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Impact of Evaporative cooling technology & Post-harvest treatments on shelf life and quality of tomato of two different harvesting stages (Solanum lycopersicum var. Pearson)

Sayed Samiullah Hakimi[1,2], Ravinder Raina[3] and Yashpal Singh Saharawat[4]

[1]*Horticulture Department, Agriculture Faculty, Kabul University, Kabul, Afghanistan*
[2]*AIHSR, Amity University Uttar Pradesh, Noida, India*
[3]*AFAF, Amity University Uttar Pradesh, Noida, India*
[4]*SSAC, Indian Agriculture Research Institute, New Delhi, India*

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ABSTRACT

The Zero Energy Cool Chamber (ZECC) is the needed evaporative cooling system introduced as one of the economical small scale on-farm storage in Afghanistan for enhancing the shelf life of tomato and other fresh crops. Tomato is one of the highest value crops, and due to excellent flavor, higher juice, and pulp content of tomato fruits of "Pearson" variety makes it further valuable. Hence, this study aims to understand the effect of ZECC and postharvest treatments on shelf life and quality of tomato's fruits harvested at turning and light red colors' stages. Fruits were treated with different concentrations of $CaCl_2$ and mint leaf extract solutions and kept in both ZECC and ambient storages. The shelf life of tomato fruits extended up to 29 days under T_4 (turning color fruits + 6% $CaCl_2$ + ZECC). Under the same treatment, the highest firmness as 840.0 $grcm^{-2}$ and the lowest PLW, Decay Losses and TSS were recorded as 1.80%, 0.0% and 4.40^0 brix, respectively; on the 20th day of the storage. The lowest shelf life under T_{11} (Light red color fruits + distilled water dip + Ambient condition) was about 8 days. As a result, the ZECC as an evaporative cooling system significantly enhanced the shelf life and maintained the quality of tomato fruits harvested at the turning color stage treated with 6% $CaCl_2$.

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1. Introduction

Annually, there is a huge amount of fresh horticultural crop loss due to harvesting in warm temperatures, lack of harvesting, postharvest management, and market facilities. The unavailability of proper on-farm storage due to its high cost is a challenge for small farmers, especially from developing countries like Afghanistan. Zero Energy Cool Chamber (ZECC) is considered the most economical and suitable evaporative cooling technology for enhancing the shelf life of fresh vegetables and fruits and is a tried and tested model in India developed by Roy & Khurdiya [1,2]. ZECC has also been tested in various other countries of the world, that utilizes high relative humidity and low temperature as a principle of cool storage for enhancing the shelf life of the fresh commodities. In comparison to ambient conditions, ZECC increases the relative humidity and decreases the temperature to suitable levels for enhancing the shelf life of fresh fruits and vegetables. Such storage provides cool humid conditions by dropping cool water on the sand between the two brick walls. Warm air passing through the moist sand picks up water in the form of water vapor, increasing the relative humidity. A stable natural wind blow around the ZECC for the proper air movement inside the structure is good. Accordingly, latent heat is absorbed by the increased humidity, which reduces heat in the air, thus cooling fruits inside the ZECC with a low range of transpiration and physiological activities [1].

During the course of the present research studies, ZECC was introduced in Afghanistan for the first time to try and test its suitability to small scale farmers as on-farm storage (cooling technology) for enhancing fruits and vegetables' shelf life. Most of the small scale farmers are having an average farm size of 1.14 hectares of irrigated land and are not much wealthy. During the year 2019, the total production area of fruits and vegetables was about 307,434 and 116,970 hectares respectively [3], but huge quantities might have been lost due to challenges described above and additionally also due to lack of skills and knowledge about harvest and postharvest practices. In Afghanistan, tomato was the 4th most cultivated vegetable (after potato, muskmelon and watermelon) during 2018 and it covered 24,892 hectares' land producing 275,222 metric tons.

Tomato (*Solanum lycopersicum* L.) is an essential high-value crop globally that plays a vital role in human health. It contains high levels of carotenoids, lycopene, antioxidants that are beneficial in reducing diseases such as cancer, heart diseases, and also cardiovascular disorders [4]. Tomatine reduces cholesterol and triglyceride levels in blood plasma that boost body immunity against bacterial contaminations. Tomato is a good source of phenolic compounds, vitamins C, E, A, etc., [4–7].

The most common and famous varieties of tomatoes, such as Pearson, Roma, and Heinz are grown in Afghanistan. In recent times, many more hybrid varieties are being grown all over the country. Among different types, "Pearson" is the most popular due to its best test and flavor, higher juice content, good pulp, medium to large size, etc., making it appropriate for fresh use in burger, salad, sandwich, and in processing. However, its fruits are

Corresponding author: SS Hakimi
Email: hakimi.ss.ku.af@gmail.com

sensitive to postharvest handling and have a concise shelf life; full red color fruits have a 3 to 6 days shelf life under ambient condition.

In Afghanistan, tomatoes are usually used fresh and dried (used as a flavoring agent in food items mostly during the offseason). In recent times, the manufacture of tomato paste and puree has become common at the household level, but the scale is limited due to the lack of required infrastructure. Farmers face various problems and have more than 40% loss of tomatoes and other fresh crops because of low level of skills and knowledge about appropriate maturity stages, lack of experience of proper harvest and post-harvest practices, lack of suitable post-harvest treatments and on-farm storage to prolong the shelf life of tomato fruits. Targeting the challenges mentioned above, present studies were planned to find out the low cost and easily available on-farm storage to be introduced at farmers' level. Furthermore, understanding the proper harvesting stages of tomato fruits and their post-harvest treatments is also critical for maintaining tomato fruit quality, increasing shelf life during storage, and reducing their losses [8].

This study was carried out to understand the impact of ZECC as an evaporative cooling technology and post-harvest treatments on postharvest quality and shelf life of tomato fruits (variety "Pearson") harvested at two different maturity stages. As a result of this study, we succeeded in prolonging the shelf life of tomatoes up to 29 days in ZECC. The shelf life of tomato treated using hot water (at 60^0C temperature) and stored under ZECC extended up to 29 days [9]. Also, the tomatoes' shelf life extended to 28 days under ZECC, whereas it was up to a maximum of 7 days at ambient condition said by [9,10]. The ZECC was developed at Indian Agricultural Research Institute (IARI), New Delhi, India, and significantly affects the enhancement of the shelf life of vegetables and fruits [11]. The postharvest treatments and harvesting stages of tomatoes may also affect the fruit's quality and shelf life. As tomato' fruits of the pink stage treated with 6% $CaCl_2$ for 20 minutes had retained their quality to the optimum level [12]. Also, the mint leaves' extract might have been a good substitute for chemicals due to its antimicrobial activities [13] and even the antifungal activities of peppermint reported by [14].

2. Materials and methods

ZECC, a tested model in other countries, was introduced in Afghanistan to test its suitability for on-farm storage of tomato fruits to improve shelf life. In 2018, the study was conducted in the Research Farm of Agriculture Faculty of Kabul University, located at 340 52 N and 690 12 E with an elevation of 1810 meters above sea level and its soil type alkaline, silty loam.

2.1. Production of tomatoes

Before setting up the ZECC, pure seeds of tomato 'Pearson', variety has procured from an authorized seed production agency, was sowed on 9th March 2018 for nursery in the aforesaid research farm. After nine days, seeds germinated and seedlings transplanted in the tomato production field after 38 days from germination. The best agricultural practices considered for the proper management of tomato fields from seed sowing to fruit harvesting.

2.2. Fruits harvesting and postharvest management

The tomato fruits have been turned to the green mature stage after 90 days from transplanting. The maturity understood by the appearance of the fruits with the help of the tomato color chart. Since the study was planned to be carried out on the tomatoes of two different (Turning and light red color) maturity stages under both storage condition, fruits were harvested simultaneously after 101 days from transplanting. Before treatment application, fruits were sorted, graded, and precooled for proper postharvest management of tomatoes.

2.3. Storage type

The tomato fruits were studied under two different storage conditions as Ambient and ZECC at the same research farm.

2.3.1. Zero Energy Cool Chamber

Before tomatoes harvesting, the standard Pusa ZECC was established having a size of 165 x 115 x 67.5 cm^3 as reported in the literature [1,15]. The ZECC had the capacity of about 300 kg fruits provided next to the tomato production field. The space between the two walls of bricks maintained was 7.5 cm apart and filled with sand. One end of the drip irrigation pipe was fixed at the top of the wall (an outlet on sand held between two walls on the top of the sand) and the other to the water tank. The frame was made of bamboo sticks, woven with straw, and covered with the gunny sack to put it on the ZECC.

Furthermore, a shade by the woven mesh and followed by a tarpaulin cover was provided above the whole structure of ZECC. The temperature decreased from the maximum average of 30^0C to 12^0C and the relative humidity has increased from average of 25 % to the 95% inside the ZECC recorded during the storage period. Although the relative humidity might have been increased up to 99 %, it controlled to prevent the fungal infection and decay of tomato fruits.

2.3.2. Ambient storage

The ambient storage managed properly having an appropriate structure and air ventilation system. During 17 days storage period, the average relative humidity and temperature of ambient condition recorded as 26% and 22^0C, respectively.

2.4. Experimental details

The research was planned considering three factorial Completely Randomized Design (CRD).

2.4.1. Factors

The experiment included three factors as (harvesting stage x postharvest treatment x storage condition) at two, five, and two levels respectively presented in Table 1.

Table 1: Factors' level and details.

Factors	
Factor I - Harvesting stage (H)	H1 (Harvest stage 1/Turning color stage)
	H2 (Harvest stage 2/Light red color stage)
Factor II - Postharvest treatment (D)	D0 (Dip in distill water)
	D1 (Dip in 6% CaCl2 solution)
	D2 (Dip in 6% CaCl2 + 2% mint leaves' extract solution)
	D3 (Dip in 6% CaCl2 + 4% mint leaves' extract solution)
	D4 (Dip in 6% CaCl2 + 6% mint leaves' extract solution)
Factor III - Storage type (S)	S1 (Storage 1/Ambient Condition)
	S2 (Storage 2/ZECC)

2.4.2. Treatments' details

Considering factor combinations and objective, the experiment contains 20 treatments and two replications. The treatment details are shown in Table 2.

2.4.3. Treatments preparation and application

$CaCl_2$ was procured from the authorized company. Mints were procured from the central market and their leaves are washed and subjected for juice extraction through a juicer machine without adding any reagents (One liter juice extracted from 12kg of mints). The tomato fruits treated with the postharvest treatments mentioned in Table 2, fruits dipped for 20 minutes in 20 treatments' solution having various combinations under three factorial CRD design. Each treatment replicated twice and each experimental unit contains 500 gr tomato fruits put in the plastic trays. A total of 40 experimental units were subjected for each date of the data collection under ambient and ZECC conditions.

2.4.4. Data recording

The initial data had been recorded before the treatment application. Except for the shelf life, data on quality parameters have been recorded after every 10 days' interval under both ZECC and ambient condition.

Tomatoes' shelf life was observed daily till the fruits were acceptable for marketing. TSS (^{0}brix) was determined by a handheld refractometer that used tomato juice. Also, firmness (grcm^{-2}) checked from the middle of the fruit by a handheld penetrometer [16]. PLW (%) and Decay loss (%) are calculated considering the following formulas respectively [17].

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

$$\text{Decay loss (\%)} = \frac{\text{Number of decay fruits}}{\text{Total number of fruits}} \times 100 \quad (2)$$

Table 2: Treatments details.

Treatments	Treatments details
H1D0S1	T1-Turning color fruits dipped in distilled water + Ambient Condition
H1D0S2	T2-Turning color fruits dipped in distilled water + ZECC Condition
H1D1S1	T3-Turning color fruits dipped in 6% CaCl2 solution + Condition
H1D1S2	T4-Turning color fruits dipped in 6% CaCl2 solution + ZECC Condition
H1D2S1	T5- Turning color fruits dipped in 6% CaCl2 + 2% mint leaves' extract solution + Ambient Condition
H1D2S2	T6- Turning color fruits dipped in 6% CaCl2 + 2% mint leaves' extract solution + ZECC Condition
H1D3S1	T7- Turning color fruits dipped in 6% CaCl2 + 4% mint leaves' extract solution + Ambient Condition
H1D3S2	T8- Turning color fruits dipped in 6% CaCl2 + 4% mint leaves' extract solution + ZECC Condition
H1D4S1	T9- Turning color fruits dipped in 6% CaCl2 + 6% mint leaves' extract solution + Ambient Condition
H1D4S2	T10- Turning color fruits dipped in 6% CaCl2 + 6% mint leaves' extract solution + ZECC Condition
H2D0S1	T11- Light red color fruits dipped in distilled water + Ambient Condition
H2D0S2	T12- Light red color fruits dipped in distilled water + ZECC Condition
H2D1S1	T13- Light red color fruits dipped in 6% CaCl2 solution + Ambient Condition
H2D1S2	T14- Light red color fruits dipped in 6% CaCl2 solution + ZECC Condition
H2D2S1	T15- Light red color fruits dipped in 6% CaCl2 + 2% mint leaves' extract solution + Ambient Condition
H2D2S2	T16- Light red color fruits dipped in 6% CaCl2 + 2% mint leaves' extract solution + ZECC Condition
H2D3S1	T17- Light red color fruits dipped in 6% CaCl2 + 4% mint leaves' extract solution + Ambient Condition
H2D3S2	T18- Light red color fruits dipped in 6% CaCl2 + 4% mint leaves' extract solution + ZECC Condition
H2D4S1	T19- Light red color fruits dipped in 6% CaCl2 +6% mint leaves' extract solution + Ambient condition
H2D4S2	T20- Light red color fruits dipped in 6% CaCl2 + 6% mint leaves' extract solution + ZECC Condition

2.4.5. Data analysis

The data were analyzed with the R- Program. The following linear model was used to perform a three-way Analysis of Variance (ANOVA) to test the effects of H, D, and S, on response variables. P- values are considered in the table.

$$y\_ijkl = \mu + H\_i + D\_j + S\_k + (HD)\_ij + (HS)\_ik + (DS)\_jk + (HDS)\_ijk + \varepsilon\_ijkl \quad (3)$$

Where y_{ijkl} is the lth observation in kth storage condition, jth post-harvest treatment, and ith harvesting stage; μ is the overall mean; H_i is the fixed effect of harvesting stage (i = 1,2); D_j is the fixed effect of post-harvest treatment (j = 1,2,3,4,5); S_k is the fixed effect of storage condition (k = 1,2); $(HD)_{ij}$ is the interaction of harvesting stage and post-harvest treatment; $(HS)_{ik}$ is the interaction of stage of harvesting and storage condition; $(DS)_{jk}$ is the interaction of post-harvest treatment and storage condition; $(HDS)_{ijk}$ is the three-way interaction of stage of harvesting, post-harvest treatment, and storage condition; ε_{ijkl} and is random error term with $\varepsilon_{ijkl} \sim N(0, \sigma_\varepsilon^2)$. Tukey procedure was used to compare the least square means of three-way interactions at α = 0.05. Models were fit in R statistical environment using lm () function. Also, the simple linear regression analysis of two variables considered as a sample for the firmness and shelf life of the fruits.

$$Y = 4.52 + 0.022x;\ R2 = 0.66 \quad (4)$$

3. Result and discussion

ZECC was found highly innovative and low-cost evaporative cooling technology in Afghanistan. This on-farm technology dramatically increased the average relative humidity from 25 to 95%, whereas it reduced the temperature from a maximum average of 30°C to 12°C during 29 days of the tomato storage period. The combination mentioned above has positively influenced the quality and shelf life of tomato fruits. Fortunately, ZECC could be effective for tomato shelf life and may be more effective for increasing the storage life of various other vegetables and fruits in various parts of the country. Since Afghanistan has a dry temperate climate, having proper wind may increase the efficiency of the above technology. In general, the main effect of all factors was significant about all dependent variables except TSS that only postharvest treatments have a substantial impact on it.

In comparison, the two and three-way interactions were significant for the TSS (^{0}B), PLW (%), and Decay loss (%). Also, the interactions of H*D and D*S were significant about the firmness of the fruits (Table 3). It might be due to the combined effect of all factors. Specifically, ZECC is much needful technology for prolonging the tomato shelf life. It significantly impacts tomato quality and storage life compared to the ambient condition [11].

Table 3: The Anova table of the 10th day data presenting P-values.

Anova, 10th day data, P- Value, Pr(>F)					
Source of variation	Shelf life	Firmness	TSS	PLW	Decay loss
H	0.000	0.000	**0.384**	0.000	0.000
D	0.000	0.000	0.001	0.000	0.000
S	0.000	0.000	**0.125**	0.000	0.000
H*D	**0.633**	0.000	0.000	0.000	0.000
H*S	**0.534**	**0.811**	0.008	0.000	0.000
D*S	**0.179**	0.001	0.000	0.000	0.000
H*D*S	**0.633**	**0.110**	0.000	0.000	0.002

The highest shelf life was observed about 29 days under the treatment T_4 (Turning color fruits dipped in 6% $CaCl_2$ solution + ZECC condition). In contrast, the same combination (T_3) extended the shelf life until 17 days under ambient condition. Thus, the aforesaid storage life of turning color tomatoes under evaporative cooling technology and ambient condition is a significant achievement for the suitable storage of tomatoes in the markets of Afghanistan. The lowest shelf life under T_{11} (Light red color fruits + distilled water dip + Ambient condition) was about 8 days. It is reported that usually full red color fruits of tomato may have 3 to 6 days' storage life in ambient condition. The same result showed that the shelf life of tomato treated with hot water (60^{0}C temperature) and stored under ZECC extended till 29 days compared to the 7 days' storage life of tomato's fruits of the ambient condition [10].

The tomatoes under ambient condition were discarded before the data collection on the 20th day of the storage period. Hence, the result of the 20th-day data is presented based on the general mean of the data. However, all figures defining the trends of the data of both day 10th and 20th day of fruits storage. The majority of the parameters have a relationship with the shelf life of tomato fruits as a sample of regression analysis of firmness with the shelf life of tomato present in Figure 1. The line is the linear regression fit with p-value <0.0001. The Figure 1. revealed that fruits that have the highest firmness value maintained the highest shelf life compared to those with low firmness value.

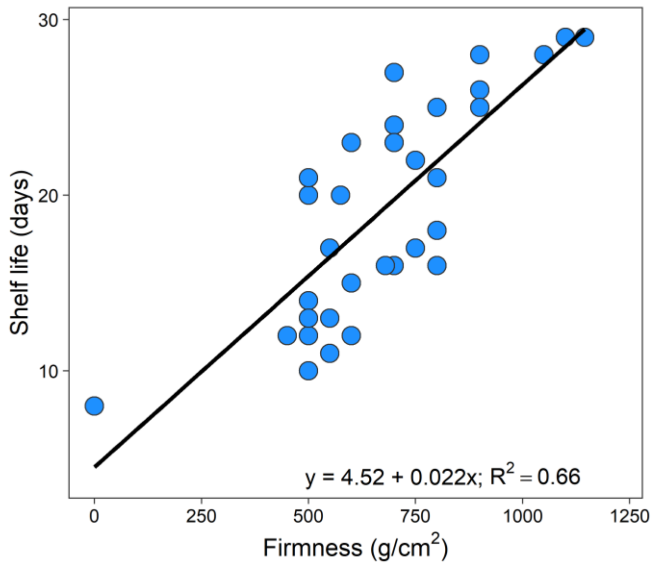

Figure 1. Scatterplot showing relationship between shelf life and firmness of tomato fruits.

Results on every specific parameter of tomato (var. Pearson) fruits have been discussed individually.

3.1. Tomatoes shelf life

ZECC technology, postharvest treatments and harvesting stage increased the shelf life of tomatoes. The tomato shelf life was much more under ZECC conditions compared to ambient storage showed in plots of Figure 2. Furthermore, the turning stage looks much better compared to the light red stage. Based on Table 3. the main effect was highly significant on the storage life of tomatoes. The shelf life of tomatoes increased up to 29 days through the effect of treatment T_4 (Turning color fruits dipped in 6% $CaCl_2$ solution + ZECC). T_{10} (Turning color fruits dipped in 6% $CaCl_2$ + 6% mint leaves' extract solution + ZECC) is at par with T_4 and prolonged the storage life of tomatoes till 28 days. The same result reported that the shelf life of tomatoes treated by hot water of 60^0C temperature and stored under ZECC extended until 29 days compared to the 7 days storage life of tomatoes stored in ambient condition [9]. Results reported by [10] present that tomatoes' shelf life has been prolonged up to 28 days under the ZECC condition. Whereas the aforesaid combinations under ambient condition such as T_3 (Turning color fruits dipped in 6% mint leaves' extract solution + Ambient condition) and T_9 (Turning color fruits dipped in 6% $CaCl_2$ + 6% mint leaves' extract solution + Ambient condition) extended the storage life of fruits up to 17 days presented in Table 4.

Early harvest of tomato fruits seems to maintain the fruits' quality and enhance shelf life [18,19]. This may be due to low physiological activities at this stage compared to late maturity stages. Moreover, the antifungal attribute of $CaCl_2$, and mint leaf extracts, the maintenance of tomato fruits' firmness through 6% $CaCl_2$, might have preserved fruit quality and had a positive effect on increasing their storage life. Significant effect of 6% $CaCl_2$ treatment for 20 minutes dipping of tomatoes on its shelf life and quality has also been reported [12]. Also, the significant effect of $CaCl_2$ on enhancing tomato postharvest life is also known [20].

The lowermost shelf life was 8 days recorded under T_{11} (Light red color fruits + distilled water dip + Ambient condition) and discarded before the data recording on the 10^{th} day of the storage as there were not any $CaCl_2$ solution that has been applied on the fruits and also affected by the ambient condition. Also, the same shelf life is known [9,10]. In contrast to ZECC, all fruits under ambient conditions were discarded before recording any data on the 20^{th} day of storage. The fruit sample was spoiled possibly due to fruits kept under high temperatures and low relative humidity of ambient condition. Therefore, the data are missed for all the parameters on the 20^{th} day of storage under ambient condition, thus the LSD analysis has done only for the day 10^{th} data showed in Table 4.

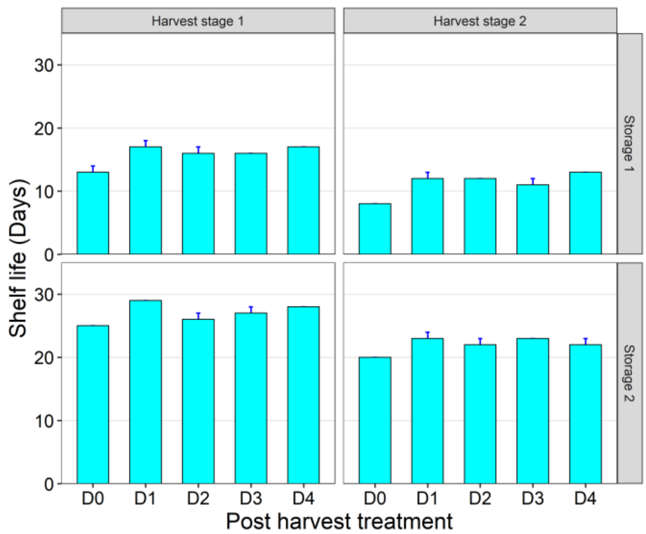

Figure 2. The storage life of marketable tomatoes affected by (Harvesting stages, postharvest treatments and storage types).

Table 4: The mean data of the day 10^{th} and day 20^{th} and the LSD analysis of the day 10^{th} data.

No	Treatments	Shelf life (Days)	Firmness (grcm-2)		TSS (0Brix)		PLW (%)		Decay loss (%)	
			10th Day	20th Day	10th Day	20th Day	10th Day	20th Day	10th Day	20th Day
T1	H1D0S1	13bc	550bcde	-	6b	-	7.6h	-	25b	-

T2	H1D0S2	25ghi	900gh	775.00	5b	5.50	2.6cd	5.80	0a	12.50
T3	H1D1S1	17de	800fgh	-	5b	-	4.5ef	-	0a	-
T4	H1D1S2	29j	1122.5i	840.00	4.25b	4.40	0.4a	1.80	0a	0.00
T5	H1D2S1	16cd	575bcde	-	5.25b	-	6g	-	12.5ab	-
T6	H1D2S2	26hij	750efg	710.00	4.4b	4.75	1.4abc	3.40	0a	0.00
T7	H1D3S1	16cd	690cdef	-	5.25b	-	5.4fg	-	0a	-
T8	H1D3S2	27fgh	900gh	800.00	4.75b	5.25	1ab	2.80	0a	0.00
T9	H1D4S1	17de	750efg	-	5.25b	-	5.6fg	-	0a	-
T10	H1D4S2	28fg	975hi	825.00	4.5b	5.00	1ab	3.00	0a	0.00
T11	H2D0S1	8a	- a	-	- a	-	- i	-	- c	-
T12	H2D0S2	20ef	537.5bcd	400.00	5.15b	6.00	3.7de	8.40	10ab	25.00
T13	H2D1S1	12b	550bcde	-	5.75b	-	6g	-	12.5ab	-
T14	H2D1S2	23fgh	725defg	660.00	4.5b	4.75	0.8ab	3.80	0a	0.00
T15	H2D2S1	12b	475b	-	6b	-	8.2h	-	20ab	-
T16	H2D2S2	22fg	600bcdef	545.00	4.75b	5.65	1.6abc	4.80	0a	0.00
T17	H2D3S1	11ab	500bc	-	6b	-	7.6h	-	25b	-
T18	H2D3S2	23fgh	700cdefg	625.00	5.5b	5.25	2bc	5.40	0a	12.50
T19	H2D4S1	13bc	500bc	-	5.75b	-	6.8gh	-	20ab	-
T20	H2D4S2	22fg	700cdefg	625.00	4.75b	5.00	1.2abc	4.70	0a	0.00
T20	H2D4S2	22fg	700cdefg	625.00	4.75b	5.00	1.2abc	4.70	0a	0.00

3.2. Tomatoes firmness (gr cm^{-2})

The trends in Figure 3. reveal the effect of harvesting stages, postharvest treatments, and storage conditions on tomato firmness that also presented in Table 4. Generally, the fruits' firmness has decreased during storage. However, it looks faster under ambient conditions, there was a significant difference between the two harvesting stages. Whereby significant differences were there in maintaining the highest firmness among treatments.

Thus, the main effects and the interaction of H*D and D*S were significant in the firmness of the fruits presented in Table 3. The firmest fruits were seen under the ZECC condition, which might be due to low temperature during the storage life, which slows down the fruits' biological activities [9]. Also, the application of $CaCl_2$ is a critical treatment for maintaining fruit firmness, as has also been reported earlier [7,16,18]. The highest firmness under T_4 (Turning color fruits dipped in 6% $CaCl_2$ solution + ZECC) was 1123 and 840 grcm^{-2} recorded on the 10th and 20th days of the storage period, respectively.

The T_{10} (Turning color fruits dipped in 6% $CaCl_2$ + 6% mint leaves' extract solution + ZECC) was on-far of T_4 recorded on the 10th and 20th days of storage revealed from Table 4. The aforesaid factors might be well effective for maintaining fruits' firmness due to ZECC as also reported earlier [9,10] compare to ambient conditions. Also, the early stage of harvesting (turning color stage) might significantly affect maintaining tomatoes' firmness.

As reported previously [17,19,21] and the preservation of maximum firmness may be due to combining factors of harvesting stages and $CaCl_2$, also known by [22].

3. 3. Total Soluble Solid (TSS ^{0}Brix): The data from Table 4 and the trends of figure -4 revealed that the TSS increased for all treatments up to the 10th and 20th days of storage of both ambient and ZECC conditions, respectively. It is known [9,10] that there are no differences in TSS of tomato fruits at Ambient and ZECC conditions. However, the main effects were non-significant about TSS, but the two-way and three-way interaction effects were significant as presented in Table 3. Although the TSS increasing was slow under ZECC condition compared to ambient presenting with the trends in figure-4, the same result was reported by [4].

More specifically, Table-4 shows the low changes of TSS that were 4.25 and 4.40 ^{0}Brix in T_4 (Turning color fruits dipped in 6% $CaCl_2$ solution + ZECC) recorded after the 10th and 20th days of the storage, respectively. The result shows that harvesting stages, postharvest treatments, and storage conditions didn't significantly affect the TSS. However, the increase of TSS was faster under ambient condition. This result collaborates with the results obtained in tomato as a non-significant difference of 6% $CaCl_2$ on tomato TSS presented by [16]. But maintaining fruits to the lowest changes of its TSS under T_4 might be because of the combined effect of all three factors. The turning color stage might have been slightly physiologically active and because of 6% $CaCl_2$ application under ZECC as the same result reported by [12].

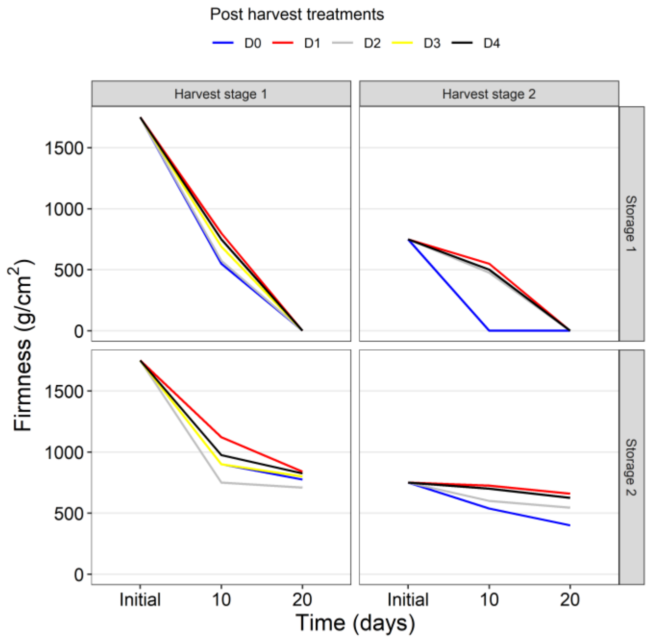

Figure 3. The trends of tomatoes firmness affected by harvesting stages, postharvest treatments and storage conditions.

(Fruits discarded before the aforesaid date of data collection.)

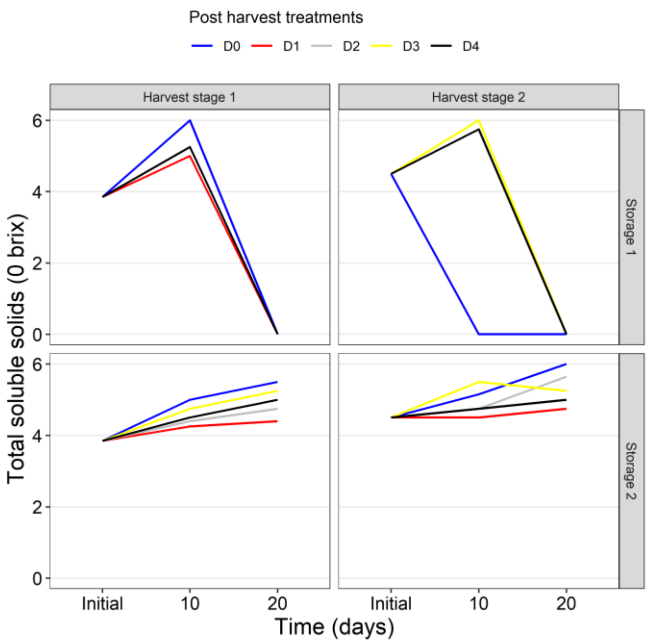

Figure 4. The trends of TSS changes of the two harvested fruits' categories under both storage conditions.

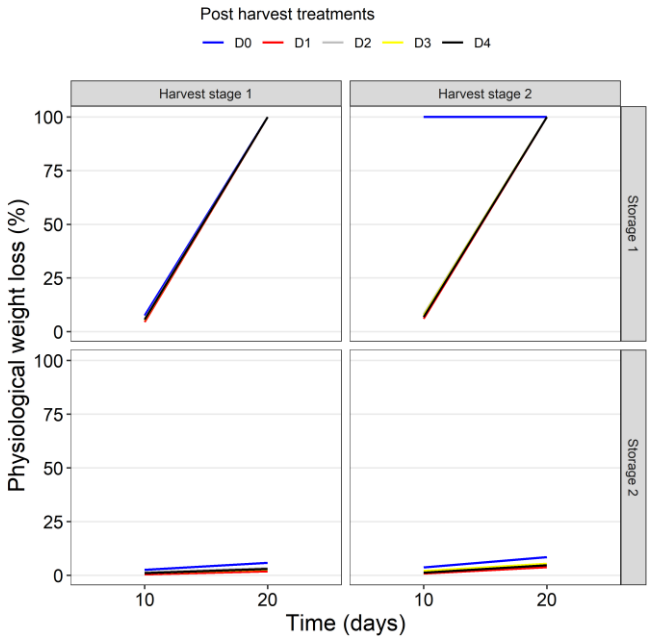

Figure 5. The PLW trends of tomato fruits during both storage conditions.

3.3. Decay loss (%)

As similar to PLW, the decay losses were increased during the storage period. It was also slow under ZECC condition compared to the ambient condition presented in plots of figure-6 as the same results were reported by [4,9]. Since the average temperature was recorded around 12^0C, it might have significantly affected the fruit's physiology and fungal control. The main effects and interactions were significantly different regarding decay loss of the tomato fruits present through Table 3. Other than that, the T_{11} (Light red color fruits dipped in distilled water + Ambient Condition) as control had discarded after 8th day storage that had the lowest shelf life. That might be due to ripe fruits stored under high temperatures of ambient condition without the application of any postharvest treatment.

However, on day 10th, the highest decay losses were recorded under control T_1 (Turning color fruits dipped in distilled water + Ambient Condition) and also T_{17} (Light red color fruits dipped in 6% $CaCl_2$ + 4% mint leaves' extract solution + Ambient Condition). The T_4 (Turning color fruits dipped in 6% CaCl2 solution + ZECC) and some other combination under ZECC condition did not have decay losses up to 20th day storage shown by Table 4. As mentioned above, the aforesaid low temperature might have been very effective for slowing fruits' physiological activities and controlling the fungal activities. Moreover, the postharvest treatments might have control the decay losses, the less decay loss of tomato fruits was recorded due to $CaCl_2$ application reported by [20]. Also, the slow decay losses might be due to the early harvesting of fruits and postharvest treatments as similarly said by [17,19].

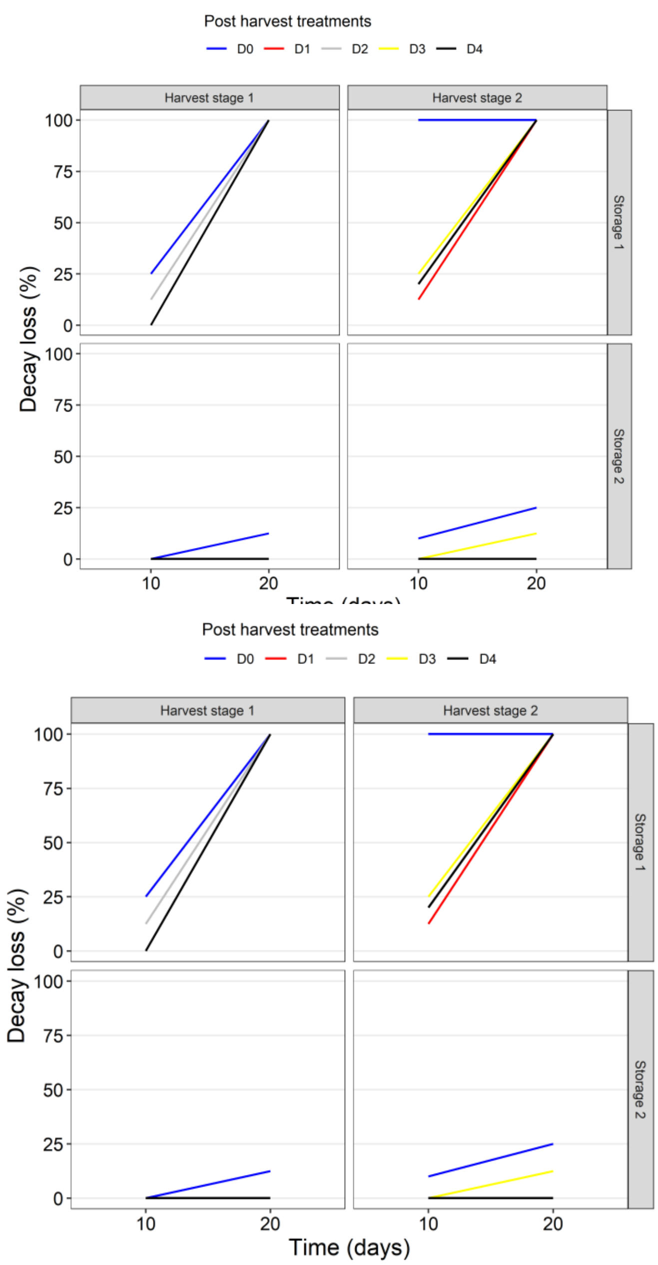

Figure 6. The trends of decay loss during the storage period of both conditions (ZECC and Ambient).

4. Conclusion

As new findings, the evaporative cooling technology, turning color stage of tomato maturity, and 6% $CaCl_2$ application have been the most recommended factors that positively influence the shelf life and postharvest quality of tomatoes of Pearson variety. ZECC extended the storage life of turning color fruits of Pearson tomato till 29 days treated through 6% $CaCl_2$. In comparison, it had 25 days shelf life without 6% $CaCl_2$ application under ZECC. The turning color fruits treated by 6% $CaCl_2$ solution had 17 days shelf life in ambient condition. And the same color fruits had 13 days shelf life without 6% $CaCl_2$ treatment under ambient condition. The untreated light red color fruits had 8 days shelf life under ambient condition. Maybe due to the low concentration, the mint leaves extract's solution might not significantly affect tomato fruits' quality and storage life.

In conclusion, ZECC could be the best on-farm storage (evaporative cooling technology) for small-scale farmers to be established at the farm itself for increasing the shelf life of tomato and other fruit crops in Afghanistan. Also, ZECC could be recommended for various small-scale market owners to keep fresh fruits and vegetables until its distribution to the consumers.

Furthermore, the turning color stage is the best maturity stage of tomato fruits of Pearson variety that could be handed over to a long distance from one corner of the country to another. Or else they could have one week more shelf life compare to light red color fruits of the same variety. Whereas, it had reported that, in Afghanistan, the Pearson variety fruits of full red color maturity stage has a maximum 6 days storage life in ambient condition.

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