

Improving Quality Attributes of Tomato during Cold Storage by Preharvest Foliar Application of Calcium Chloride and Potassium Thiosulfate

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Abstract. The aim of this trial was to investigate the pre-harvest foliar application of calcium chloride and potassium thiosulfate each at 0.0, 0.2 and 0.4 % on some quality of tomato fruit (hybrid 65010) during cold storage. The experimental layout of cold storage experiments was a split-split-plot based on Randomized Complete Blocks design with three replications. Time of cold storage, calcium chloride and potassium thiosulfate levels were randomly distributed in the main, sub- and sub-sub plots, orderly. At the termination of cold storage, effect on tomato fruit titratable acidity, vitamin C and lycopene contents while, negative impact on firmness and total soluble sugars contents was obtained. At termination of cold storage, pre-harvest foliar calcium chloride at 0.2 and/or 0.4 % caused increments in fruit titratable acidity, vitamin C, total soluble sugars, lycopene and firmness contents. In addition, pre-harvest foliar potassium thiosulfate at 0.4 % enhanced fruit vitamin C, total soluble sugars, lycopene and firmness contents and also increased titratable acidity content. Generally, the interaction between cold storage × pre-harvest foliar calcium chloride or potassium thiosulfate at 0.2 and/or 0.4 % increased fruit total titratable acidity, vitamin C, total soluble sugars, lycopene and firmness contents. Also, the interaction between pre-harvest calcium chloride × potassium thiosulfate at 0.4 % was distinguished and increased all studied fruit quality at the end of cold storage. The interaction treatment of cold storage × calcium chloride at 0.4 % × potassium thiosulfate at 0.4 % was the best that improved fruit quality more than others.

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is a member of the *Solanaceae* family, which includes potato, eggplant and pepper. Tomato crop is the most popular and a major food crop vegetable in the world [1]. In Egypt, tomato ranks the 5th internationally in production after China, India, United States of America and Turkey [2]. Each 100 grams of ripe red tomatoes fruit almost contains of 93.8 g water, 3.9 g total carbohydrates, 0.9 g protein, 0.2 g total fat, 1.2 g row fibers and appropriate quantities of vitamins especially vitamin C and minerals in addition, some favor amounts of carotenes and lycopene [3]

Approximately half population in developing countries does not have adequate food supplies. One of the causes for food losses is tend to be highest due to postharvest system through transporting, handling, storage, processing and marketing to final delivery to the consumer [4]. Post-harvest loss of tomato fruits sometimes as high as fifty percent [5]. Reduction in postharvest food losses can be avoided to be of great significance to growers and consumers alike [6].

Postharvest qualities of tomatoes partially depend upon pre-harvest factors such as cultural practices, genetic and environmental conditions [7] [8]. Cultural practices such as nutrient, water supply and harvesting methods etc. affect quality of tomato before and after harvest [9] [10], [11], [12] proved that, calcium chloride and potassium thiosulfate have major and important roles on plant behavior, storability and quality attributes of tomato

Accordingly, the present investigation was proposed to study the effects of spraying canopy of tomato plant with calcium chloride and potassium thiosulfate on subsequent effect on fruit quality attributes during cold storage.

Materials and Methods

Two similar filed experiments were achieved during the two fall seasons of 2014 and 2015, in a private farm located at Senoras, Fayoum Governorate, Egypt. To identify some physical and chemical properties of the experimental site, soil samples to 25 cm depth, preceding the initiation of each field experiment, were collected. Soil samples were analyzed at Soil Testing Laboratory, College of Agriculture, Fayoum University, according to the standard published procedures [13]. Results of the soil analysis are given in Table 1.

Table 1. Some important physical and chemical properties of the experimental site in 2014 and 2015 seasons

Physical characteristics	Value	
	2014	2015
Silt (%)	46.8	46.2
Clay (%)	43.5	44.1
Fine sand (%)	4.1	3.9
Coarse sand (%)	5.6	5.8
Soil texture	Silty Clay	Silty Clay
Chemical characteristics		
pH [at a soil: water (w/v) ratio of 1:2.5]	7.587	7.635
ECe (ds/m; soil – paste extract)	2.35	2.36
Organic matter (%)	1.38	1.48
Nitrate (NO ₃) (mg/kg)	253	261
Available (P) (mg/kg)	50.1	48.8
Available (K) (mg/kg)	364	383
Ca (mg/100g soil)	14.1	12.06
Mg (mg/100g soil)	7.22	4.59
CaCO ₃ (%)	3	4.4

Tomato seed hybrid 65010 were sown in speedling trays on July 1st and 9th in 2014 of 2015, orderly and placed under net house conditions. After 30 days, tomato transplants were transplanted on rows at in-row spacing of 50 cm. Aqueous solution of each calcium chloride and potassium thiosulfate with concentrations 0, 0.2 and 0.4 % were sprayed to run off after 40, 70 and 100 days transplanting. Canopy of tomato plants were first sprayed with aqueous solution of calcium chloride then, after getting dry, with aqueous solution of potassium thiosulfate. All other agro-management practices such as nutrition, cultivation, irrigation and pests control were performed whenever it was necessary and as recommended in the commercial production of tomato. After 115 days transplanting, tomato fruits of pink maturity stage were harvested. A collective sample of tomato fruits treatment⁻¹ was mixed. There were nine tomato fruit samples in total. Each collective sample comprising 54 tomato fruits and was divided into two equal batches of 27th, packed in cardboard boxes and placed in refrigerator at temperature at 10 ± 2 °C and relative humidity of 90%. The 1st and 2nd batches were allocated to determine fruit quality at the beginning (0 day) and termination (28 days) of cold storage, respectively. The experimental layout of cold storage was a split-split plot based on Randomly Complete Blocks Design with three replications. Periods of storage was allocated to the main plots whereas, pre-harvest foliar applications of calcium chloride and potassium thiosulfate were randomly assigned to the sub- and sub-sub plots, respectively.

Data Recorded

At the beginning and termination of cold storage, the following determinations were assayed:

1. Fruit titratable acidity content; determined by titration with 0.01 N NaOH as outlined by [14]. The titratable acidity content was expressed as a percent.
2. Fruit ascorbic acid (Vitamin C) content; assayed using a method of titration with 2, 6 – dichlorophenol indophenol as outlined by [14]. Fruits ascorbic acid content was expressed as mg ml^{-1} juice.
3. Fruit total soluble sugars (TSS) content; measured by hand held brix refractometer model (RHB 0-32) in clear tomato fruits juice. Fruits total soluble solids was expressed as a percent.
4. Fruit Lycopene content; Fruit lycopene content was extracted using a mixture of hexane, acetone and ethanol (2:1:1), 0.05% (w/v) butylated hydroxyl toluene (BHT) and photometrical measured by modified method of [15] at wave length of 503 nm. The lycopene content was expressed as mg g^{-1} fruit.
5. Fruit firmness; determined by fruit firmness tester with a plunger 6 mm diameter Model 53200 fruit penetrometer, range till 13 kg (T. R. Turoni srl, Via Copernico 26, 47122 Forlì, Italy). Fruits firmness was expressed in kg cm^{-2} .

Statistical Analysis

Data subjected to analysis of Variance according to the design used and Revised Least Significant test introduced by [16] was utilized to verify difference among the experimental treatments.

Results and Discussion

Fruit titratable acidity content

Table 2 shows the main and interaction impacts of cold storage, pre-harvest foliar of calcium chloride and potassium thiosulfate on fruit titratable acidity content of tomato, during cold storage of 2014 and 2015 seasons.

Fruit titratable acidity content was, significantly, higher at the termination (28 day) than the beginning (0 day) in cold storage, in both season. Pre-harvest foliar calcium chloride at 0.2% was, significantly, higher in fruit titratable acidity content than pre-harvest foliar calcium chloride at 0.4% and control, in 1st season while, fruit titratable acidity content was, significantly, higher with untreated control than the pre-harvest foliar of calcium chloride either at 0.2 or 0.4 %, in 2nd season. Pre-harvest foliar application of potassium thiosulfate either at 0.2 or 0.4 % was, significantly, increased in total fruit acidity content relative to the untreated treatment, in 1st season, whereas, in 2nd season vice versa was true.

The 1st order interaction effect between any two studied factors on fruit titratable acidity content during cold storage was significant, in both seasons.

The interaction between cold storage at termination $\times$ foliar calcium chloride at 0.4% or 0.2% was, significantly, higher than other combined treatments in fruit titratable acidity content, in 1st and 2nd seasons, orderly. Regarding the interaction between the termination of cold storage $\times$ foliar potassium thiosulfate at 0.2 or 0.4% was, statistically, higher than other combined treatments in fruit titratable acidity content, in 1st season while, the interaction of termination in cold storage $\times$ foliar the untreated control was, statistically, higher than other combined treatments in fruit titratable acidity content, in 2nd season. Comparison the mean values of interaction between pre-harvest foliar calcium chloride $\times$ potassium thiosulfate showed that, the combined treatment of calcium chloride at 0.4% + potassium thiosulfate at 0.2% was, significantly, the highest value in fruit titratable acidity content, in 1st season nevertheless, the combined treatment of calcium chloride at 0.2% + potassium thiosulfate at 0.0% was, significantly, highest value in fruit titratable acidity content, in 2nd season.

The effect of 2nd order interaction among the three studied factors on fruit titratable acidity content was significant, in the two experimental seasons. At the termination of cold storage, pre-

harvest foliar application of calcium chloride at 0.4% + pre-harvest foliar potassium thiosulfate at 0.2% and pre-harvest foliar application of calcium chloride at 0.0 % + pre-harvest foliar potassium thiosulfate at 0.4% were, significantly, the highest mean value in fruit titratable acidity content, in 1st and 2nd season.

The enhancing effect of fruit titratable acidity content at the termination than the beginning of cold storage was expected. This result may be attributed to a sufficient time of cold storage to enable the effectiveness of retarded metabolic process which account fruit titratable acidity content to be higher.

The retarding effect of pre-harvest foliar application of calcium chloride either at 0.2 or 0.4 % on fruit titratable acidity content, in 2nd season can be explained on the basis that, calcium chloride an ethylene inhibitor [17] and ethylene plays an active role in the tomatoes ripening process [18] and ripening is also associated with the conversion of starch and acids to sugars. This conclusion was supported by [19] who mentioned that, treating tomato fruits with calcium chloride, irrespective of the concentration used, significantly decreased titratable acidity content than the control. Similar conclusion was introduced by [20].

Pre-harvest foliar application of potassium thiosulfate reflected conflicting results on fruit titratable acidity between the two seasons. In 2014 season, pre-harvest foliar application of potassium thiosulfate at 0.2 or 0.4 %, significantly, augmented fruit titratable acidity content whereas, in 2015 season, the reversal was true compared to untreated control. As an average of the two seasons, pre-harvest foliar application of potassium thiosulfate at 0.2 and 0.4 % compared to control averaged + 2.06 and – 2.86 %, orderly. As an average of the two seasons, net pre-harvest foliar application of potassium thiosulfate on fruit titratable acidity content was reduced by 0.80%. Un-likely, [21] displayed that, potassium in both soil (3.3 and 6.6 mmol kg⁻¹) and foliar forms (4.5 and 9 mM) caused a significant increase in fruit tomato titratable acidity of fruit content compared to respective controls in all genotypes.

Table 2. Main and interaction effects of time in cold storage, pre-harvest foliar application of calcium chloride and potassium thiosulfate on fruit titratable acidity content (%) during 2014 and 2015 seasons

Time	Seasons	2014			Mean	2015			Mean
	Calcium chloride (%)	Potassium Thiosulfate (%)				Potassium Thiosulfate (%)			
		0.0	0.2	0.4		0.0	0.2	0.4	
0 Day	0.0	0.3413 ^{i*}	0.4523 ^h	0.2901 ^j	0.3612 ^d	0.499 ^{e-g}	0.5291 ^e	0.4395 ^l	0.4892 ^d
	0.2	0.5632 ^g	0.4437 ^h	0.4309 ^h	0.4793 ^c	0.482 ^{f-h}	0.4608 ^{hi}	0.5163 ^e	0.4864 ^d
	0.4	0.3456 ⁱ	0.3157 ^{ij}	0.3029 ^j	0.3214 ^e	0.4480 ^{hi}	0.4693 ^{g-i}	0.3456 ^j	0.4210 ^e
28 Day	0.0	0.7936 ^c	0.7936 ^c	0.8021 ^c	0.7964 ^b	0.7936 ^c	0.7936 ^c	0.9088 ^a	0.8320 ^a
	0.2	0.6315 ^f	0.7424 ^d	0.8107 ^{bc}	0.7282 ^c	0.9387 ^a	0.7851 ^c	0.5077 ^{ef}	0.7438 ^c
	0.4	0.6827 ^e	0.9301 ^a	0.8491 ^b	0.8206 ^a	0.7808 ^c	0.6912 ^d	0.8491 ^b	0.7737 ^b
0 day		0.4167 ^c	0.4039 ^d	0.3413 ^e	0.3873 ^B	0.4764 ^c	0.4864 ^c	0.4338 ^e	0.4655 ^B
28 day		0.7026 ^b	0.8220 ^a	0.8206 ^a	0.781 ^A	0.8377 ^a	0.7566 ^b	0.7552 ^b	0.7832 ^A
	0.0	0.5675 ^{cd}	0.6229 ^a	0.5461 ^d	0.5788 ^B	0.6464 ^{cd}	0.6613 ^{bc}	0.6741 ^b	0.6606 ^A
	0.2	0.5973 ^b	0.5931 ^b	0.6208 ^a	0.6037 ^A	0.7104 ^a	0.6229 ^{de}	0.5120 ^g	0.6151 ^B
	0.4	0.5141 ^e	0.6229 ^a	0.5760 ^c	0.5710 ^B	0.6144 ^e	0.5803 ^f	0.5973 ^{ef}	0.5973 ^B
Mean		0.5596 ^C	0.6130 ^A	0.5810 ^B		0.6571 ^A	0.6215 ^B	0.5945 ^C	

*Values marked with the same letter(s) within the main and interaction effects are statically similar using Revised LSD. Test at probability = 0.05. Uppercase letter(s) indicate differences between main effects whilst, lowercase letter(s) refer to differences between interaction.

Fruit vitamin C content

Table 3 shows the main and interaction influence of period of cold storage, pre-harvest foliar of calcium chloride and potassium thiosulfate on fruit vitamin C content of tomato, during both experimental seasons.

Fruit vitamin C content in fruit was, intrinsically, higher at the termination than beginning during cold storage, in the two inquest seasons. Pre-harvest foliar calcium chloride at 0.2% was, significantly, pioneer in fruit vitamin C content compared to the control treatment, in both seasons. Increasing the exogenous application of potassium thiosulfate from 0 to 0.2 and further to 0.4 % accompanied with, significant, corresponding increases in fruit vitamin C content, in both years.

The 1st order interaction between any two studied factors was, significant, in both seasons. Concerning the effect of 1st order interaction between the terminations of cold storage × pre-harvest foliar calcium chloride at 0.2% was, statistically, higher in vitamin C than the other combined treatments, in both seasons. As for the effect of interaction between the terminations of cold storage × pre-harvest foliar calcium chloride at 0.4% was, statistically, higher in vitamin C than the other combined treatments, in both seasons. Regarding the interaction between pre-harvest foliar calcium chloride at 0.4% × pre-harvest foliar potassium thiosulfate at 0.4% was, significantly, distinguished in vitamin C compared other combined treatments, in both years.

The effect of 2nd order interaction among the three studied factors on fruit vitamin C content was significant, in both years. At the termination of cold storage, pre-harvest foliar either calcium chloride or potassium thiosulfate at 0.4% were, significantly, higher than other combined treatments in fruit vitamin C content, in two seasons.

The beneficial effect on fruit vitamin C content at the termination than the beginning in cold storage might be owe to during cold storage, fruit vitamin C content increased first with the ripening stage from light pink to red stage of ripening [10]. As an average of the two seasons, fruit vitamin C content increased at the termination over the beginning of cold storage by 66.02 % (Table 2).

The desirable effect of pre-harvest foliar calcium chloride on fruit vitamin C content during cold storage can be explained on the basis that, treated plants with calcium chloride showed slow metabolic activities therefore, untreated plants respiration rate and ethylene production were at higher rate and ascorbic acid decreased rapidly as compared to calcium treated plants. Several investigators coincided our results as [10], [23] who emphasized that, foliar application of tomato plants with calcium chloride at 10 and 15 mM, significantly, resulted in higher fruit vitamin C content compared to the check treatment.

The promoting response on fruit vitamin C content due to pre-harvest foliar application of potassium thiosulfate was in accordance with [25] who displayed that, potassium addition reflected a positive effect on the vitamin C content of tomato fruits. Also, reported that, fruit vitamin C content increased with K application regardless of the sources. On the same side, foliar treatments of potassium; 0.5, 0.6 and 0.7% maximally improved ascorbic acid contents of both tomato cultivars [27].

The enhancing effect at the termination of cold storage due to pre-harvest foliar application of calcium chloride at 0.2 %, potassium thiosulfate at 0.4 % and both at 0.4 % on fruit vitamin C content might be attributed to the contribution of pre-harvest foliar application of calcium chloride and/or potassium thiosulfate to retard the metabolic process during the cold storage with an eventual result of increasing fruit vitamin C content.

Table 3. Main and interaction effects of time in cold storage, pre-harvest foliar application of calcium chloride and potassium thiosulfate on fruit vitamin C (mg ml⁻¹ juice) content during 2014 and 2015 seasons

Seasons		2014			2015				
Time	Calcium	Potassium Thiosulfate			Mean	Potassium Thiosulfate			Mean
	chloride	(%)				(%)			
	(%)	0.0	0.2	0.4		0.0	0.2	0.4	
0 Day	0.0	0.2222 ^{h*}	0.2307 ^h	0.2159 ^h	0.2229 ^d	0.2118 ^l	0.3431 ^d	0.2755 ^{fg}	0.2787 ^c
	0.2	0.1672 ^J	0.2476 ^g	0.1947 ^l	0.2032 ^e	0.2216 ^{kl}	0.2637 ^{gh}	0.2284 ^{ef}	0.2379 ^d
	0.4	0.1016 ^l	0.1418 ^k	0.1418 ^k	0.1284 ^f	0.2598 ^{hi}	0.3412 ^d	0.2324 ^{jk}	0.2768 ^c
28 Day	0.0	0.2703 ^f	0.2162 ^h	0.2919 ^e	0.2595 ^c	0.2467 ^{ij}	0.2233 ^{kl}	0.3680 ^c	0.2793 ^c
	0.2	0.4468 ^b	0.3910 ^d	0.4523 ^b	0.4300 ^a	0.4800 ^b	0.4707 ^b	0.2973 ^e	0.4160 ^a
	0.4	0.2757 ^f	0.4180 ^c	0.5613 ^a	0.4183 ^b	0.2853 ^{ef}	0.2107 ^l	0.5613 ^a	0.3524 ^b
0 day		0.1637 ^f	0.2067 ^d	0.1841 ^e	0.1848 ^B	0.2310 ^f	0.3160 ^c	0.2454 ^e	0.2642 ^B
28 day		0.3309 ^c	0.3417 ^b	0.4352 ^a	0.3693 ^A	0.3373 ^b	0.3016 ^d	0.4089 ^a	0.3493 ^A
	0.0	0.2462 ^e	0.2235 ^f	0.2539 ^e	0.2412 ^C	0.2292 ^g	0.2832 ^e	0.3217 ^d	0.2781 ^C
	0.2	0.3070 ^c	0.3193 ^b	0.3235 ^b	0.3166 ^A	0.3508 ^c	0.3672 ^b	0.2629 ^f	0.3270 ^A
	0.4	0.1886 ^g	0.2799 ^d	0.3516 ^a	0.2734 ^B	0.2726 ^f	0.2759 ^{ef}	0.3968 ^a	0.3151 ^B
Mean		0.2473 ^C	0.2742 ^B	0.3096 ^A		0.2842 ^C	0.3088 ^B	0.3272 ^A	

* Values marked with the same letter(s) within the main and interaction effects are statically similar using Revised LSD. Test at probability = 0.05. Uppercase letter(s) indicate differences between main effects whilst, lowercase letter(s) refer to differences between interaction.

Fruit total soluble sugars content

Comparisons listed in Table 4 show the main and different order interactions effects of three studied factors under study on total soluble sugars, through both experimental seasons.

The response of fruit total soluble sugars content to period of cold storage was varied, significantly, between the two seasons. In 2014 season, the mean value of fruit total soluble sugars content was, significantly, increased at end than beginning of cold storage. In 2015 season, vice versa was really true. Pre-harvest foliar application of calcium chloride at 0.4 %, statistically, produced the highest content of fruit total soluble sugars, in both seasons. Pre-harvest foliar potassium thiosulfate at 0.4 %, statistically, gave higher mean value in fruit total soluble sugars content than foliar potassium thiosulfate at 0.2 % and standard treatment, in both seasons.

Influence of 1st order interaction between any two studied factors on fruit total soluble sugars content was significant, in both seasons. Concerning the effect of interaction between termination of cold storage × pre-harvest foliar calcium chloride or potassium thiosulfate at 0.4% was, statistically, higher in fruit total soluble sugars content than other combined treatments, in both seasons. Regarding the impact of interaction between pre-harvest foliar calcium chloride at 0.4% × potassium thiosulfate at 0.2 and/or 0.4 % was, truly, higher in fruit total soluble sugars content than other combined treatments, in both seasons.

Comparisons among the 2nd interaction illustrated that, the combined treatment of termination in cold storage + calcium chloride at 0.4% + potassium thiosulfate at 0.4% recoded, significantly, highest mean value in fruit total soluble sugars content, in both seasons.

The promoting effect of pre-harvest calcium chloride at 0.4 % on fruit total soluble sugars content during cold storage probably due to increase the respiration and metabolic activity, hence increment the ripening process. Results of [24] ; [19] were in accordance with our results. On the other extreme, several investigators approach to the conclusion that treated plants with calcium chloride decreased fruit total soluble sugars content [28]; [22].

Result of enhancing treated- tomato plants with potassium thiosulfate at 0.4 % on fruit total soluble sugars content during cold storage was in close accordance with those of [29] ; [24]. [30] displayed that, the application of foliar potassium via Nutri-Vant-PeaK is beneficial for tomato fruits cv. Durinta after storage at 12 C° for 12 days as, significantly, increased fruit glucose and total soluble solid contents relative to the untreated fruit.

The 1st interaction effect between time in cold storage and either pre-harvest foliar application of calcium chloride or potassium thiosulfate each at 0.4 %, during the termination of cold storage, recorded the highest mean value of fruit total soluble sugars content. Accordingly, at the termination in cold storage, the 1st interaction between pre-harvest foliar applications of calcium chloride together with potassium thiosulfate each at 0.4 % attained the highest mean value of fruit total soluble sugars content.

The effect of 2nd order interaction among three studied factors under study on fruit lycopene content was, significant, in both years. Comparisons among mean value of 2nd interactions showed that, the combined treatment at termination of cold storage + calcium chloride at 0.4% + potassium thiosulfate at 0.4% was, significantly, higher mean value than values of other combined treatments, in both years.

The stimulative influence on fruit lycopene content at the termination than the beginning of cold storage may be arise due to degradation of chlorophyll and increase the synthesis of lycopene which comprising 80 – 90 % of carotenoids [31] [32]. Similar result has been reported by [23].

The positive effect of pre-harvest foliar application of calcium chloride on fruit lycopene content at termination than beginning of cold storage were in parallel to the results obtained by [10], [22] and [24] who elucidated that, foliar application of tomato plants with 10 and 15 mM Ca, significantly, resulted in higher fruit lycopene content compared to the check treatment.

The synergistic effect of pre-harvest foliar application of potassium thiosulfate on fruit lycopene content during cold storage was in accordance with [21] and [27] who mentioned that, exogenous application of potassium in tomato plants cv. Nagina at 0.6% and cv. Roma at 0.7% reflected maximum fruit lycopene content. On the other extreme, fruits lycopene content of tomato did not show any appropriate effect whether exogenous application of potassium was at 6 or 8 m M compared to control treatment [24].

The improving effect of 1st order interaction between time of cold storage and foliar treated plants with calcium chloride or potassium thiosulfate at 0.4% on fruit lycopene content can be discussed on the basis that, As an average of the two seasons, at termination of cold storage; exogenous application of tomato plants at 0.4 % calcium chloride surpassed over 0.2 % and untreated control by 4.42 and 9.82 % and pre-harvest foliar application of potassium thiosulfate at 0.4 % augmented over 0.2 % and control by 11.29 and 19.24 %, respectively.

The enhancing effect of 2nd order interaction among the three studied factors on fruit lycopene content can be discussed on the current results; as an averaged of the two seasons, the combined treatment of termination of cold storage + pre-harvest foliar calcium chloride at 0.4% + potassium thiosulfate at 0.4 % achieved the highest fruit lycopene content compared to untreated treatment by 29.80%.

Table 4. Main and interaction effects of time in cold storage, pre-harvest foliar application of calcium chloride and potassium thiosulfate on fruit total soluble sugars (%) content during 2014 and 2015 seasons

Time	Seasons Calcium chloride (%)	2014			Mean	2015			Mean
		Potassium Thiosulfate (%)				Potassium Thiosulfate (%)			
		0.0	0.2	0.4		0.0	0.2	0.4	
0 Day	0.0	3.167 ^{bc*}	3.033 ^{c-e}	3.333 ^{b-e}	3.178 ^{b-d}	5.367 ^{a-c}	5.167 ^{a-c}	5.23 ^{a-c}	5.256 ^{bc}
	0.2	3.100 ^{b-e}	3.400 ^{b-d}	3.100 ^{b-e}	2.889 ^d	5.033 ^{bc}	4.933 ^c	5.200 ^{a-c}	5.056 ^c
	0.4	2.800 ^e	2.967 ^{de}	2.900 ^{de}	3.200 ^{bc}	5.800 ^{ab}	5.933 ^a	5.367 ^{a-c}	5.700 ^{ab}
28 Day	0.0	3.033 ^{c-e}	2.833 ^e	3.100 ^{b-e}	2.989 ^{cd}	3.000 ^d	2.833 ^d	5.233 ^{a-c}	3.689 ^d
	0.2	3.600 ^b	3.000 ^{de}	3.500 ^{bc}	3.367 ^b	5.800 ^{ab}	5.733 ^{a-c}	5.700 ^{a-c}	5.556 ^{ab}
	0.4	3.400 ^{b-d}	3.567 ^{bc}	5.933 ^a	4.300 ^a	5.167 ^{a-c}	5.567 ^{a-c}	5.933 ^a	5.744 ^a
0 day		3.022 ^{bc}	3.133 ^{bc}	3.111 ^{bc}	3.089 ^B	5.400 ^a	5.344 ^a	5.267 ^a	5.337 ^A
28 day		3.344 ^b	3.133 ^{bc}	4.178 ^a	3.552 ^A	4.656 ^b	4.711 ^b	5.622 ^a	4.996 ^B
	0.0	3.100 ^{bc}	2.933 ^c	3.217 ^{bc}	3.083 ^B	4.183 ^b	4.000 ^b	5.233 ^a	4.472 ^B
	0.2	3.350 ^b	3.200 ^{bc}	3.300 ^{bc}	3.283 ^B	5.417 ^a	5.333 ^a	5.450 ^a	5.400 ^A
	0.4	3.100 ^{bc}	3.267 ^{bc}	4.417 ^a	3.594 ^A	5.483 ^a	5.750 ^a	5.650 ^a	5.628 ^A
Mean		3.183 ^B	3.133 ^B	3.644 ^A		5.028 ^B	5.028 ^B	5.444 ^A	

*Values marked with the same letter(s) within the main and interaction effects are statically similar using Revised LSD. Test at probability = 0.05. Uppercase letter(s) indicate differences between main effects whilst, lowercase letter(s) refer to differences between interaction.

Fruit lycopene content

The results of main and different interactions as affected by three factors under study during 2014 and 2015 seasons are presented in Table 5.

Fruit lycopene content was, significantly, higher at the termination than beginning of cold storage, in both seasons. Increasing the pre-harvest foliar application of calcium chloride or potassium thiosulfate from 0 to 0.2 and further to 0.4 % accompanied by gradually and significantly increased on fruit lycopene content, in both years.

The 1st order interaction between any two of studied factors on fruit lycopene content was, significant, in both seasons. Regarding the interaction between termination of cold storage × pre-harvest calcium chloride or potassium thiosulfate at 0.4% was, significantly, higher in fruit lycopene content than other combined treatments, in both years. Concerning the influence of interaction between of both pre-harvest foliar calcium chloride × potassium thiosulfate at 0.4% was, truly, higher in fruit lycopene content than other combined treatments, in two experimental seasons.

The 2nd interaction among three factors under study on fruit lycopene content was significant, in both tested seasons. The combined treatment at termination of cold storage + pre-harvest foliar calcium chloride or potassium thiosulfate at 0.4% was, truly, higher value than values other combined treatments, in both seasons.

The stimulative influence on fruit lycopene content at termination than beginning of cold storage may be arise due to degradation of chlorophyll and increase the synthesis of lycopene which comprising 80 – 90 % of carotenoids [31] [32]. Similar result has been reported by [23].

The positive effect of pre-harvest foliar application of calcium chloride on fruit lycopene content at termination of cold storage can be attributed to numerous factors like environment conditions and genotype, which can increase the biosynthesis of carotenoid [33]; [34]). The aforementioned result was in parallel to the results obtained by [10], [22] and [24] who elucidated that, foliar application of tomato plants with 10 and 15 mM Ca, significantly, resulted in higher fruit lycopene content compared to the check treatment.

The synergistic effect of pre-harvest foliar application of potassium thiosulfate on fruit lycopene content during cold storage was in accordance with [21] and [27] who mentioned that, exogenous application of potassium in tomato plants cv. Nagina at 0.6% and cv. Roma at 0.7% reflected maximum fruit lycopene content. On the other extreme, fruits lycopene content of tomato did not show any appropriate effect whether exogenous application of potassium was at 6 or 8 mM compared to control treatment [24].

The improving effect of 1st order interaction between termination of cold storage and pre-harvest foliar calcium chloride or potassium thiosulfate at 0.4% on fruit lycopene content can be discussed on the basis that, As an average of the two seasons, at the termination of cold storage; exogenous application of tomato plants at 0.4 % calcium chloride surpassed over 0.2 % and untreated control by 4.42 and 9.82 % and pre-harvest foliar application of potassium thiosulfate at 0.4 % augmented in comparison with 0.2 % and control by 11.29 and 19.24 %, respectively. According to a positive results of the main effect of pre-harvest spraying of calcium chloride and potassium thiosulfate at 0.4 % on fruit lycopene content consequently, the combined treatment of both; calcium chloride and potassium thiosulfate at 0.4 % logically recorded the best of fruit lycopene content during cold storage.

The enhancing effect of the 2nd order interaction among three studied factors on fruit lycopene content can be discussed on the current results; as an averaged of the two seasons, the combined treatment at termination of cold storage + pre-harvest foliar calcium chloride at 0.4% + potassium thiosulfate at 0.4 % achieved the highest fruit lycopene content compared to untreated treatment by 29.80 %.

Table 5. Main and interaction effects of time in cold storage, pre-harvest foliar application of calcium chloride and potassium thiosulfate on fruit lycopene (mg g⁻¹ fruit) content during 2014 and 2015 seasons

Time	Seasons Calcium chloride (%)	2014			Mean	2015			Mean
		Potassium Thiosulfate (%)				Potassium Thiosulfate (%)			
		0.0	0.2	0.4		0.0	0.2	0.4	
0 Day	0.0	0.0009 ^{k*}	0.0015 ^j	0.0015 ^j	0.0013 ^f	0.0008 ^g	0.0008 ^g	0.0011 ^g	0.0009 ^d
	0.2	0.0021 ⁱ	0.0020 ⁱ	0.0018 ^{ij}	0.0019 ^e	0.0010 ^g	0.0010 ^g	0.0011 ^g	0.0011 ^d
	0.4	0.0017 ⁱ	0.0019 ^{ij}	0.0029 ^h	0.0022 ^d	0.0011 ^g	0.0010 ^g	0.0011 ^g	0.0011 ^d
28 Day	0.0	0.0173 ^g	0.0191 ^e	0.0210 ^{cd}	0.0191 ^c	0.0176 ^f	0.0194 ^d	0.0218 ^b	0.0196 ^c
	0.2	0.0183 ^f	0.0205 ^d	0.0218 ^b	0.0202 ^b	0.0184 ^e	0.0210 ^c	0.0220 ^b	0.0205 ^b
	0.4	0.0193 ^e	0.0211 ^c	0.0225 ^a	0.0210 ^a	0.0197 ^d	0.0219 ^b	0.0228 ^a	0.0215 ^a
0 day		0.0016 ^f	0.0018 ^e	0.0021 ^d	0.0018 ^B	0.0010 ^{de}	0.0009 ^e	0.0011 ^d	0.0010 ^B
28 day		0.0183 ^c	0.0202 ^b	0.0218 ^a	0.0201 ^A	0.0186 ^c	0.0208 ^b	0.0222 ^a	0.0205 ^A
	0.0	0.0091 ^e	0.0103 ^d	0.0113 ^c	0.0102 ^C	0.0092 ^g	0.0101 ^e	0.0114 ^b	0.0102 ^C
	0.2	0.0102 ^d	0.0113 ^c	0.0118 ^b	0.0111 ^B	0.0097 ^f	0.0110 ^c	0.0116 ^b	0.0108 ^B
	0.4	0.0105 ^d	0.0115 ^c	0.0127 ^a	0.0116 ^A	0.0104 ^d	0.0115 ^b	0.0120 ^a	0.0113 ^A
Mean		0.0099 ^C	0.0110 ^B	0.0119 ^A		0.0098 ^C	0.0109 ^B	0.0117 ^A	

*Values marked with the same letter(s) within the main and interaction effects are statically similar using Revised LSD. Test at probability = 0.05. Uppercase letter(s) indicate differences between main effects whilst, lowercase letter(s) refer to differences between interaction.

Fruit firmness

The results in Table 6 illustrate the main and interactions impact of the three studied factors on fruit firmness content, in both experimental seasons.

Fruit firmness content was, significantly, lower at termination than beginning of cold storage period, in both seasons. Pre-harvest foliar application of calcium chloride at 0.4 %, significantly, produced more firm fruits than the untreated control during storage period, in both seasons. Pre-harvest tomato plants with potassium thiosulfate at 0.4% was, truly, higher in fruit firmness than other concentrations during cold storage, in both seasons except the difference between foliar potassium thiosulfate at 0.4% and control was not significant, in 2014 season.

The effect of 1st interactions between any two studied factors under study was true, in both years. Concerning the termination of cold storage, pre-harvest calcium chloride at 0.2 and/or 0.4% was, significantly, more fruit firmness than other treatments, in both seasons. As for the termination of cold storage, pre-harvest potassium thiosulfate at 0.4% was, significantly, higher in fruit firmness than other combined treatments, in both years. Concerning the influence of interaction between pre-harvest foliar calcium chloride at 0.4 and/or 0.2% $\times$ potassium thiosulfate at 0.4% was, truly, higher in fruit firmness than other combined treatments, in two experimental seasons.

The 2nd interaction among three factors under study on fruit firmness was significant, in the both seasons. At termination of cold storage, pre-harvest foliar calcium chloride at 2 and/or 4% + potassium thiosulfate at 4% was, truly, the highest mean value in fruit firmness, in both seasons.

The beneficial effect of pre-harvest calcium chloride at 0.4 % on fruit firmness during cold storage can be discussed on the ground that, calcium appears to be involved in maintaining firmness due to its role as a major component of pectin's and in strengthening cell wall and membrane structure [35][36]. Calcium application usually leads to an increase in tissues calcium concentration that may affect the structure and functions of cell walls and membranes and cell metabolism events [37]. Calcium ions bind tightly to the pectin's in the cell walls and produce cationic bridges between pectic acids or between pectic acids and other acidic polysaccharides. These bridges make the cell walls less accessible to the action of pectolytic enzymes [38] [39]. A positive correlation between fruit firmness and its response to calcium treatment has been observed by [37]. Preliminary greenhouse studies have indicated that supplemental calcium chloride can improve onion bulb firmness [40].

The desirable impact of foliar pre-harvest potassium thiosulfate at 0.4 % on fruit firmness during cold storage can be discussed on the basis of results [41] who indicated potassium nutrition had a positive influence on fruit firmness compared to untreated control. Some researchers as [42] and [43] have reported that K is the most important nutrient with regard to fruit firmness content.

According to a positive result of the main effect of foliar pre-harvest calcium chloride and potassium thiosulfate at 0.4% on fruit firmness during cold storage therefore, the combined treatment for calcium chloride and potassium thiosulfate at 0.4 % together was additive and recorded the, significantly, highest mean value of fruit firmness, in both seasons.

Table 6. Main and interaction effects of time in cold storage, pre-harvest foliar application of calcium chloride and potassium thiosulfate on fruit firmness (kg cm^{-2}) content during 2014 and 2015 seasons

Seasons		2014				2015			
Time	Calcium chloride (%)	Potassium Thiosulfate (%)			Mean	Potassium Thiosulfate (%)			Mean
		0.0	0.2	0.4		0.0	0.2	0.4	
0 Day	0.0	5.567 ^{b-d*}	5.367 ^{b-d}	5.267 ^{b-d}	5.400 ^b	6.63 ^{ab}	6.53 ^{a-c}	6.23 ^{b-d}	6.47 ^a
	0.2	5.867 ^b	5.367 ^{b-d}	4.967 ^d	5.400 ^b	6.77 ^{ab}	6.63 ^{ab}	6.37 ^{a-c}	6.59 ^a
	0.4	6.767 ^a	5.633 ^{bc}	5.433 ^{b-d}	5.944 ^a	7.87 ^a	6.73 ^{ab}	6.57 ^{a-c}	7.06 ^a
28 Day	0.0	2.233 ⁱ	2.900 ^{gh}	2.767 ^{hi}	2.633 ^e	2.03 ^g	2.90 ^{fg}	4.70 ^{de}	3.21 ^c
	0.2	2.667 ^{hi}	3.133 ^{f-h}	3.967 ^e	3.256 ^d	3.73 ^{ef}	3.60 ^{e-g}	7.63 ^{ab}	4.99 ^b
	0.4	3.700 ^{ef}	3.467 ^{e-g}	5.167 ^{cd}	4.111 ^c	4.27 ^{ef}	4.30 ^{ef}	5.03 ^{c-e}	4.53 ^b
0 day		6.067 ^a	5.456 ^b	5.222 ^b	5.581 ^A	7.09 ^a	6.63 ^{ab}	6.39 ^{ab}	6.70 ^A
28 day		2.867 ^d	3.167 ^d	3.967 ^c	3.333 ^B	3.34 ^c	3.60 ^c	5.79 ^b	4.24 ^B
	0.0	3.900 ^d	4.133 ^{b-d}	4.017 ^{cd}	4.017 ^B	4.33 ^d	4.72 ^{cd}	5.47 ^{b-d}	4.84 ^B
	0.2	4.267 ^{bc}	4.250 ^{b-d}	4.467 ^{bc}	4.328 ^B	5.25 ^{b-d}	5.12 ^{b-d}	7.00 ^a	5.79 ^A
	0.4	5.233 ^a	4.550 ^b	5.300 ^a	5.028 ^A	6.07 ^{ab}	5.52 ^{bc}	5.80 ^{bc}	5.79 ^A
Mean		4.467 ^{AB}	4.311 ^B	4.594 ^A		5.22 ^B	5.12 ^B	6.09 ^A	

* Values marked with the same letter(s) within the main and interaction effects are statically similar using Revised LSD. Test at probability = 0.05. Uppercase letter(s) indicate differences between main effects whilst, lowercase letter(s) refer to differences between interaction.

Conclusions

Results of the current study indicate that foliar application of the integrated treatment of calcium chloride $\times$ potassium thiosulfate at 0.4 % for both to tomato plants was distinguished and increased fruit quality; tomato fruit titratable acidity, vitamin C and lycopene contents at the end of cold storage. Compared to other treatments, therefore, the interaction of cold storage at 10 ± 2 °C for 28 days (with relative humidity of 90%) $\times$ calcium chloride at 0.4 % $\times$ potassium thiosulfate at 0.4 % was the best treatment that improved tomato fruit quality, which we recommend to use contributing to agriculture sustainability.

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