Journal of Applied Horticulture, 24(2): 172-177, 2022

DOI: https://doi.org/10.37855/jah.2022.v24i02.32

Journal of Applied Horticulture

ISSN: 0972-1045

Identification of appropriate maturation stages and postharvest treatment for tomato fruits of the "Pearson" variety for local and distant markets

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Abstract

This study was conducted under ambient conditions at the research farm of the Agriculture Faculty at Kabul University, Afghanistan. The objectives were to identify suitable harvesting maturity stages for tomato crop that will result in adequate shelf life of tomato fruits for local and distant markets. The results indicated that fruits of the turning color stage treated with 6 % $CaCl_2$ solution had the best quality and highest shelf life (17.5 days) compared to other treatments. Based on the significant main effect, the 15.38 and 14.17 days' highest shelf life was recorded for tomatoes of H_1 (turning color stage) and D_1 (dipped in 6 % $CaCl_2$ solution), respectively. The TSS (^{o}Brix) and PLW (%) were increased till the end of storage life, but the tomato fruits' firmness (g cm^{-2}) decreased. Hence, the lowest values were noted as 4.79 and 4.74 (^{0}brix) TSS and 3.31 and 2.93 (%) PLW, but the highest firmness of 932.50 and 854.17 (g cm^{-2}) were recorded for fruits of H_1 (turning color stage) and D_1 (dipped in 6 % $CaCl_2$ solution), respectively. The turning color, pink color and light red color stage fruits of the Pearson variety are recommended to be harvested and considered for distant market, local market and immediate use, respectively. And the 6 % $CaCl_2$ solution could increase shelf life and maintain tomato's quality.

Key words: Pearson variety, harvesting stages, postharvest treatments, ambient storage, shelf life, quality, and market

Introduction

Determining the suitable maturity stage of fresh horticultural crops is an important factor affecting fruit quality. In developing countries, yield loss of fruits and vegetables is very common during storage and transport due to premature or late harvesting. In Afghanistan, fruits and vegetable market prices fluctuate considerably, mainly due to mismanagement of harvesting and postharvest practices.

Tomato (*Solanum lycopersicum* L.) is one of the important high-value crops in Afghanistan. It is grown commercially across the country in the open and inside greenhouses. Various local and hybrid varieties of tomatoes are grown in Afghanistan, but the most common varieties are Roma, Pearson and Heinz, Beefsteak, Rio Grande, Kabul-64, and Geno. The Agricultural Research Institute of Afghanistan at the Ministry of Agriculture, Irrigation and Livestock (MAIL) officially released two new varieties of tomato (Noori-21 and Panae-21) in 2021. "Pearson" is the most popular among these varieties because of its high commercial value, optimum size, better taste, flavor, higher juice and pulp content. It is commonly used for making salads, burgers, sandwiches, concentrate, paste, and puree (MAIL Information Systems, n.d.).

Tomato is a major dietary source and has an important role in human health due to its high amounts of carotenoids, lycopene, and antioxidants, which are useful in mitigating diseases like cancer and cardiovascular disorders. Phenolic compounds, vitamin C, E, and A, and tomatine in its fruits reduce cholesterol and triglyceride levels in blood plasma, thereby increasing body immunity against bacterial contamination (Dandago *et al.*, 2017; Dhall, 2013).

Fruits of the Pearson variety are very sensitive to handling due to their high water content and thin pericarp. In Afghanistan, this variety has a very short shelf life of 3 to 6 days under normal conditions (MAIL Information Systems, n.d.). As a result, growers and local businessmen experience high fruit losses after harvest. Casierra-Posada and Aguilar-Avendaño (2008) identified the turning color stage as the best harvesting time for tomatoes. Both chemical and organic postharvest treatments have been recommended for maintaining the shelf life. Fruits dipped in 6 % $CaCl_2$ for 20 minutes at the pink color stage have maintained higher quality for an optimum time postharvest (Arthur *et al.*, 2015). Dandago *et al.* (2017) have reported the best fruit quality in mature green tomatoes with 200 ppm NaOCl and 1 % $CaCl_2$ solutions. Mint leaf extract has been suggested as a good chemical substitute for peppermint's antimicrobial and antifungal activities (Al-Sum and Al-Arfaj, 2014; Moghaddam *et al.*, 2013).

Harvesting tomatoes in different maturity stages and applying postharvest treatments, especially $CaCl_2$ and mint leaves extract, are new concepts implemented in Afghanistan. These factors may significantly affect fruit quality and thus, farmers may consider it for long shelf life tomato in markets.

Therefore, the present study was carried out for the first time in Afghanistan to identify proper harvesting stages of the Pearson variety for local and distant markets based on its suitable shelf life and quality treated with postharvest treatments. The research achievement can be a tangible principle for farmers to properly manage and market their tomato fruits.

Material and methods

The study was conducted at the Research Farm of the Agriculture Faculty of Kabul University, located at 34^o 52 N and 69^o 12 E, with an elevation of 1810 meters above sea level. The soil type of the research farm was alkaline silty loam (POWER Data Access Viewer, n.d.).

Fruit production: Seeds of the Pearson variety were acquired from an authorized seed production company. Planting took place between March 9 and 11 in both 2018 and 2019. Following a growth period of 38 to 40 days in the nursery, the seedlings were subsequently transplanted into the main field with a spacing of 40 x 90 cm between plants and rows.

Harvesting and postharvest handling: Fruits color chart and visual appearance were used to identify the stage of maturity. Three different maturity stages (turning color, pink color and light red color) were harvested 101 and 97 days from transplanting in 2018 and 2019, respectively.

Storage: The fruits were kept under ambient storage conditions and managed with appropriate air ventilation. A digital hygrometer recorded daily climatic data during the 18 days storage period.

Experimental design and treatments: The experimental design was a two-factor, Completely Randomized Design (CRD). The experimental factors were harvesting three stages and eight postharvest treatments. In total, the experiment contained 24 treatments, and each was replicated two times (Table 1). Turning color, pink color, and light red color were the three harvesting stages employed in the experiment. The postharvest treatments comprised treating the fruits with distilled water, 6 % $CaCl_2$ solution, 2, 4, and 6 % dipping in mint leaves extract solutions, and a combination of $CaCl_2$ + mint extract solutions. Mint juice was extracted from fresh mint leaves using a juicer machine. The dipping time for the postharvest treatments was 20 minutes for all treatments. The treated tomato fruits were kept in plastic trays.

Measurements: Data on quality parameters were recorded every five days until the end of storage life. The shelf life and quality parameters were assessed in this study. Initial data was recorded for all parameters before treatment application. According to Moneruzzaman *et al.* (2009), the shelf life of fruits was visually assessed daily until the fruits were healthy and acceptable for marketing.

Table 1. Factors' level and details

Factors	Levels
Harvesting stage (H)	H_1 - Harvesting stage 1 (turning color stage)
	H_2 - Harvesting stage 2 (pink color stage)
	H_3 - Harvesting stage 3 (light red color stage)
Postharvest treatment (D)	D_0 - (Dip-in distill water)
	D_1 - (Dip in 6 % $CaCl_2$ solution)
	D_2 - (Dip 2 % mint leaves' extract solution)
	D_3 - (Dip in 4 % mint leaves' extract solution)
	D_4 - (Dip in 6 % mint leaves' extract solution)
	D_5 - (Dip in 6 % $CaCl_2$ + 2 % mint leaves' extract solution)
	D_6 - (Dip in 6 % $CaCl_2$ + 4 % mint leaves' extract solution)
	D_7 - (Dip in 6 % $CaCl_2$ + 6 % mint leaves' extract solution)

Total soluble solids (TSS ^{o}Brix) were determined by a hand-held refractometer (Sugar/brix Refractometer, range from 0 – 32 %, 300001 Sper Scientific) using the tomato juice from each sample (Abera, 2013). The juice of fruits was made using the juicer/blender.

Fruit firmness was measured at the midpoint of each fruit using a two-size hand-held penetrometer. The amount of pressure employed by the device was FT02: 2 lb x 1/16 lb and FT327: 28 lb x 0.25 lb. The fruit's skin was removed to properly measure the firmness (Ranatunga *et al.*, 2008).

Physiological loss in weight (PLW) was recorded at every five-day interval using an electronic weighing balance. The percent PLW was calculated using the method explained by Pimpalpalle *et al.* (2018).

Data analysis: Data cleaning and processing was performed in the Microsoft Excel program. To evaluate the effects of H (harvesting stages) and D (postharvest treatments) on response variables, data were analyzed using two-way ANOVA in the Statistical Tool for Agricultural Research (STAR) statistical analysis software. The Least Significant Difference (LSD) test was used for comparing the least square means for the main effects of harvesting stages and postharvest treatments and their interactions at $\alpha = 0.05$.

Result and discussion

The relative humidity and temperature of the ambient storage condition averaged 26.48 % and 22.01^{o}C, respectively. The result of the first observation (after five days of storage) was analyzed and ANOVA and LSD were considered for mean comparision. Whereas, the 10th and 15th day's data are only discussed based on their averages as fruits of some treatments were discarded before observation. Overall, the harvesting stages and postharvest treatments significantly impacted the shelf life and quality of tomato fruits under ambient storage conditions, corroborating the findings of other studies (Al & Naser, 2011; Dandago *et al.*, 2017). Details of the results are discussed below.

Shelf life (days): In this study, the tomato's shelf life improved by harvesting stages and postharvest treatments. Both factors' main effect on shelf life was significant, but the two-way interaction was not (Table 2). Although not significantly different from other treatments, the maximum shelf life of tomato fruits was highest (17.5 days) when treated with 6 % $CaCl_2$ solution at the turning color stage (D_1H_1). The 6 % $CaCl_2$ solution (D_1) and 6 % $CaCl_2$ + 6 % mint leaves extract solution (D_7) resulted in significantly higher shelf life (14.17 and 14 days, respectively) of tomato fruits among all postharvest treatments. Likewise, the turning color stage (H_1) appeared to be the best harvesting stage due to the higher shelf life of tomato fruits (15.38).

Table 2. The effect of harvesting stages and postharvest treatments and their interaction on the shelf life of tomatoes under ambient conditions.

Factor	Year											
	2018				2019				Mean			
	H_1	H_2	H_3	Mean D	H_1	H_2	H_3	Mean D	H_1	H_2	H_3	Mean D
D_0	13.00	10.00	8.00	10.33c	14.00	10.00	8.00	10.67c	13.50	10.00	8.00	10.50d
D_1	17.00	13.00	12.00	14.00a	18.00	13.00	12.00	14.33a	17.50	13.00	12.00	14.17a
D_2	13.00	10.00	8.00	10.33c	13.00	11.00	9.00	11.00c	13.00	10.50	8.50	10.67d
D_3	15.00	10.00	10.00	11.67bc	15.00	10.00	9.00	11.33c	15.00	10.00	9.50	11.50cd
D_4	15.00	12.00	10.00	12.33b	15.00	11.00	10.00	12.00bc	15.00	11.50	10.00	12.17bc
D_5	16.00	11.00	12.00	13.00ab	16.00	12.00	12.00	13.33ab	16.00	11.50	12.00	13.17ab
D_6	16.00	12.00	11.00	13.00ab	17.00	14.00	11.00	14.00a	16.50	13.00	11.00	13.50a
D_7	17.00	13.00	13.00	14.33a	16.00	13.00	12.00	13.67a	16.50	13.00	12.50	14.00a
Mean H	15.25a	11.38b	10.50c		15.50a	11.75b	10.38c		15.38a	11.56b	10.44c	
	P- Value		F-Test	SEM ±	P- Value		F-Test	SEM ±	P- Value		F-Test	SEM ±
H	0.000		**	0.30	0.000		**	0.32	0.000		**	0.22
D	0.000		**	0.49	0.000		**	0.51	0.000		**	0.36
H x D	0.902		NS		0.832		NS		0.647		NS	

** and NS stand for highly significant and non-significant, respectively. Not only in this table, the mean of H and D factors are mentioned as "Mean H" and "Mean D" at the end of H values and the right of H3, respectively

The H_3 fruits (light red color stage) and D_0 (dipped in distilled water solution) resulted in the lowest mean shelf life (10.44 and 10.50 days, respectively). Though the lowest shelf life was 8 (day) as a general mean, it has not been considered due to the non-significant differences between the two way interaction effects. The significant main effects of harvesting stages and postharvest treatments might be related to harvesting the tomatoes at an earlier maturity stage, effect fruits' quality and enhancing shelf life, which was also found by John *et al.* (2020) and Parker and Maalekuu (2013). Also, the antifungal activities in the 6 % $CaCl_2$ might have affected the quality and firmness of fruits, enhancing the shelf life of tomatoes, as reported by other published research (Arthur *et al.*, 2015; Chepngeno *et al.*, 2016; Senevirathna and Daundasekera, 2010).

Total soluble solid (TSS ^{0}Brix): The total soluble solids of tomato fruits was highest at the end of the storage period in all treatments. The TSS increase was higher under ambient conditions (Dandago *et al.*, 2017).

After five days of ambient storage, the main effects of harvesting stages and postharvest treatments on TSS were highly significant, while the two-way interaction effects were not significant during both years and with their mean values (Table 3). The lowest mean values of TSS changes were 4.79 and 4.74 (^{0}brix) noted for the fruits of H_1 (turning color stage) and D_1 (dipped in 6 % $CaCl_2$ solution), respectively. The highest mean values of TSS were recorded for H_3 (5.64) and D_0 (5.72). The lowest average TSS changes were 5.05 and 5.53 (^{0}brix) in the fruits of H_1D_1 (turning color stage dipped in 6 % $CaCl_2$ solution) on the 10th and 15th days of ambient storage (Table 4). The

Table 3. The effect of harvesting stages and postharvest treatments and their interaction on tomato total soluble solids (TSS 0brix) after 5 days of ambient storage

Factor	Year											
	2018				2019				Mean			
	H_1	H_2	H_3	Mean	H_1	H_2	H_3	Mean	H_1	H_2	H_3	Mean
D_0	5.00	6.00	6.25	5.75a	5.23	5.65	6.20	5.69a	5.12	5.83	6.23	5.72a
D_1	4.30	4.50	5.25	4.68c	4.35	4.75	5.30	4.80bc	4.33	4.63	5.28	4.74d
D_2	5.00	5.50	6.25	5.58ab	5.20	5.75	6.35	5.77a	5.10	5.63	6.30	5.68ab
D_3	5.00	5.00	5.75	5.25abc	5.00	5.50	6.25	5.58ab	5.00	5.25	6.00	5.42bc
D_4	5.00	5.25	5.25	5.17bc	5.25	5.65	5.50	5.47b	5.13	5.45	5.38	5.32c
D_5	4.50	5.00	5.25	4.92c	4.40	4.85	5.25	4.83c	4.45	4.93	5.25	4.88d
D_6	4.75	4.75	5.50	5.00c	4.65	4.78	5.30	4.91c	4.70	4.77	5.40	4.96d
D_7	4.50	4.75	5.25	4.83c	4.45	4.65	5.28	4.79c	4.48	4.70	5.27	4.81d
Mean	4.76b	5.09b	5.59a		4.82c	5.20b	5.68a		4.79c	5.15b	5.64a	
	P- Value		F-Test	SEM ±	P- Value		F-Test	SEM ±	P- Value		F-Test	SEM ±
H	0.0001		**	0.120	0.0001		**	0.06	0.0001		**	0.06
D	0.0101		**	0.196	0.0001		**	0.10	0.0001		**	0.10
H x D	0.946		NS		0.393		NS		0.385		NS	

** and NS stand for highly significant and non-significant, respectively. Initial TSS (^{0}brix) in 2018 (H_1: 3.85, H_2: 4.25, H_3:4.50); 2019 (H_1: 4.00, H_2: 4.20, H_3:5.00); and average (H_1: 3.93, H_2: 4.23, H_3:4.75).

small TSS changes could have been because of the turning color stage when fruits might have been slightly physiologically active. Another possible reason could be the 6 % $CaCl_2$ application, which may have slowed down the TSS accumulation. These findings align with the earlier results (Arthur *et al.*, 2015; Casierra-Posada and Aguilar-Avendaño, 2008; Parker and Maalekuu, 2013).

Fruit firmness (g cm^{-2}): The firmness of tomato fruits decreased during storage. The harvesting stages and postharvest treatments positively affected the tomato's ability to retain the highest firmness. The data revealed that the tomato firmness on the 5th day of ambient storage was significantly affected by harvesting stages and postharvest treatments, whereas their two-way interactions were not significant

Table 4. Total soluble solids (TSS) of tomatoes affected by harvesting stages and postharvest treatments after 10 and 15 days of ambient storage

Treatment	Day					
	10^{th} day			15^{th} day		
	2018	2019	Average	2018	2019	Average
H_1D_0	6.00	6.00	6.00	–	–	–
H_1D_1	5.00	5.10	5.05	5.50	5.55	5.53
H_1D_2	6.00	5.95	5.98	–	–	–
H_1D_3	5.50	5.55	5.53	6.50	6.00	6.25
H_1D_4	5.50	5.70	5.60	6.25	5.88	6.06
H_1D_5	5.25	5.20	5.23	5.50	5.65	5.58
H_1D_6	5.25	5.15	5.20	5.75	5.55	5.65
H_1D_7	5.25	5.05	5.15	6.00	5.60	5.80
H_2D_0	6.50	6.25	6.38	–	–	–
H_2D_1	5.50	5.40	5.45	–	–	–
H_2D_2	6.00	6.15	6.08	–	–	–
H_2D_3	6.25	6.10	6.18	–	–	–
H_2D_4	5.50	5.90	5.70	–	–	–
H_2D_5	5.75	5.70	5.73	–	–	–
H_2D_6	5.75	5.45	5.60	–	–	–
H_2D_7	5.75	5.50	5.63	–	–	–
H_3D_0	–	–	–	–	–	–
H_3D_1	5.75	5.80	5.78	–	–	–
H_3D_2	–	–	–	–	–	–
H_3D_3	6.50	–	6.50	–	–	–
H_3D_4	6.25	6.25	6.25	–	–	–
H_3D_5	6.00	5.85	5.93	–	–	–
H_3D_6	6.00	6.00	6.00	–	–	–
H_3D_7	5.75	5.90	5.83	–	–	–

– stand for fruits discarded before data collection. Initial TSS (^{0}brix) are 2018 (H_1: 3.85, H_2: 4.25, H_3:4.50); 2019 (H_1: 4.00, H_2: 4.20, H_3:5.00); and average (H_1: 3.93, H_2: 4.23, H_3:4.75).

within and across 2018 and 2019 (Table 5).

In terms of the main effects, H_1 (turning color stage) and D_1 (dipped in 6 % $CaCl_2$ solution) had the highest mean firmness values of 932.50 and 854.17 (g cm^{-2}), respectively. The D_7 is on par with D_1, keeping the higher firmness at 823.33 (g cm^{-2}). Additionally, the lowest mean values of the tomatoes' firmness were 566.88 and 620.00 (g cm^{-2}) indicated for fruits of H_3 (light red color stage) and D_0 (dipped in distilled water), respectively.

The fruits combined with the H_1D_1 (turning color stage dipped in 6 % $CaCl_2$ solution) had higher mean firmness of 825.00 and 686.50 (g cm^{-2}) on the 10^{th} and 15^{th} days of ambient storage, respectively. Besides, some of the fruits were discarded before day 10^{th} and the majority of them were thrown out before the 15^{th} day of data observation, but the lowest firmness was recorded with the combination of H_3D_4 (light red colored stage dipped in 6 % mint leaves' extract solution) and H_1D_3 (turning color stage dipped in 4 % mint leaves' extract solution) as 425.00 and 500.00 on the 10^{th} and 15^{th} days of storage, respectively (Table 6).

The highest firmness value may be due to the fruits harvested at early stages of maturity that retained firmness up to the end of storage. Such findings were also reported in the previously published research (Brashlyanova *et al.*, 2014; Moneruzzaman *et al.*, 2009; Parker and Maalekuu, 2013). The $CaCl_2$ solutions could have been a critical treatment for maintaining fruit firmness, which was also confirmed by other studies (Casierra-Posada and Aguilar-Avendaño, 2008; Pinheiro and Almeida, 2008; Senevirathna and Daundasekera, 2010)

Physiological loss in weight (PLW %): The PLW (%) of the tomatoes has increased during the ambient storage period. Table 7 presents that the main effects of harvesting stages and postharvest treatments are highly significant, but the effects of two-way interaction are non-significant in both seasons and mean values of two years. Regarding the main effects, the lowest mean PLW was 3.31 percent of tomatoes for H_1 (turning color stage) and 2.93 percent for D_1 (dipped in 6 % $CaCl_2$ solution). While the fruits of H_3 (light red color stage) and D_2 (dipped in 2 % mint leaves' extract solution) showed the highest PLW % at 5.51 and 5.40, respectively.

Furthermore, the fruits of the combination of H_1D_1 (turning color stage dipped in 6 % $CaCl_2$ solution) had lowest values of PLW at 3.75 and 5.25 (%) on the 10^{th} and 15^{th} days, respectively. However, the combination of H_3D_3 (light red colored stage dipped in 4 % mint leaves' extract solution) and H_1D_3 (turning color stage dipped in 4 % mint leaves' extract solution) showed highest average PLW of tomato fruits at 9.20 and 8.30 (%) on the 10^{th} and 15^{th} days of storage, respectively. Even though some of the

Table 5. The effect of harvesting stages and postharvest treatments and their interaction on tomatoes' firmness (g cm^{-2}) after 5 days ambient storage

Factor	Year											
	2018				2019				Mean			
	H_1	H_2	H_3	Mean	H_1	H_2	H_3	Mean	H_1	H_2	H_3	Mean
D_0	700.00	500.00	400.00	533.33d	945.00	675.00	500.00	706.67c	822.50	587.50	450.00	620.00d
D_1	1000.00	800.00	625.00	808.33a	1150.00	850.00	700.00	900.00a	1075.00	825.00	662.50	854.17a
D_2	750.00	525.00	425.00	566.67d	950.00	750.00	545.00	748.33bc	850.00	637.50	485.00	657.50cd
D_3	725.00	525.00	420.00	556.67d	995.00	700.00	550.00	748.33bc	860.00	612.50	485.00	652.50cd
D_4	725.00	625.00	465.00	605.00cd	1000.00	710.00	640.00	783.33b	862.50	667.50	552.50	694.17c
D_5	850.00	700.00	500.00	683.33bc	1100.00	825.00	675.00	866.67a	975.00	762.50	587.50	775.00b
D_6	850.00	675.00	575.00	700.00b	1155.00	800.00	735.00	896.67a	1002.50	737.50	655.00	798.33ab
D_7	900.00	750.00	625.00	758.33ab	1125.00	850.00	690.00	888.33a	1012.50	800.00	657.50	823.33ab
Mean	812.50a	637.50b	504.38c		1052.50a	770.00b	629.38c		932.50a	703.75b	566.88c	
	P- Value		F-Test	SEM ±	P- Value		F-Test	SEM ±	P- Value		F-Test	SEM ±
H	0.000		**	19.89	0.000		**	15.73	0.000		**	13.71
D	0.000		**	32.48	0.000		**	25.69	0.000		**	22.38
H x D	0.995		NS		0.949		NS		0.994		NS	

** and NS stand for highly significant, and non-significant respectively. The initial firmness (g cm^{-2}) is 2018 (H_1: 1750, H_2: 950, H_3: 750); 2019 (H_1: 1700, H_2: 1000, H_3:800); and average (H_1: 1725, H_2: 975, H_3:775).

Table 6. Firmness (g cm^{-2}) of tomatoes effected by harvesting stages and postharvest treatments after 10 and 15 days' storage at ambient conditions.

Treatment	Day					
	10th Day			15th Day		
	2018	2019	Average	2018	2019	Average
H_1D_0	550.00	600.00	575.00	–	–	–
H_1D_1	800.00	850.00	825.00	675.00	698.00	686.50
H_1D_2	550.00	595.00	572.50	–	–	–
H_1D_3	575.00	685.00	630.00	475.00	525.00	500.00
H_1D_4	600.00	645.00	622.50	490.00	540.00	515.00
H_1D_5	575.00	845.00	710.00	525.00	640.00	582.50
H_1D_6	700.00	800.00	750.00	575.00	645.00	610.00
H_1D_7	750.00	840.00	795.00	600.00	650.00	625.00
H_2D_0	390.00	485.00	437.50	–	–	
H_2D_1	650.00	675.00	662.50	–	–	–
H_2D_2	400.00	495.00	447.50	–	–	–
H_2D_3	425.00	550.00	487.50	–	–	–
H_2D_4	475.00	600.00	537.50	–	–	–
H_2D_5	525.00	650.00	587.50	–	–	–
H_2D_6	500.00	670.00	585.00	–	–	–
H_2D_7	565.00	650.00	607.50	–	–	–
H_3D_0	–	–	–	–	–	–
H_3D_1	550.00	610.00	580.00	–	–	–
H_3D_2	–	–	–		–	–
H_3D_3	400.00	–	400.00	–	–	–
H_3D_4	400.00	450.00	425.00	–	–	–
H_3D_5	475.00	585.00	530.00	–	–	–
H_3D_6	500.00	595.00	547.50	–	–	–
H_3D_7	500.00	598.00	549.00	–	–	–

– stand for fruits discarded before data collection. The initial firmness (g cm^{-2}) is 2018 (H_1: 1750, H_2: 950, H_3: 750); 2019 (H_1: 1700, H_2: 1000, H_3: 800); and average (H_1: 1725, H_2: 975, H_3: 775).

Table 8. The average data of PLW (%) of tomatoes affected by harvesting stages and postharvest treatments after 10 and 15 days of ambient storage conditions

Treatment	Day					
	10th day			15th day		
	2018	2019	Average	2018	2019	Average
H_1D_0	7.60	6.20	6.90	–	–	–
H_1D_1	4.50	3.00	3.75	6.40	4.10	5.25
H_1D_2	7.20	6.30	6.75	–	–	–
H_1D_3	6.80	5.70	6.25	10.0	6.60	8.30
H_1D_4	6.80	5.40	6.10	9.60	6.20	7.90
H_1D_5	6.00	3.20	4.60	8.80	4.30	6.55
H_1D_6	5.40	3.40	4.40	8.00	4.00	6.00
H_1D_7	5.60	3.50	4.55	7.60	4.40	6.00
H_2D_0	8.60	6.80	7.70	–	–	–
H_2D_1	5.60	3.80	4.70	–	–	–
H_2D_2	8.60	6.90	7.75	–	–	–
H_2D_3	8.40	6.70	7.55	–	–	–
H_2D_4	8.00	6.00	7.00	–	–	–
H_2D_5	6.60	4.00	5.30	–	–	–
H_2D_6	6.70	3.60	5.15	–	–	–
H_2D_7	6.20	3.90	5.05	–	–	–
H_3D_0	–	–	–	–	–	–
H_3D_1	6.00	5.00	5.50	–	–	–
H_3D_2	–	–	–	–	–	–
H_3D_3	9.20	–	9.20	–	–	–
H_3D_4	9.00	7.00	8.00	–	–	–
H_3D_5	8.20	5.20	6.70	–	–	–
H_3D_6	7.60	5.40	6.50	–	–	–
H_3D_7	6.80	5.30	6.05	–	–	–

– stand for fruits discarded before data collection. The initial PLW (%) is 2018 (H_1: 0.00, H_2: 0.00, H_3: 0.00); 2019 (H_1: 0.00, H_2: 0.00, H_3: 0.00); and average (H_1: 0.00, H_2: 0.00, H_3: 0.00).

Table 7. The effect of harvesting stages and postharvest treatments and their interaction on the PLW (%) of tomato after 5 days' storage at ambient conditions

Factor	Year											
	2018				2019				Mean			
	H_1	H_2	H_3	Mean D	H_1	H_2	H_3	Mean D	H_1	H_2	H_3	Mean D
D_0	4.60	6.00	8.20	6.27a	3.60	4.20	5.60	4.47a	4.10	5.10	6.90	5.37a
D_1	2.40	3.20	4.40	3.33c	1.80	2.60	3.20	2.53b	2.10	2.90	3.80	2.93c
D_2	4.90	5.40	8.50	6.27a	3.80	4.00	5.80	4.53a	4.35	4.70	7.15	5.40a
D_3	5.20	5.60	8.00	6.27a	3.30	4.60	5.70	4.53a	4.25	5.10	6.85	5.40a
D_4	4.30	5.60	7.20	5.70a	3.50	4.30	5.00	4.27a	3.90	4.95	6.10	4.98a
D_5	3.20	4.00	5.60	4.27bc	2.00	2.40	3.30	2.57b	2.60	3.20	4.45	3.42bc
D_6	3.60	4.20	6.00	4.60b	2.20	2.80	3.40	2.80b	2.90	3.50	4.70	3.70b
D_7	2.90	3.40	5.00	3.77bc	1.70	2.90	3.20	2.60b	2.30	3.15	4.10	3.18bc
Mean H	3.89c	4.68b	6.61a		2.74c	3.48b	4.40a		3.31c	4.08b	5.51a	
	P- Value		F-Test	SEM ±	P- Value		F-Test	SEM ±	P- Value		F-Test	SEM ±
H	0.000		**	0.20	0.000		**	0.13	0.000		**	0.12
D	0.000		**	0.33	0.000		**	0.21	0.000		**	0.19
H x D	0.932		NS		0.771		NS		0.616		NS	

** and NS stand for highly significant and non-significant, respectively. The initial PLW (%) is 2018 (H_1: 0.00, H_2: 0.00, H_3: 0.00); 2019 (H_1: 0.00, H_2: 0.00, H_3: 0.00); and average (H_1: 0.00, H_2: 0.00, H_3: 0.00).

fruits were thrown out before day ten and most were discarded before the 15th day of data collection (Table 8).

Similar to the findings of Islam *et al.* (2013) and Mishra *et al.* (2020), the PLW % was faster due to the high temperature and RH of the ambient conditions. However, the lowest PLW % might have been due to the early harvesting stages, especially turning color stage fruits. Early harvested fruits might not have reached a higher level of respiration rates. The fruit ingredient degradation and low water losses with high firmness might have maintained the overall quality of the fruits (John *et al.*, 2020; Parker and Maalekuu, 2013). Similarly, postharvest treatments such as $CaCl_2$ application and some others might have restricted the PLW % of fruits till the end of the storage, as reported by (Arthur *et al.*, 2015; Chacon. *et al.*, 2017; Chepngeno *et al.*, 2016; Hosea *et al.*, 2017; Sajid, 2019).

In this study, the shelf life of the tomato fruits was found to be significantly higher a when the fruits were stored at H_1-turning color stage followed by H_2-pink color and H_3-light red color stages, respectively. Use of 6 % $CaCl_2$ after postharvest helped maintain the shelf life of tomato fruits during storage. The mint leaf extract solutions was not effective may be due to their low concentration. The turning color stage could be recommended as a suitable maturity stage for Pearson tomatoes. Turning color stage harvesting could be suitable for distant markets, followed by the pink-colored stage, which could be an appropriate harvesting stage for those handed over to the local markets.

Moreover, the fruits of the light-color stage may be recommended for immediate use of tomatoes. However, proper packaging and handling tools would be necessary. The 6 % $CaCl_2$ application could be suggested for enhancing tomatoes' shelf life and quality retention, but it may not be suitable for small-scale farmers from an economic perspective.

Acknowledgment

The first author would like to thank research advisory committee for research guidance. The author is also thankful to Dr. Shalizi and Mr. Khurram for editing, the farm manager and other faculties of the Agriculture Faculty of Kabul University for support.

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Received: September, 2021; Revised: January, 2022; Accepted: February, 2022