulb air temperature and relative humidity of the experimental area varied from 23.8 to 28.6 °C and 59.2–63.5%, respectively. Inside the zero energy cooling chamber,

the dry bulb temperature and relative humidity varied from 12.1 to 16.9 °C and 86.2%–92.7%, respectively (Figure 1).

3.2. Physiological loss in weight (PLW)

The interaction of preharvest sprays and storage conditions had significant ($p < 0.05$) influence on the PLW of tomatoes in the first 12 days of storage (Table 1). Generally, the PLW increased gradually with the advancement of storage period. On day 12 of storage period, the highest PLW was recorded on the control tomatoes stored in ambient condition while the lowest was recorded on calcium chloride (5%) sprayed tomatoes stored inside ZECC storage. On the same day, the control tomatoes had 219.53% higher loss in weight compared to tomatoes sprayed with calcium chloride (5%). The PLW of tomatoes was significantly ($p \leq 0.001$) affected by preharvest sprays and storage conditions on day 16, 20, 24 and 28 of storage period (Table 2). At the end of storage period, control fruits recorded the highest (12.00%) PLW while the lowest (8.27%) was recorded on tomatoes sprayed of calcium chloride (5%) followed by salicylic acid (0.045%). While all fruits in ambient environment condition were discarded on day 28, fruits stored inside ZECC continued to day 28 with less than 11% PLW. On day 28 of storage period, fruits treated with calcium chloride (5%) and salicylic acid (0.045%) had significantly lower PLW compared to other treatments including chitosan treated ones.

The main reason for the loss of physiological weight could be moisture loss in fruits by respiration and transpiration (Islam et al., 2016). Calcium has influential role in the creation of calcium pectate hydrogel, which holds more water and slows the dehydration process (Turmanidze et al., 2017). Chitosan is also involved in reducing the rates of metabolic activities during respiration and transpiration processes (Gayed et al., 2017). The decrement of transpiration can also be associated with the reduction in hydrolytic cell wall enzymes activity which can be greatly influenced by salicylic acid (Zoran et al., 2001). The findings are in agreement with Sarinana-aldaco et al. (2020), who reported that 0.125 mM salicylic acid preharvest sprays decreased the weight loss by 60.38%. Similar results were reported by Perdones et al. (2016), who found that tomatoes sprayed with chitosan reduced the weight loss. Similar trends of reduction in weight loss was also reported by Gayed et al. (2017) with preharvest sprays of calcium.

The result showed that tomato stored inside ZECC significantly ($p \leq 0.01$) reduced physiological loss in weight compared to ambient storage condition (Table 2). Tomatoes stored inside ZECC recorded 10.51% loss in weight during the 28 days of storage period while the weight loss in the ambient storage condition was 11.77% after 24 days of storage period. Tolesa and Workneh (2017) explained that evaporative cooling maintained the water content of tomatoes high by lowering respiration and removal of water from the fruit surface. The present findings are in agreement with Mekbib (2016), who reported that storing tomatoes inside ZECC storage reduced physiological loss in weight compared to ambient storage. Reduction in weight loss of tomato stored at 5 °C compared to storing at 10 °C was also reported by Znidarcic et al. (2010).

Table 1. Interaction effects of preharvest sprays of chemicals and storage condition on the physiological loss in weight (%) of tomatoes on day 4, 8 and 12 of storage period.

Treatments	Storage period (days)		
	4	8	12
Ambient Storage			
Chitosan (0.1%)	2.48^{bc}	1.60^{fgh}	4.06^{bcd}
Chitosan (0.3%)	2.72^{b}	3.14^{bc}	5.11^{ab}
Chitosan (0.5%)	2.17^{cd}	2.78^{bcd}	4.38^{bc}
SA (0.015%)	2.30^{bc}	3.05^{bc}	3.27^{cde}
SA (0.03%)	1.12^{ghi}	1.43^{ghi}	2.66^{efg}
SA (0.045%)	1.06^{ghi}	1.42^{ghi}	1.82^{g}
$CaCl_2$ (1%)	1.81^{de}	2.54^{cde}	3.89^{cd}
$CaCl_2$ (3%)	1.25^{fghi}	1.75^{fgh}	2.76^{efg}
$CaCl_2$ (5%)	0.82^{ij}	1.67^{fgh}	1.97^{fg}
Control	3.58^{a}	3.30^{ab}	5.40^{a}
Zero Energy Cooling Chamber			
Chitosan (0.1%)	1.55^{efg}	3.92^{a}	3.53^{cde}
Chitosan (0.3%)	1.40^{efgh}	2.13^{defg}	4.36^{bc}
Chitosan (0.5%)	1.55^{efg}	2.05^{efg}	2.99^{def}
SA (0.015%)	1.58^{efg}	1.76^{fgh}	4.22^{bc}
SA (0.03%)	0.55^{j}	1.17^{hi}	2.01^{fg}
SA (0.045%)	0.80^{ij}	1.18^{hi}	1.87^{g}
$CaCl_2$ (1%)	1.77^{def}	2.20^{def}	3.87^{cd}
$CaCl_2$ (3%)	0.91^{hij}	1.23^{hi}	2.58^{efg}
$CaCl_2$ (5%)	0.45^{j}	0.84^{i}	1.69^{g}
Control	2.49^{bc}	2.98^{bc}	3.93^{cd}
CV (%)	17.22	18.03	17.50
SEM (±)	0.161	0.219	0.335
F-Test			
Preharvest sprays (A)	***	***	***
Storage conditions (B)	***	**	**
A*B	*	***	*

3.3. Percentage marketability

The interaction of preharvest sprays of chemicals and storage conditions significantly ($p < 0.05$) affected the percentage marketability of tomatoes only on day 20 and 24 of storage periods (Table 3). During the

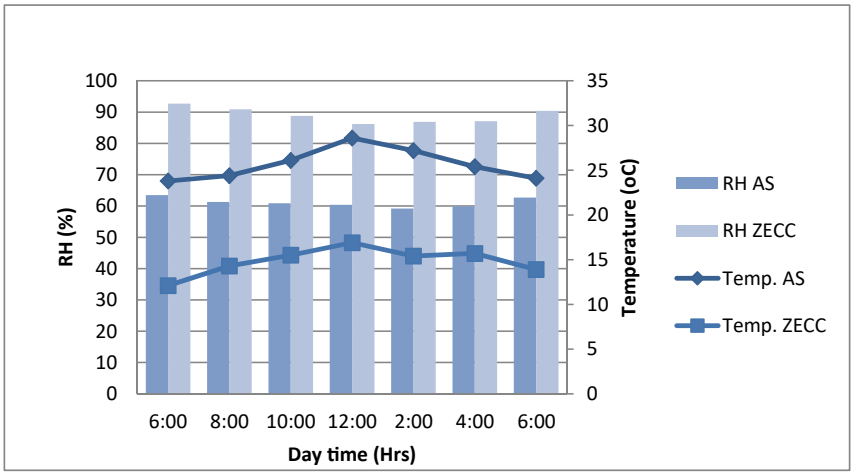

Figure 1. Average daily temperature (°C) and relative humidity (%) of the storage environments.

Table 2. Main effects of preharvest sprays of chemicals and storage condition on the physiological loss in weight (%) of tomatoes on day 16, 20, 24 and 28 of storage period.

Treatments	Storage period (days)			
	16	20	24	28
Preharvest sprays (A)				
Chitosan (0.1%)	5.77^{ab}	8.50^{abc}	10.99^{b}	11.08^{abc}
Chitosan (0.3%)	6.27^{ab}	8.60^{ab}	11.80^{ab}	11.49^{ab}
Chitosan (0.5%)	5.99^{ab}	9.06^{ab}	11.18^{b}	11.51^{ab}
SA (0.015%)	5.28^{bc}	8.55^{abc}	10.91^{b}	10.79^{abc}
SA (0.03%)	4.38^{cd}	7.01^{de}	9.42^{c}	10.55^{abc}
SA (0.045%)	3.92^{d}	6.78^{e}	8.77^{c}	8.93^{cd}
$CaCl_2$ (1%)	5.65^{ab}	8.28^{bcd}	11.24^{b}	10.82^{abc}
$CaCl_2$ (3%)	4.15^{d}	7.27^{cde}	9.58^{c}	9.61^{bcd}
$CaCl_2$ (5%)	3.79^{d}	6.72^{e}	9.05^{c}	8.27^{d}
Control	6.55^{a}	9.89^{a}	12.45^{a}	12.00^{a}
SEM (±)	0.420	0.446	0.509	0.702
Storage conditions (B)				
AS	5.42^{a}	8.90^{a}	11.77^{a}	
ZECC	4.93^{b}	7.23^{b}	9.30^{b}	10.51
SEM (±)	0.063	0.216	0.319	
F-Test				
Preharvest sprays (A)	***	***	***	*
Storage conditions (B)	*	***	***	-
A*B	ns	ns	ns	-
CV (%)	14.97	14.21	8.71	11.58

AS: ambient storage; ZECC: zero energy cooling chamber; $CaCl_2$: calcium chloride; SA: salicylic acid; ns: non-significant difference at $p \leq 0.05$; means followed by the same letter in a column are not significantly different at $p \leq 0.05$ (DMRT). ns, *, **, *** not significant or significant at $P \leq 0.05$ or $P \leq 0.01$ or $P \leq 0.001$, ANOVA.

Table 3. Interaction effects of preharvest sprays of chemicals and storage condition on the percentage marketability (%) of tomatoes on day 20 and 24 of storage period.

Treatments	Storage period (days)	
	20	24
Ambient Storage		
Chitosan (0.1%)	46.67^{g}	36.67^{g}
Chitosan (0.3%)	43.33^{g}	33.33^{g}
Chitosan (0.5%)	53.33^{fg}	36.67^{g}
SA (0.015%)	63.33^{ef}	53.33^{f}
SA (0.03%)	70.00^{cde}	56.67^{ef}
SA (0.045%)	73.333^{bcde}	70.00^{abcd}
$CaCl_2$ (1%)	73.33^{bcde}	60.00^{def}
$CaCl_2$ (3%)	73.33^{bcde}	63.33^{cde}
$CaCl_2$ (5%)	73.33^{bcde}	66.67^{bcde}
Control	43.33^{g}	26.67^{g}
Zero Energy Cooling Camber		
Chitosan (0.1%)	73.33^{bcde}	66.67^{bcde}
Chitosan (0.3%)	66.67^{de}	63.33^{cdef}
Chitosan (0.5%)	76.67^{abcd}	70.00^{abcd}
SA (0.015%)	76.67^{abcd}	66.67^{bcde}
SA (0.03%)	76.67^{abcd}	70.00^{abcd}
SA (0.045%)	86.67^{a}	80.00^{a}
$CaCl_2$ (1%)	80.00^{abc}	73.33^{abc}
$CaCl_2$ (3%)	83.33^{ab}	73.33^{abc}
$CaCl_2$ (5%)	86.67^{a}	76.67^{ab}
Control	73.33^{bcde}	60.00^{def}
CV (%)	9.63	10.29
SEM (±)	3.873	3.575
F-Test		
Preharvest sprays (A)	***	***
Storage conditions (B)	***	***
A*B	*	***

24 days of storage, the control and tomatoes sprayed with chitosan (0.3%) and stored in ambient condition recorded the lowest fruit marketability whereas tomatoes sprayed with salicylic acid (0.045%) and calcium chloride (5%) and stored inside ZECC storage recorded the highest marketable fruit. The marketability of tomatoes was significantly ($p \leq 0.05$) influenced by preharvest sprays of chemicals in all storage periods except on day 8 (Table 4). Preharvest sprays resulted in better retention of fruit marketability than the control. The fruit marketability did not change on days 4 and started to significantly decline on day 12 of storage period. On day 28, the highest percentage of marketable fruits were observed with preharvest spray of salicylic acid (0.045%) followed by calcium chloride (5%) while the lowest marketable fruits were observed with the control followed by preharvest spray of chitosan (0.3%) in fruits stored in ambient environment condition. Preharvest sprays of chitosan (0.3%) and chitosan (0.5%) also recorded significantly higher percentage marketability compared to the control over 28 days of storage.

Better retention of marketability of tomatoes with preharvest spray of chemicals could be attributed to the formation of calcium pectate, which helps to reduce degradation of cell wall (Hocking et al., 2016). Beside this, salicylic acid induces resistance against postharvest diseases (Asghari and Aghdam, 2010) and decreases the activities of cell wall degrading enzymes (Wang and Li, 2008). Furthermore, chitosan acts as inhibitor of various enzymes involved in fruit senescence (Dutta et al., 2009) and has antifungal activity (Carrieri et al., 2016). The findings of the present study agrees with Migliori et al. (2017) who reported that preharvest spray of chitosan improved marketability of tomato compared to the control. Baninaiem et al. (2016) indicated that spray of 4 mM salicylic acid 3 weeks before harvest reduced decay and improved marketability of tomatoes. Similarly, preharvest sprays of calcium improvement in the overall marketability of tomato (Bhattarai and Gautam, 2006).

The main effects of storage conditions had significant ($p < 0.05$) influence on the marketability of tomatoes on day 8, 12 and 16 of storage period (Table 4). Tomatoes stored inside ZECC storage remained fresh and firm for a reasonably longer period of time than those stored in ambient environment condition, in agreement with the reports of Mekbib (2016) and Getinet et al. (2011). On day 28, tomatoes stored inside ZECC had 61% marketable fruits. The higher fruit marketability with evaporative cooling could be due to reduced physiological activity resulting in slowed senescence of fruit (Pinto et al., 2004). The present findings agree with Mekbib (2016) who reported that storing tomatoes inside ZECC storage resulted in more than threefold retention of the marketability than in ambient condition. Similarly, Tolesa & Workneh (2017) also reported higher marketability of tomatoes in storing inside evaporative cooling.

3.4. Firmness

Firmness is an important physical parameter for postharvest storage, transportation and monitoring the fruit ripening process (Javanmardi and Akbari, 2016). Both preharvest sprays and storage conditions had significant ($p \leq 0.01$) effect on the changes in the firmness of tomato fruits (Table 5). Tomatoes treated with salicylic acid (0.045%), calcium chloride (5%) and the control experienced a decline in firmness from 10.70 N to 4.80 N, 10.62 N to 4.36 N and 8.95 N to 2.75 N, respectively in 28 days of storage period. At the end of the storage period, tomatoes treated with salicylic acid (0.045%) and calcium chloride (5%) better maintained the firmness whereas the control fruits had the lowest firmness.

Table 4. Main effects of preharvest sprays of chemicals and storage condition on the percentage marketability (%) of tomatoes on day 8, 12, 16 and 28 of storage period.

Treatments	Storage period (days)			
	8	12	16	28
Preharvest sprays (A)				
Chitosan (0.1%)	98.33	96.67^{a}	83.33^{abc}	46.67^{e}
Chitosan (0.3%)	98.33	96.67^{a}	81.67^{bc}	56.67^{d}
Chitosan (0.5%)	100.00	100.00^{a}	90.00^{ab}	60.00^{cd}
SA (0.015%)	100.00	98.33^{a}	83.33^{abc}	60.00^{cd}
SA (0.03%)	100.00	100.00^{a}	85.00^{abc}	63.33^{cd}
SA (0.045%)	100.00	100.00^{a}	91.67^{a}	76.67^{a}
$CaCl_2$ (1%)	100.00	98.33^{a}	83.33^{abc}	63.33^{cd}
$CaCl_2$ (3%)	100.00	100.00^{a}	88.33^{ab}	66.67^{bc}
$CaCl_2$ (5%)	100.00	100.00^{a}	88.33^{ab}	73.33^{ab}
Control	96.67	91.67^{b}	76.67^{c}	43.33^{e}
SEM (±)	0.476	1.085	1.827	2.981
Storage conditions (B)				
AS	98.67^{b}	96.67^{b}	80.67^{b}	
ZECC	100.00^{a}	99.67^{a}	89.67^{a}	61
SEM (±)	0.172	0.387	1.162	
F-Test				
Preharvest sprays (A)	ns	***	*	***
Storage conditions (B)	*	***	***	-
A*B	ns	ns	ns	-
CV (%)	2.25	3.22	8.02	8.47

AS: ambient storage; ZECC: zero energy cooling chamber; $CaCl_2$: calcium chloride; SA: salicylic acid; ns: non-significant difference at $p \leq 0.05$; means followed by the same letter in a column are not significantly different at $p \leq 0.05$ (DMRT). ns, *, **, *** not significant or significant at $P \leq 0.05$ or $P \leq 0.01$ or $P \leq 0.001$, ANOVA.

The retention of firmness with preharvest sprays might be attributed to the inhibitory effects of calcium, salicylic acid and chitosan on the actions of the enzymes responsible for cell wall degradation such as cellulose, pectin-methyl esterase and polygalacturonase (Asghari and Aghdam, 2010; Doesburg, 1975). In agreement with the present findings, Sarinana-aldaco et al. (2020) reported that 0.125 mM dose of salicylic acid application produced tomatoes with 75.3% higher in firmness than the control. Javanmardi and Akbari (2016) also reported better retention of firmness with salicylic acid treatment. Higher firmness in tomatoes treated with 3% and 5% calcium were also reported by Daundasekera et al. (2015). Similarly, Rab & Haq (2012) reported that tomatoes with preharvest applications of calcium at a rate of 0.2–0.6% retained their firmness better than the control. The report by Basit et al. (2020a,b) also indicated that treating tomatoes with chitosan retained the firmness and this could be attributed to the role of chitosan in delaying ripening.

The result showed that tomatoes stored inside ZECC storage maintained higher firmness than those stored in ambient storage condition. On day 24 of storage period, tomatoes stored inside ZECC storage had firmness of 5.11 N while those stored in ambient condition had firmness of 4.34 N. Softening of tomato tissue during storage is mainly caused by the enzymatic breakdown of pectin (Van Dijk et al., 2006). Low storage temperature slows the metabolic activities of the stored tomatoes resulting in reduction in loss of firmness (Sualeh et al., 2016). The present finding is in agreement with Tolesa and Workneh (2017) who reported that tomatoes stored inside evaporative cooling environment had higher firmness than in ambient storage condition. The report by Abiso et al. (2015) also indicated that tomatoes stored inside ZECC storage had significantly higher firmness than those stored in ambient condition in 10 days of storage.

The interaction of preharvest sprays and storage conditions did not significantly ($p \leq 0.05$) affect the firmness of tomatoes in any of the storage periods.

3.5. pH value

pH is a good index of ripening indicating the degradation or respiration of organic acids (Mujtaba and Masud, 2014). The pH values of tomatoes were significantly ($p \leq 0.05$) affected by preharvest sprays of

Table 5. Main effects of preharvest sprays of chemicals and storage condition on the firmness (N) of tomatoes.

Treatments	Storage period (days)						
	4	8	12	16	20	24	28
Preharvest sprays (A)							
Chitosan (0.1%)	8.81^{c}	8.39^{bc}	7.57^{de}	6.65^{cd}	5.52^{cd}	4.45^{b}	3.23^{cde}
Chitosan (0.3%)	10.75^{a}	9.35^{ab}	7.84^{cde}	6.84^{bcd}	5.94^{bc}	4.57^{b}	3.16^{de}
Chitosan (0.5%)	10.55^{a}	9.67^{a}	8.37^{abc}	7.29^{b}	5.92^{bc}	4.61^{b}	3.76^{bcd}
SA (0.015%)	10.40^{a}	9.74^{a}	7.86^{cde}	7.21^{bc}	5.90^{bc}	4.51^{b}	4.01^{bc}
SA (0.03%)	9.89^{ab}	9.19^{abc}	8.30^{bc}	7.37^{b}	6.15^{b}	4.84^{b}	3.98^{bc}
SA (0.045%)	10.70^{a}	9.82^{a}	9.09^{a}	8.10^{a}	7.18^{a}	5.69^{a}	4.80^{a}
$CaCl_2$ (1%)	10.72^{a}	10.05^{a}	8.19^{cd}	7.05^{bc}	5.80^{bc}	4.55^{b}	3.55^{cd}
$CaCl_2$ (3%)	10.75^{a}	9.63^{a}	8.44^{abc}	7.30^{b}	6.11^{b}	4.83^{b}	3.79^{bcd}
$CaCl_2$ (5%)	10.62^{a}	9.84^{a}	8.98^{ab}	7.98^{a}	6.96^{a}	5.45^{a}	4.36^{ab}
Control	8.95^{bc}	8.22^{c}	7.17^{e}	6.44^{d}	5.15^{d}	3.76^{c}	2.75^{e}
SEM (±)	0.306	0.254	0.243	0.215	0.248	0.220	0.245
Storage conditions (B)							
AS	9.83^{b}	9.00^{b}	7.92^{b}	6.96^{a}	5.78^{b}	4.34^{b}	
ZECC	10.60^{a}	9.78^{a}	8.44^{a}	7.48^{a}	6.38^{a}	5.11^{a}	3.74
SEM (±)	0.099	0.101	0.067	0.067	0.077	0.099	
F-Test							
Preharvest sprays (A)	***	**	***	***	***	***	***
Storage conditions (B)	**	***	**	***	***	***	-
A*B	ns	ns	ns	ns	ns	ns	-
CV (%)	8.73	8.81	7.50	7.03	6.88	7.19	11.13

AS: ambient storage; ZECC: zero energy cooling chamber; $CaCl_2$: calcium chloride; SA: salicylic acid; ns: non-significant difference at $p \leq 0.05$; means followed by the same letter in a column are not significantly different at $p \leq 0.05$ (DMRT). ns, *, **, *** not significant or significant at $P \leq 0.05$ or $P \leq 0.01$ or $P \leq 0.001$, ANOVA.

chemicals on day 16, 24 and 28 storage periods (Table 6). The result showed that pH values increased with the advancement of ripening, in agreement with the findings of Al-Dairi et al. (2021) in which the pH of tomatoes increased with 12 days of storage. The increment in pH with storage might be attributed to the accumulation of organic acids (Ghafir et al., 2009).

The pH values of tomatoes stored in ambient environment ranged from 3.83 with calcium chloride (5%) on day 4 to 5.31 on the control tomatoes on day 28. The result showed that tomatoes sprayed with chemicals except chitosan (0.1%) had significantly lower pH values compared to other treatments and the control after 28 days of storage. The lowest pH values were recorded on tomatoes sprayed with salicylic acid (0.045%) followed by calcium chloride (5%) and calcium chloride (1%) whereas the highest was recorded on the control and tomatoes sprayed with chitosan (0.1%).

The reduction of pH values with sprays of chemicals could probably be due to the availability of more water inside the cells through production of osmotic pressure and enzymatic activities (Guan et al., 2009). Consistent with the present findings, Tolasa et al. (2021) reported that pH values were lower with pre-storage calcium chloride treatment compared to the control. Similar to this, Basit et al. (2020a,b) and Ullah et al. (2020) reported lower pH values of tomatoes with the application of chitosan. Contrary to the present finding, Almunqedi et al. (2017) and Tejashvini and Thippeshappa (2017) reported higher pH values with preharvest sprays of chitosan, calcium and salicylic acid compared to the control.

pH values were significantly ($p \leq 0.05$) affected by storage conditions in all the storage periods except on day 4 (Table 4). The result showed that the pH values of tomato increased with the advancement of ripening in both storage conditions. However, faster increment in pH was observed on tomatoes stored in ambient environment than inside ZECC storage conditions. Respiration and metabolic activities of tomatoes are directly related to the temperatures of the storage (Arah et al., 2015), which might have influence the pH. The present findings are in agreement with Mekbib (2016) who observed slow rate of increment in pH values on tomatoes stored inside ZECC storage than those stored in ambient condition. Melkamu et al. (2009) and Tolesa and Workneh (2017) also reported that the pH values of tomatoes stored inside evaporative cooling were lower compared to storing in ambient environment.

The interaction of preharvest sprays of chemicals and storage conditions did not have significant ($p \leq 0.05$) influence on the pH values of tomato in any of the storage periods.

3.6. Titratable acidity

Titratable acidity (TA) is one of the most important chemical attribute associated with the edible quality of fruits and it is used as maturity and ripening related indices in quality measurements (Cha et al., 2019). The interaction of preharvest sprays of chemicals and storage condition had significant ($p < 0.05$) influence on the TA of tomatoes on day 12 and 16 of storage period (Table 7). The result also showed that the TA values progressively decreased with the advancement of storage period. The loss of TA with ripening might be attributed to the utilization of malic or citric acids as respiratory substrates (Reddy et al., 2000). On day 16, tomatoes sprayed with salicylic acid (0.03%), salicylic acid (0.045%) and calcium chloride (5%) subjected to ZECC storage had highest (0.39%) TA while the control fruits stored in ambient condition had the lowest (0.27%) TA. The main effects of preharvest sprays of chemicals had significant ($p < 0.05$) influence on the TA of tomatoes on day 8, 20, 24 and 28 of storage periods (Table 8). At the end of storage period, tomatoes sprayed with calcium chloride, salicylic acid (0.045%) and chitosan (0.5%) had significantly higher TA values than the control. The highest TA was recorded on tomatoes sprayed with salicylic acid (0.045%) followed by calcium chloride (5%) while the lowest TA was recorded on the control fruits. The result showed that spraying tomatoes with salicylic acid (0.045%) and calcium chloride (5%) had 47.62% and 42.86%, respectively higher TA than the control. The retention of TA with preharvest sprays could be attributed to the role of chitosan and calcium in reducing respiration rate, thereby reducing the metabolic changes of organic acids into carbon dioxide and water (Gayed et al., 2017). In addition, Ding

Table 6. Main effects of preharvest sprays of chemicals and storage environment on the pH value of tomato fruits.

Treatments	Storage period (days)						
	4	8	12	16	20	24	28
Preharvest sprays (A)							
Chitosan (0.1%)	3.84	4.11^{ab}	4.41^{abc}	4.52^{bc}	4.77	5.11^{a}	5.30^{a}
Chitosan (0.3%)	3.84	4.20^{ab}	4.50^{a}	4.68^{a}	4.79	4.95^{bc}	4.94^{b}
Chitosan (0.5%)	3.96	3.99^{b}	4.34^{bc}	4.51^{bc}	4.74	4.89^{cde}	4.93^{b}
SA (0.015%)	3.84	4.05^{ab}	4.32^{bc}	4.64^{ab}	4.74	4.92^{bcd}	4.98^{b}
SA (0.03%)	4.02	4.06^{ab}	4.32^{bc}	4.53^{bc}	4.74	4.90^{cde}	4.92^{b}
SA (0.045%)	3.91	4.00^{b}	4.27^{c}	4.46^{c}	4.73	4.78^{e}	4.78^{b}
$CaCl_2$ (1%)	3.84	4.05^{ab}	4.35^{bc}	4.55^{bc}	4.76	4.89^{cde}	4.91^{b}
$CaCl_2$ (3%)	3.88	4.02^{b}	4.28^{bc}	4.50^{c}	4.74	4.88^{cde}	4.94^{b}
$CaCl_2$ (5%)	3.83	4.06^{ab}	4.31^{bc}	4.49^{c}	4.71	4.79^{de}	4.85^{b}
Control	4.00	4.24^{a}	4.43^{ab}	4.50^{c}	4.75	5.04^{ab}	5.31^{a}
SEM (±)	0.030	0.034	0.030	0.028	0.009	0.041	0.089
Storage conditions (B)							
AS	3.94	4.12^{a}	4.40^{a}	4.57^{a}	4.78^{a}	4.94^{a}	
ZECC	3.86	4.03^{b}	4.31^{b}	4.51^{b}	4.71^{b}	4.88^{b}	4.99
SEM (±)	0.010	0.012	0.012	0.008	0.009	0.008	
F-Test							
Preharvest sprays (A)	ns	ns	*	*	ns	***	**
Storage conditions (B)	ns	*	**	*	*	*	-
A*B	ns	ns	ns	ns	ns	ns	-
CV (%)	6.06	3.78	2.74	2.22	1.39	2.02	3.17

AS: ambient storage; ZECC: zero energy cooling chamber; $CaCl_2$: calcium chloride; SA: salicylic acid; ns: non-significant difference at $p \leq 0.05$; means followed by the same letter in a column are not significantly different at $p \leq 0.05$ (DMRT). ns, *, **, *** not significant or significant at $P \leq 0.05$ or $P \leq 0.01$ or $P \leq 0.001$, ANOVA.

Table 7. Interaction effects of preharvest sprays of chemicals and storage condition on the titratable acidity (% citric acid) of tomatoes on day 12 and 16 of storage period.

Treatments	Storage period (days)	
	12	16
Ambient Storage		
Chitosan (0.1%)	0.39^{abc}	0.28^{fg}
Chitosan (0.3%)	0.33^{cd}	0.32^{def}
Chitosan (0.5%)	0.36^{bc}	0.35^{abcde}
SA (0.015%)	0.36^{bc}	0.39^{a}
SA (0.03%)	0.36^{bc}	0.38^{ab}
SA (0.045%)	0.37^{abc}	0.37^{abc}
$CaCl_2$ (1%)	0.35^{bc}	0.34^{bcde}
$CaCl_2$ (3%)	0.35^{bc}	0.36^{abcd}
$CaCl_2$ (5%)	0.40^{ab}	0.38^{abc}
Control	0.29^{d}	0.27^{g}
Zero Energy Cooling Chamber		
Chitosan (0.1%)	0.29^{d}	0.33^{bcde}
Chitosan (0.3%)	0.37^{bc}	0.35^{abcde}
Chitosan (0.5%)	0.37^{abc}	0.37^{abc}
SA (0.015%)	0.38^{abc}	0.33^{cde}
SA (0.03%)	0.39^{abc}	0.39^{a}
SA (0.045%)	0.39^{abc}	0.39^{a}
$CaCl_2$ (1%)	0.37^{abc}	0.36^{abcd}
$CaCl_2$ (3%)	0.40^{ab}	0.37^{abc}
$CaCl_2$ (5%)	0.43^{a}	0.39^{a}
Control	0.34^{cd}	0.31^{ef}
CV (%)	8.32	6.77
SEM (±)	0.018	0.014
F-Test		
Preharvest sprays (A)	***	***
Storage conditions (B)	*	*
A*B	*	*

Table 8. Main effects of preharvest sprays of chemicals and storage condition on the titratable acidity (% citric acid) of tomatoes on day 4, 8, 20, 24 and 28 of storage period.

Treatments	Storage period (days)				
	4	8	20	24	28
Preharvest sprays (A)					
Chitosan (0.1%)	0.45	0.36^{c}	0.27^{d}	0.24^{c}	0.22^{bc}
Chitosan (0.3%)	0.46	0.41^{ab}	0.31^{bc}	0.30^{ab}	0.27^{abc}
Chitosan (0.5%)	0.42	0.37^{bc}	0.32^{bc}	0.31^{ab}	0.28^{ab}
SA (0.015%)	0.46	0.42^{ab}	0.30^{c}	0.28^{b}	0.26^{abc}
SA (0.03%)	0.46	0.41^{ab}	0.34^{ab}	0.31^{ab}	0.27^{abc}
SA (0.045%)	0.42	0.42^{ab}	0.34^{ab}	0.33^{a}	0.31^{a}
$CaCl_2$ (1%)	0.46	0.41^{ab}	0.32^{bc}	0.30^{ab}	0.28^{ab}
$CaCl_2$ (3%)	0.44	0.41^{ab}	0.32^{bc}	0.30^{ab}	0.28^{ab}
$CaCl_2$ (5%)	0.46	0.43^{a}	0.36^{a}	0.32^{ab}	0.30^{a}
Control	0.41	0.35^{c}	0.26^{d}	0.23^{c}	0.21^{c}
SEM (±)	0.008	0.011	0.013	0.013	0.018
Storage conditions (B)					
AS	0.45	0.39^{b}	0.29^{b}	0.28^{b}	
ZECC	0.44	0.41^{a}	0.34^{a}	0.30^{a}	0.27
SEM (±)	0.001	0.003	0.006	0.003	
F-Test					
Preharvest sprays (A)	ns	**	***	***	*
Storage conditions (B)	ns	*	***	**	-
A*B	ns	ns	ns	ns	-
CV (%)	8.25	9.11	8.10	10.84	11.42

AS: ambient storage; ZECC: zero energy cooling chamber; $CaCl_2$: calcium chloride; SA: salicylic acid; ns: non-significant difference at $p \leq 0.05$; means followed by the same letter in a column are not significantly different at $p \leq 0.05$ (DMRT). ns, *, **, *** not significant or significant at $P \leq 0.05$ or $P \leq 0.01$ or $P \leq 0.001$, ANOVA.

et al. (2007) stated that salicylic acid regulates the activities of synthetic and hydrolytic enzymes that affect the amount of organic acids. The present findings are in conformity with Kant & Arora (2014) who reported that treating tomatoes with 0.75 mM salicylic acid retained higher TA. Similarly, Mandal et al. (2016) also reported that tomatoes treated with 1−1.2 mM salicylic acid slowed the rate of drop in TA compared to the control. Regarding chitosan, Basit et al. (2020a, b) observed higher TA in tomatoes treated with 100 mgl^{-1} compared to the control. Similar to this, Parvin et al. (2019) also reported better retention of TA in tomatoes with preharvest foliar and soil application of chitosan. The main effects of storage conditions had significant ($p < 0.05$) influence on the TA of tomatoes on day 8, 20, 24 and 28 of storage periods (Table 8). The result showed that tomatoes stored inside ZECC retained higher TA than those kept in ambient condition. Higher rate of TA depletion in ambient storage condition could be attributed to the higher ripening and respiration rate where organic acids can be utilized as a substrate during the respiration process or due to conversion to other sugars (Hatami et al., 2013). The result indicated that ZECC storage kept the fruit acidic, which might contribute to the retention of tomato quality. The present result is in agreement with the findings of Abiso et al. (2015) and Mekbib (2016) who reported slow rate of TA decrement on tomatoes with storage inside ZECC. Similarly, Tolesa & Workneh (2017) and Melkamu et al. (2009) reported tomatoes stored inside evaporative cooling retained higher TA than those stored in ambient environment condition.

3.7. Total soluble solids (TSS)

Total soluble solids (TSS) reflects the tasting quality of produce and it is considered as an index of the ripening and an indicator of the number of soluble minerals and sugar present in fresh produce (Abiso et al., 2015). The TSS of the tomatoes was significantly ($p \leq 0.05$) influenced by both preharvest sprays and the storage conditions (Table 9). The TSS of tomatoes with preharvest sprays progressively increased during the first 20 days of storage period and started to decrease thereafter, which was in agreement with reports of Tolasa et al. (2021). The increment in TSS during storage period is probably attributed to the degradation of pectin substances in to simple sugars resulting in increase in TSS (Munhuewyi, 2012).

The result revealed that preharvest sprays of salicylic acid, calcium chloride and chitosan slowed down the rate of TSS increment compared to the control until the TSS reached its peak. This could be due to the role of salicylic acid in wide range of physiological and metabolic responses including delaying of the ripening process and decrease of fruit decay (Zeng et al., 2006). Abbasi et al. (2009) also noted that calcium chloride and chitosan are involved in the reduction of the activities of enzymes responsible for starch hydrolysis to soluble sugars.

The TSS value ranged from 3.85% in tomatoes sprayed with calcium chloride (5%) on day 4 to 5.20% on the control tomatoes on day 20. On day 20 of storage period, the highest TSS (5.20%) was recorded on the control followed by preharvest sprays of chitosan (0.1%) while the lowest (4.93%) was recorded on tomatoes sprayed with calcium chloride (5%). The findings of the present study are in line with Kumar et al. (2018a,b) who reported that preharvest spray of tomatoes with 0.75 mM salicylic acid resulted in 19% less TSS than the control. Hao and Papadopoulos (2004) observed slow rate of TSS increment of tomatoes with the application of 300 mg L^{-1}calcium. Moreover, lower TSS with preharvest applications of chitosan was reported in tomato by Migliori et al. (2017) and in kiwifruit by Kumarihami et al. (2021).

Generally, the TSS of tomatoes stored in ambient condition was higher than those stored inside ZECC storage. It ranged from 3.84% on

Table 9. Interaction effect of preharvest sprays of chemicals and storage environment on the TSS (%) of tomatoes.

Treatments	Storage period (days)						
	4	8	12	16	20	24	28
Preharvest sprays (A)							
Chitosan (0.1%)	3.86	4.01^{b}	4.53^{ab}	5.05^{ab}	5.08^{ab}	5.03^{abcd}	4.95^{ab}
Chitosan (0.3%)	3.88	3.98^{b}	4.47^{abc}	4.98^{ab}	5.02^{b}	5.14^{abc}	4.95^{ab}
Chitosan (0.5%)	3.87	4.01^{b}	4.40^{bc}	4.95^{b}	5.02^{b}	4.94^{cd}	4.82^{cd}
SA (0.015%)	3.89	4.08^{b}	4.53^{ab}	4.98^{ab}	5.09^{ab}	5.04^{abcd}	4.87^{bcd}
SA (0.03%)	3.89	4.02^{b}	4.49^{abc}	4.93^{b}	5.00^{b}	5.16^{ab}	5.02^{a}
SA (0.045%)	3.91	3.98^{b}	4.42^{bc}	4.89^{b}	4.98^{b}	4.97^{bcd}	4.80^{cd}
$CaCl_2$ (1%)	3.88	3.99^{b}	4.40^{bc}	4.92^{b}	5.02^{b}	4.89^{d}	4.80^{cd}
$CaCl_2$ (3%)	3.93	4.03^{b}	4.53^{ab}	4.87^{b}	4.98^{b}	5.22^{a}	4.88^{bc}
$CaCl_2$ (5%)	3.85	3.89^{b}	4.33^{c}	4.88^{b}	4.96^{b}	5.09^{abcd}	4.88^{bc}
Control	4.04	4.44^{a}	4.64^{a}	5.15^{a}	5.20^{a}	5.06^{abcd}	4.77^{d}
SEM (±)	0.022	0.060	0.036	0.035	0.029	0.042	0.033
Storage conditions (B)							
AS	3.96^{a}	4.13^{a}	4.52^{a}	5.02^{a}	5.05	5.10^{a}	
ZECC	3.84^{b}	3.95^{b}	4.43^{b}	4.90^{b}	5.02	5.00^{b}	4.87
SEM (±)	0.015	0.023	0.012	0.015	0.004	0.013	
F-Test							
Preharvest sprays (A)	ns	**	*	*	ns	*	***
Storage conditions (B)	*	***	*	**	ns	*	-
A*B	ns	ns	*	ns	ns	ns	-
CV (%)	5.56	4.82	3.09	2.83	2.55	3.01	1.21

AS: ambient storage; ZECC: zero energy cooling chamber; $CaCl_2$: calcium chloride; SA: salicylic acid; ns: non-significant difference at $p \leq 0.05$; means followed by the same letter in a column are not significantly different at $p \leq 0.05$ (DMRT). ns, *, **, *** not significant or significant at $P \leq 0.05$ or $P \leq 0.01$ or $P \leq 0.001$, ANOVA.

Table 10. Interaction effect of preharvest sprays of chemicals and storage environment on the ascorbic acid (mg $100g^{-1}$) of tomatoes on day 4, 16 and 24 of storage period.

Treatments	Storage period (days)		
	4	16	24
Ambient Storage			
Chitosan (0.1%)	9.37^{e}	15.43^{cdef}	11.43^{fgh}
Chitosan (0.3%)	12.38^{bcd}	15.75^{cdef}	11.20^{gh}
Chitosan (0.5%)	10.38^{cde}	15.76^{cdef}	13.17^{cdefg}
SA (0.015%)	15.89^{a}	17.73^{bcde}	14.32^{abcd}
SA (0.03%)	11.33^{bcde}	15.15^{def}	11.99^{efgh}
SA (0.045%)	11.85^{bcde}	15.11^{def}	12.83^{cdefg}
$CaCl_2$ (1%)	9.87^{de}	15.50^{cdef}	11.85^{efgh}
$CaCl_2$ (3%)	11.86^{bcde}	15.28^{def}	12.51^{defg}
$CaCl_2$ (5%)	11.70^{bcde}	17.64^{bcde}	12.96^{cdefg}
Control	9.25^{e}	14.12^{f}	10.27^{h}
Zero Energy Cooling Chamber			
Chitosan (0.1%)	11.49^{bcde}	15.87^{cdef}	13.41^{bcdef}
Chitosan (0.3%)	13.58^{ab}	16.45^{bcdef}	13.18^{cdefg}
Chitosan (0.5%)	11.74^{bcde}	16.64^{bcdef}	14.02^{abcde}
SA (0.015%)	11.44^{bcde}	15.73^{cdef}	12.94^{cdefg}
SA (0.03%)	11.58^{bcde}	18.01^{abcd}	14.87^{abc}
SA (0.045%)	13.97^{ab}	20.62^{a}	15.35^{ab}
$CaCl_2$ (1%)	11.98^{bcde}	18.91^{ab}	15.53^{a}
$CaCl_2$ (3%)	12.89^{bc}	18.39^{abc}	14.65^{abcd}
$CaCl_2$ (5%)	13.56^{ab}	19.22^{ab}	15.94^{a}
Control	12.04^{bcde}	14.89^{ef}	13.02^{cdefg}
CV (%)	12.80	9.14	8.46
SEM (±)	0.880	0.877	0.648
F-Test			
Preharvest sprays (A)	**	**	**
Storage conditions (B)	*	***	***
A*B	*	*	*

Table 11. Main effects of preharvest sprays of chemicals and storage environment on the ascorbic acid (mg $100g^{-1}$) of tomatoes on day 8, 12, 20 and 28 of storage period.

Treatments	Storage period (days)			
	8	12	20	28
Preharvest sprays (A)				
Chitosan (0.1%)	13.10^{ab}	13.97^{bc}	15.27^{b}	11.22^{cd}
Chitosan (0.3%)	12.95^{ab}	14.08^{abc}	16.28^{ab}	10.46^{e}
Chitosan (0.5%)	13.64^{ab}	15.93^{ab}	16.63^{ab}	10.42^{e}
SA (0.015%)	13.95^{a}	13.71^{bc}	17.55^{a}	10.73^{de}
SA (0.03%)	14.14^{a}	14.97^{ab}	16.96^{ab}	10.73^{de}
SA (0.045%)	14.81^{a}	15.15^{ab}	16.82^{ab}	12.52^{a}
$CaCl_2$ (1%)	12.80^{ab}	14.40^{abc}	16.58^{ab}	11.20^{cd}
$CaCl_2$ (3%)	14.60^{a}	16.54^{a}	16.92^{ab}	11.76^{bc}
$CaCl_2$ (5%)	14.70^{a}	15.42^{ab}	17.94^{a}	12.15^{ab}
Control	11.70^{b}	12.29^{c}	15.02^{b}	9.06^{f}
SEM (±)	0.408	0.499	0.369	0.212
Storage conditions (B)				
AS	12.75^{b}	14.09^{b}	15.24^{b}	
ZECC	14.52^{a}	15.20^{a}	17.95^{a}	11.03
SEM (±)	0.229	0.143	0.350	
F-Test				
Preharvest sprays (A)	*	*	*	***
Storage conditions (B)	***	*	***	-
A*B	ns	ns	ns	-
CV (%)	11.46	12.58	8.95	3.33

AS: ambient storage; ZECC: zero energy cooling chamber; $CaCl_2$: calcium chloride; SA: salicylic acid; ns: non-significant difference at $p \leq 0.05$; means followed by the same letter in a column are not significantly different at $p \leq 0.05$ (DMRT). ns, *, **, *** not significant or significant at $P \leq 0.05$ or $P \leq 0.01$ or $P \leq 0.001$, ANOVA.

tomatoes stored inside ZECC on day 4 to 5.10% on tomatoes stored in ambient condition on day 20. This could be due to the presence of higher temperature in ambient storage leading to higher rate of respiration and transpiration. The present study is in line with the findings of Abiso et al. (2015) and Mekbib (2016) who reported lower TSS values on tomatoes stored inside ZECC storage than ambient environment condition. Similarly, slow rate of TSS increment with evaporative cooling than ambient environment storage was observed by Melkamu et al. (2009).

The interaction of preharvest sprays and storage conditions did not have significant ($p \leq 0.05$) influence on the TSS of tomatoes except on day 12 of storage period. On day 12, the highest TSS was recorded on the control stored in ambient environment condition while the lowest TSS was recorded on tomatoes sprayed with calcium chloride (5%) and stored inside ZECC.

3.8. Ascorbic acid (AA)

The interaction of preharvest sprays of chemicals and storage conditions had significant ($p < 0.05$) effect on the ascorbic acid (AA) contents of tomatoes on day 4, 16 and 24 of storage periods (Table 10). The AA contents of tomatoes stored in ambient environment condition increased during the first 16 days of storage while it continued to increase up to 20 days on tomatoes stored inside ZECC storage, followed by a gradual decrease. The loss of AA after reaching the peak could be attributed to its susceptibility to oxidative destruction as impacted by the ripening environments (Nour et al., 2014). On day 16, the highest AA was recorded on tomatoes sprayed with salicylic acid (0.015%) and stored inside ZECC storage whereas the lowest AA was recorded on the control stored in ambient condition. Similarly, on day 24 of storage period, the highest AA was recorded on tomatoes sprayed with calcium chloride (5%) stored inside ZECC whereas the lowest was recorded on the control fruits stored in ambient condition. This indicates that preharvest sprays of chemicals integrated with evaporative cooling can result in tomatoes having higher AA contents. The main effects of preharvest sprays of chemicals had significant ($p < 0.05$) influence on the AA of tomatoes on day 8, 12, 20 and 28 of storage period (Table 11). At the end of storage period, tomatoes sprayed with chemicals showed significantly higher AA than the control, the highest being recorded on tomatoes sprayed with calcium chloride (5%) followed by salicylic acid (0.045%) and calcium chloride (3%).

The higher retention of AA with sprays of chemicals might be due to the role of calcium in regulating the oxidative processes in the cytosol (Hussain et al., 2012). Salicylic acid is also involved in the enhanced activation of some enzymes such as ascorbate peroxidase (Javaheri et al., 2012) and reduction of the rate of respiration and ethylene production (D. Mandal, Lalhmingchawii, Hazarika and Shukla, 2018). Moreover, chitosan is involved in the enhancement photosynthesis process that strongly are correlated with the synthesis of vitamins (Khan et al., 2002). The findings of the present study coincide with Islam et al. (2016), who reported that preharvest applications of calcium combined with boron increased the AA contents of tomatoes. Sarinana-aldaco et al. (2020) also reported 31.55% increment in AA of tomatoes with foliar applications of salicylic acid compared to the control. Similarly, application of chitosan either as foliar on tomatoes or on soil increased the AA content (Parvin et al., 2019).

The main effects of storage condition had significant ($p < 0.05$) influence on the AA of tomatoes on day 8, 12 and 20 of storage period (Table 11). Tomatoes stored inside ZECC recorded higher AA content

Table 12. Interaction effect of preharvest sprays of chemicals and storage environment on the lycopene content (mg $100g^{-1}$ FW) of tomato fruits.

Treatments	Storage period (days)						
	4	8	12	16	20	24	28
Ambient Storage							
Chitosan (0.1%)	2.39^{bcd}	3.32^{abcd}	4.31^{abcd}	4.76^{b}	6.18^{a}	6.63^{abc}	
Chitosan (0.3%)	2.53^{abc}	3.46^{ab}	4.32^{abcd}	4.59^{bcdef}	5.49^{bcd}	6.62^{abc}	
Chitosan (0.5%)	2.54^{ab}	3.44^{ab}	4.02^{cde}	4.61^{bcde}	5.27^{bcde}	6.50^{abcd}	
SA (0.015%)	2.44^{bc}	2.83^{e}	4.54^{ab}	4.45^{bcdef}	5.65^{b}	6.84^{a}	
SA (0.03%)	2.62^{ab}	3.23^{abcd}	4.11^{bcde}	4.43^{cdef}	5.49^{bcd}	6.36^{abcd}	
SA (0.045%)	2.64^{ab}	3.16^{abcde}	4.12^{bcde}	4.36^{cdef}	4.47^{g}	5.53^{ef}	
$CaCl_2$ (1%)	2.53^{abc}	3.35^{abc}	4.10^{bcde}	4.68^{bc}	5.62^{bc}	6.45^{abcd}	
$CaCl_2$ (3%)	2.61^{ab}	3.25^{abcd}	4.14^{bcde}	4.49^{bcdef}	5.48^{bcd}	6.00^{bcde}	
$CaCl_2$ (5%)	2.64^{ab}	3.13^{bcde}	4.10^{cde}	4.38^{cdef}	5.48^{bcd}	6.01^{bcde}	
Control	2.42^{bcd}	3.51^{a}	4.46^{abc}	5.10^{a}	5.24^{bcde}	6.66^{ab}	
Zero Energy Cooling Chamber							
Chitosan (0.1%)	2.74^{a}	3.23^{abcd}	4.67^{a}	4.60^{bcdef}	5.25^{bcde}	5.91^{def}	6.59^{bcd}
Chitosan (0.3%)	2.50^{bc}	3.01^{cde}	4.06^{cde}	4.36^{cdef}	5.14^{def}	6.01^{bcde}	6.70^{abcd}
Chitosan (0.5%)	2.47^{bc}	3.17^{abcde}	4.42^{abc}	4.34^{def}	5.06^{ef}	6.04^{bcde}	7.14^{ab}
SA (0.015%)	2.20^{d}	3.30^{abcd}	4.09^{bcde}	4.47^{bcdef}	5.21^{cde}	5.92^{cdef}	6.81^{abc}
SA (0.03%)	2.47^{bc}	3.06^{cde}	3.89^{de}	4.32^{ef}	5.13^{def}	6.01^{bcde}	6.04^{de}
SA (0.045%)	2.51^{abc}	3.11^{bcde}	3.96^{de}	4.27^{f}	5.08^{def}	5.28^{f}	5.85^{e}
$CaCl_2$ (1%)	2.50^{bc}	3.11^{bcde}	3.93^{de}	4.65^{bcd}	5.21^{cde}	5.90^{def}	6.70^{abcd}
$CaCl_2$ (3%)	2.41^{bcd}	3.09^{bcde}	3.94^{de}	4.29^{ef}	5.20^{cde}	5.83^{def}	6.14^{cde}
$CaCl_2$ (5%)	2.45^{bc}	2.96^{de}	3.83^{e}	4.28^{ef}	5.12^{def}	5.27^{f}	6.38^{cde}
Control	2.29^{cd}	3.17^{abcde}	4.13^{bcde}	4.36^{cdef}	4.79^{f}	6.00^{bcde}	7.33^{a}
CV (%)	5.01	6.07	5.51	3.73	4.10	5.94	5.46
SEM (±)	0.072	0.112	0.132	0.097	0.125	0.209	0.207
F-Test							
Preharvest sprays (A)	*	ns	**	***	***	***	**
Storage conditions (B)	*	**	*	***	***	***	-
A*B	*	*	*	*	***	ns	-

AS: ambient storage; ZECC: zero energy cooling chamber; $CaCl_2$: calcium chloride; SA: salicylic acid; ns: non-significant difference at $p \leq 0.05$; means followed by the same letter in a column are not significantly different at $p \leq 0.05$ (DMRT). ns, *, **, *** not significant or significant at $P \leq 0.05$ or $P \leq 0.01$ or $P \leq 0.001$, ANOVA.

compared to those stored in ambient environment condition. On day 20, tomatoes stored inside ZECC had 17.78% more AA than the control. Under higher temperature condition, the losses of vitamin C are accelerated (Lee and Kader, 2000) due to increased respiration rate and other metabolic processes. The results are in accordance with Mekbib (2016) who reported that storing tomatoes inside ZECC reduced the storage temperature and resulted in higher AA than storing in ambient environment. Similar to this, Melkamu et al. (2009) also reported higher AA with storage of tomatoes inside evaporative cooling.

3.9. Lycopene

Lycopene is a carotenoid that is found mainly in tomatoes having antioxidant, anti-inflammatory and chemotherapeutic effects on cardiovascular, neurodegenerative diseases and some types of cancer (Przybylska, 2020). The lycopene contents of tomatoes were significantly ($p \leq 0.05$) influenced by preharvest sprays of chemicals and storage conditions. It increased progressively with the advancement of ripening (Table 12). This increment could be attributed to the rapid accumulation of carotenoid as chloroplasts are converted to chromoplast (Abiso et al., 2015). The lycopene content of tomatoes sprayed with salicylic acid (0.045%) and the control stored in ambient storage condition increased from 2.64 to 5.53 mg $100g^{-1}$ fresh weight (FW) and 2.42–6.66 mg $100g^{-1}$FW, respectively over 24 days of storage period. Similarly, the lycopene contents of tomatoes sprayed with salicylic acid (0.045%) and the control stored inside ZECC increased from 2.51 to 5.85 mg $100g^{-1}$ FW and 2.29–7.33 mg $100g^{-1}$ FW, respectively over 28 days of storage period.

Table 13. Interaction effect of preharvest sprays of chemicals and storage condition on the shelf life of tomatoes.

Treatments	Shelf life (days)
Ambient Storage	
Chitosan (0.1%)	18.33^{g}
Chitosan (0.3%)	19.00^{fg}
Chitosan (0.5%)	18.33^{g}
SA (0.015%)	21.00^{ef}
SA (0.03%)	21.67^{de}
SA (0.045%)	24.33^{c}
$CaCl_2$ (1%)	23.67^{cd}
$CaCl_2$ (3%)	24.67^{c}
$CaCl_2$ (5%)	25.33^{bc}
Control	14.67^{h}
Zero Energy Cooling Chamber	
Chitosan (0.1%)	25.33^{bc}
Chitosan (0.3%)	25.33^{bc}
Chitosan (0.5%)	26.00^{bc}
SA (0.015%)	25.67^{bc}
SA (0.03%)	25.33^{bc}
SA (0.045%)	29.67^{a}
$CaCl_2$ (1%)	26.00^{bc}
$CaCl_2$ (3%)	27.33^{b}
$CaCl_2$ (5%)	30.33^{a}
Control	24.33^{c}
CV (%)	5.74
SEM (±)	0.789
F-Test	
Preharvest sprays (A)	***
Storage (B)	***
A*B	***

AS: ambient storage; ZECC: zero energy cooling chamber; $CaCl_2$: calcium chloride; SA: salicylic acid; ns: non-significant difference at $p \leq 0.05$; means followed by the same letter in a column are not significantly different at $p \leq 0.05$ (DMRT). ns, *, **, *** not significant or significant at $P \leq 0.05$ or $P \leq 0.01$ or $P \leq 0.001$, ANOVA.

At the initial stage, the lycopene contents of tomatoes with preharvest sprays were higher than the control and this finding is consistent with the reports of different authors (Parvin et al., 2019; Sarinana-aldaco et al., 2020). However, the rate of lycopene accumulation of the control exceeded tomatoes with preharvest sprays resulting in higher lycopene content on the control. The lower lycopene content in tomatoes with preharvest sprays could be attributed to the role of salicylic acid in delaying the biosynthesis of lycopene (Kant and Arora, 2014). In addition, calcium and chitosan are involved in the reduction of the rate of respiration and maturity (Olawuyi et al., 2019; Saftner et al., 1999). The present finding is in agreement with Mazumder et al. (2021) who reported that 3% calcium foliar applications lowered the rate of lycopene increment. The report by Kumar et al. (2018a,b) also indicated that preharvest sprays of salicylic acid on tomatoes at a concentration of 0.75 mM rate resulted in 20% less lycopene content than the control in 12 days of storage.

Tomatoes stored in ambient environment condition had higher lycopene than those stored inside ZECC storage. The lycopene content of tomatoes stored in ambient storage condition increased from 2.54 to 6.36 mg $100g^{-1}$FW over 24 days of storage period whereas it increased from 2.45 to 6.57 mg $100g^{-1}$FW on tomatoes stored inside ZECC storage over 28 days of storage. The higher lycopene content in ambient storage condition could probably be due to the role of higher temperature below 30 °C in lycopene formation (Dumas et al., 2003). The findings of the present study is in agreement with Abiso et al. (2015) who reported that storing tomatoes inside ZECC storage increased the lycopene contents at slower rate than storing in ambient environment condition. Al-Dairi et al. (2021) also observed higher lycopene contents in tomatoes stored at 22 °C than tomatoes stored at 10 °C.

The interaction of preharvest sprays of chemicals and storage conditions had significant ($p \leq 0.05$) effect on the lycopene contents of tomatoes on day 4, 8, 12 and 16 of storage period. On day 16, the highest lycopene was recorded on the control stored in ambient environment condition while the lowest was recorded on tomatoes with preharvest sprays of salicylic acid (0.045%) and stored inside ZECC storage. The lower lycopene content in salicylic acid sprayed tomatoes and stored inside ZECC storage might be due to role of salicylic acid and low temperature condition in reducing respiration rate (Kant and Arora, 2014; Mekbib, 2016).

3.10. Shelf life

Both preharvest sprays of chemicals and storage conditions had significant ($p \leq 0.001$) effect on the shelf life of tomatoes (Table 13). The result showed that preharvest sprays of salicylic acid, calcium chloride and chitosan were effective in extending the shelf life of tomatoes. The shelf life of tomatoes stored in ambient storage condition ranged from 25.33 days with calcium chloride (5%) to 14.67 days on the control while the shelf life of tomatoes stored inside ZECC storage ranged from 30.33 days with calcium chloride (5%) to 24.33 days on the control. All preharvest sprays prolonged the shelf life of tomatoes in ambient environment whereas storing tomatoes inside ZECC resulted in extended shelf life with only salicylic acid (0.045%) and calcium chloride (3% and 5%).

The extended storability could be attributed to the inhibitory effects of salicylic acid on climacteric respiration and ethylene production (Kant and Arora, 2014). Calcium also plays a key role in the structure of cell wall and cell membrane (Kadir, 2005) influencing cell metabolisms. Calcium also enhances resistance to bacteria and virus diseases (Ustun et al., 2009). Moreover, chitosan increases cell wall contents, suppresses genes involved in the ethylene signaling pathway and triggers immunity (He et al., 2018). The findings of the present study agrees with the reports by Javanmardi and Akbari (2016) with sprays of SA. Islam et al. (2016) also reported prolonged shelf life of tomato with spray of calcium. The study by Almunqedi et al. (2017) indicated that spray of chitosan alone or

in combination with salicylic acid was found to extend the shelf life of tomatoes.

Tomatoes stored inside ZECC storage showed extended shelf life than those stored under ambient condition. The shorter shelf life of tomatoes stored in ambient storage might be due to the role of high temperature in enhancing the rates of physico-chemical changes, shortening the time to reach fully ripe stage. This finding is in accordance with reports of different authors (Getinet et al., 2011; Tolesa and Workneh, 2017), in which low temperature through evaporative cooling reduced the rate of deterioration of tomatoes.

The interaction of preharvest sprays and storage conditions had significant ($p \leq 0.001$) effect on the shelf life of tomatoes. Tomatoes sprayed with calcium chloride (5%) had the longest shelf life followed by salicylic acid (0.045%) stored in ZECC storage, while the shortest shelf life was recorded on the control stored under ambient environment. Generally, preharvest sprays of chemicals integrated with cold storage prolonged the shelf life of tomatoes. This could be attributed to the role of calcium in cell wall structure and salicylic acid in the reduction of respiration rate (Kadir, 2005; Kant and Arora, 2014). Besides this, the lower temperature condition created inside the storage environment by ZECC reduced the rate of ripening (Mekbib, 2016).

4. Conclusion

Preharvest sprays of salicylic acid, calcium chloride and chitosan influenced the postharvest quality and shelf life of tomatoes. Among the preharvest sprays, calcium chloride (5%) and salicylic acid (0.045%) were better in delaying the changes in physico-chemical characteristics of tomatoes during storage as compared to the untreated control. Maximum firmness was maintained by preharvest sprays of calcium chloride (5%) and salicylic acid (0.045%). In addition, they reduced the weight loss and maintained the marketability for longer period. Preharvest spray of calcium chloride and salicylic acid slowed the rate of increment of TSS, lycopene and pH. Furthermore, the titratable acidity and ascorbic acid contents increased with preharvest spray of these chemicals. The study also indicated that chitosan improved the shelf life of tomato under ambient storage condition. Compared to ambient environment storage, evaporative cooling provided in the form of zero energy cool chamber maintained the physico-chemical qualities and extended the shelf life of tomatoes. This suggests that integrating cold storage and preharvest spray of chemicals can be used to prolong the shelf life and keep the postharvest quality of tomatoes.

Declarations

Author contribution statement

Aleminew Tagele: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Kebede Woldetsadik; Fikreyohannes Gedamu: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Mokula Mohammed Rafi: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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