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Effects of pre-harvest foliar spraying of potassium and zinc on the physicochemical properties and shelf-life of 'Malas Saveh' pomegranates

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Review Article

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ABSTRACT

Despite being a non-climacteric fruit, the pomegranate is highly perishable because its skin has numerous tiny pores that allow for the free movement of water vapor, making the fruit highly susceptible to water loss. Foliar spraying of nutrient solutions is a very effective way to maintain the quality and increase the shelf-life of fruits. In this study, the effect of foliar spraying of different levels of K_2SO_4 (0, 1, and 2 %) and $ZnSO_4$ (0, 0.5, and 1 %) on the shelf life, quality, and physicochemical parameters of 'Malas Saveh' pomegranate fruits during cold storage was assessed. Physicochemical parameters were evaluated on the day of harvest and after 30, 60, and 90 days of storage. The mineral solutions were sprayed to a runoff on each tree using a backpack sprayer in four times: the first application was during the time of flowering and rest three applications were applied at two-week intervals. Based on statistical analysis, the fruits of treated trees were significantly higher in TSS (total soluble solids), TA (titratable acidity), anthocyanin, vitamin C, and sensory attributes, nevertheless lower in TSS/TA, firmness, and weight loss during storage compared to the control. The findings of the study revealed that foliar spraying with K_2SO_4 and $ZnSO_4$ has high potential in maintaining quality characteristics and increasing the storability of pomegranate fruits.

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1. Introduction

Pomegranate fruits are usually consumed fresh. This fruit is rich in antioxidants (anthocyanins, phenolic acids, and flavonoids), vitamins and minerals. Iran is one of the important pomegranate-producing countries with an annual production of more than 800,000 tons (Malekshahi and ValizadehKaji, 2021). 'Malas Saveh' is the leading commercial cultivar in Markazi and province, with high productivity, big fruit, bright appearance, red aril, favorable taste, high juice percentage, high content of total soluble solids, and anthocyanin. This cultivar reacts strongly to foliar application of zinc and potassium, and a deficiency of these two elements can have a significant impact on its fruit yield and quality (ValizadehKaji and Naeini, 2024).

Despite being a non-climacteric fruit, the pomegranate is highly perishable because its skin has numerous tiny pores that allow for the free movement of water vapor, making the fruit highly susceptible to water loss (Barman et al., 2011). The use of chemicals and cold storage are the main methods to preserving quality and increasing the shelf-life of pomegranates (Mohammadi et al., 2024). Nevertheless, the use of chemicals is restricted in nearly all countries, and cold storage causes chilling damage to pomegranate fruits (Ranjbari et al., 2016; Malekshahi and ValizadehKaji, 2021).

Among pre-harvest factors, optimal fertilization plays a vital role in the quality of fruits before and after harvest (Ziogas et al., 2022). Deficiency or excess of essential elements can affect the quality, susceptibility to physiological disorders, disease occurrence, and textural changes of harvested fruit. The leading cause of post-harvest losses is the improper ratio of nutrients (Bai et al., 2021). Thus, pre-harvest foliar spraying of nutrient solutions is recommended to increase the shelf-life of fruits.

Post-harvest quality and shelf-life of fruits can be increased by pre-harvest application of essential elements (Tagele et al., 2022; Ziogas et al., 2022). Potassium foliar spraying is very effective and fast in meeting the tree's nutritional needs during critical periods (Azizi Ilami et al., 2024). Potassium plays a fundamental role in cell division, gas exchange, enzyme synthesis and activation, sugar synthesis, sugar transfer to fruit, fruit coloring, soluble solids content, the ripening process, and increasing fruit shelf life (Abidi et al., 2023). Zinc delays the ripening and maintains the quality of fruits such as peaches (Batool et al., 2022) and mangoes (Hmmam et al., 2023) during storage.

In fruit trees, foliar nutrient applications are very efficient. However, to our knowledge, no research has been reported on the effect of foliar K_2SO_4 and $ZnSO_4$ application on the shelf-life of pomegranate fruits. In this study, for the first time, the impact of foliar spraying of different concentrations of K_2SO_4 and $ZnSO_4$ on the quality and physicochemical parameters of 'Melas Saveh' pomegranate fruits during cold storage was evaluated.

2. Materials and Methods

2.1. Nutrient treatments

Foliar application of K_2SO_4 and $ZnSO_4$ were done in 2023, on 12-year-old 'Malas Saveh' pomegranate trees in a commercial orchard located at Qom province, Iran. The trees were planted at 3 × 4 m in sandy clay loam soil, the characteristics of which are presented in Table 1. According to soil analysis, all trees received similar chemical fertilizers.

Table 1 Soil mineral contents, physical and chemical properties of the experimental orchard

Soil texture	Clay	Silt	Sand	Organic matter	EC (ds m^{-1})	pH	N	P	K	Zn	Mn	Fe	Cu
	(%)						(ppm)						
Sandy clay loam	12	22	66	1.6	2.4	8.1	0.17	13	242	0.8	3.5	8.1	0.88

A completely randomized block design with nine treatments and three replications (trees) per treatment was used. The treatments were three concentrations of K_2SO_4 (0, 1, and 2 %) and three concentrations of $ZnSO_4$ (0, 0.5, and 1 %). The mineral solutions were sprayed to a runoff on each tree using a backpack sprayer in four times: the first application was during the time of flowering (Late April) and rest three applications were applied at two-week intervals. Due to the intense heat, spraying was done in the evening.

At the commercial ripening stage, fruits were picked. Pomegranate fruits were selected for uniformity in size, shape, and color. The fruits were randomized and divided into nine parts of 15 fruits for nine treatments in three replicates (each replicate contained 5 individual fruits). Fruits were packed in polyethylene terephthalate, and transferred to cold storage (80% relative humidity and 5 °C). On days 0, 30, 60, and 90, one fruit from each replicate was analyzed to measure physiochemical traits.

2.2. TSS and TA

Using a refractometer (Atago, PAL-1, Japan), the levels of TSS in the juice of three separate fruits for each treatment were determined at 20±1 °C and results expressed as °Brix. Titratable acidity (TA) was determined by titration with 0.1 N NaOH up to pH of 8.1, using 1 ml of diluted juice in 25 ml distilled water and results expressed as % citric acid (ValizadehKaji and Almasian, 2025).

2.3. Anthocyanin

According to the pH differential method (Kim et al., 2003), the total anthocyanin level of fruit juice was obtained. Absorbance was measured at 520 and 700 nm and expressed as cyanidin-3-glycoside equivalents per 100 g of fresh weight of fruit.

2.4. Vitamin C

By oxidizing ascorbic acid with 2,6-dichloro phenol-indo-phenol, the vitamin C of pomegranate juice was calculated, and the results were expressed as mg 100 mL^{-1} juice (Nielsen, 2017).

2.5. Fruit firmness

Using a penetrometer (STEP SYSTEM, Germany), the firmness of pomegranate fruits was determined. To measure the firmness of the fruits, a plunger tip with an 8 mm diameter and 21 mm height was used. Results were expressed as kg cm^{-2} (ValizadehKaji and Almasian, 2025).

2.6. Sensory evaluation

Sensory evaluation of fruits during the storage was determined by a panel of five experts on a hedonic scale ranging from 0 to 5, where 1 = very bad, 2 = bad, 3 = medium, 4 = good, and 5 = excellent. Color, taste, appearance, and overall acceptability were done by this method, and the average values were comprised of assessing the acceptability by the consumers (ValizadehKaji and Almasian, 2025).

2.7. Weight loss

Weights of fruits were recorded following treatment (day 0) and at different intervals (days 30, 60, and 90) during storage. Weight loss percentage was expressed as the percentage of weight loss relative to the initial weight.

2.8. Data analysis

A two-factorial (the storage time and different concentrations of K_2SO_4 and $ZnSO_4$) design based on a completely randomized design was used for the experiment. Data were analyzed using SAS software. Using Duncan's multiple ranges, significant differences were evaluated at $P \leq 0.05$.

3. Results

There was no significant interaction between the storage time and fertilizer for TSS and vitamin C. In contrast, significant interaction was detected between the storage time and fertilizer for TA, TSS/TA, anthocyanin, firmness, sensory attributes, and weight loss (Table 2).

Table 2. Variance analysis of physicochemical parameters of pomegranate fruits in response to fertilizer treatments during cold storage.

S.O.V	df	Mean Square							
		TSS	TA	TSS/TA	Anthocyanin	Vitamin C	Firmness	Sensory attributes	Weight loss
Time	3	44.68**	1.18**	57.35**	49.19**	97.14**	44.23**	19.56**	1191.64**
Fertilizer	8	8.54**	0.02**	13.72**	4.82**	22.13**	5.58**	3.22**	4.27**
Time× Fertilizer	24	0.03 ns	0.02**	3.12**	0.12**	0.069 ns	0.26**	0.59**	1.22**
Error	72	0.29	0.004	0.50	0.011	0.10	0.011	0.24	0.010
CV (%)	-	3.81	5.90	5.39	1.91	2.12	1.21	11.54	1.46

ns and **: not significant, significant at $P \leq 0.01$, respectively.

3.1. TSS, TA, and TSS/TA

During cold storage, the TSS of pomegranate fruits decreased, although this decrease was less pronounced in fruits from trees fertilized with K_2SO_4 and $ZnSO_4$ (Table 3). On all sampling days, the greatest TSS was related to fruits from trees sprayed with 2% K_2SO_4+0.5% $ZnSO_4$, although no significant differences were found among 2% K_2SO_4+0.5% $ZnSO_4$, 1% K_2SO_4+1% $ZnSO_4$, and 2% K_2SO_4+1% $ZnSO_4$ at days 0, 30, and 90 (Table 3).

The TA of pomegranates declined during the storage period, although this decline was less in the fruits under K_2SO_4 and $ZnSO_4$ treatments. No significant differences were found in the TA of the fruits among K_2SO_4 and $ZnSO_4$ treatments. By the end of cold storage, the lowest fruit TA was related to control treatment (0% K_2SO_4+0% $ZnSO_4$) which was statistically lower than the other treatments (Table 4). In addition, the TSS/TA of pomegranates increased over the cold storage. Nevertheless, the increase in TSS/TA in the fruits of fertilized trees was lesser (Table 4).

Table 3 Effect of the fertilizer treatments on the TSS of pomegranate fruits during cold storage

Parameter	Treatment		Storage day			
	K_2SO_4 (%)	$ZnSO_4$ (%)	0	30	60	90
TSS (°Brix)	0	0	14.10±0.80 d	13.63±0.62 d	13.00± 0.69 e	11.12± 0.40 d
	1	0	15.13±0.85 bc	14.70±0.30 bcd	14.16± 0.87 bcd	12.35± 0.65 bc
	2	0	15.40±0.09 bc	14.94±0.55 bc	14.48± 0.50 bcd	12.29± 0.29 bc
	0	0.5	14.50±0.08 cd	13.99±0.50 cd	13.49± 0.50 de	11.25± 0.25 d
	1	0.5	15.70±0.12 b	15.07±0.95 bc	14.57± 0.45 bcd	12.84± 0.37 b
	2	0.5	16.80±0.13 a	16.22±0.77 a	15.75± 0.25 a	13.90± 0.30 a
	0	1	14.70±0.09 cd	14.10±0.40 cd	13.76± 0.250 cde	12.02± 0.49 c
	1	1	16.03±1.05 ab	15.49±0.50 ab	15.01± 0.98 ab	12.95± 0.48 b
	2	1	15.90±0.10 ab	15.39±0.60 ab	14.82± 0.36 abc	12.99± 0.40 b

Mean values followed by the same letters are not significantly different from each other at $P \leq 0.05$ (Duncan's multiple range test). Significant differences were separately evaluated on days 0, 30, 60, and 90. Values represent the mean ± SD.

Table 4 The interaction effect of fertilizer treatment and time on the TA and TSS/TA of pomegranate fruits during cold storage

Parameter	Treatment		Storage day			
	K_2SO_4 (%)	$ZnSO_4$ (%)	0	30	60	90
TA (%)	0	0	1.44±0.10 a	1.33±0.09 abcd	1.05±0.05 ijk	0.62±0.07 m
	1	0	1.31±0.09 bcde	1.28±0.07 cdef	1.15±0.10 g-k	0.88±0.02 l
	2	0	1.25±0.05 c-g	1.23±0.07 c-h	1.13±0.02 g-k	0.86±0.04 l
	0	0.5	1.44±0.06 a	1.35±0.05 abc	1.12±0.08 h-k	0.78±0.04 l
	1	0.5	1.22±0.03 d-h	1.19±0.06 e-h	1.05±0.05 ijk	0.85±0.05 l
	2	0.5	1.14±0.06 g-k	1.12±0.08 h-k	1.03±0.07 k	0.89±0.06 l
	0	1	1.42±0.08 ab	1.33±0.06 abcd	1.11±0.09 h-k	0.81±0.09 l
	1	1	1.20±0.05 e-h	1.18±0.06 f-i	1.05±0.04 ijk	0.87±0.03 l
	2	1	1.20±0.03 e-h	1.17±0.10 f-g	1.05±0.05 ijk	0.88±0.06 l
TSS/TA	0	0	9.75±0.16 n	10.21±0.25 n	12.38±0.06 jkl	17.85±1.34 a
	1	0	11.56±0.14 klm	11.50±0.39 lm	12.33±0.31 jkl	14.03±0.42 c-h
	2	0	12.33±0.42 jkl	12.16±0.24 jkl	12.81±0.21 h-l	14.32±1.00 b-f
	0	0.5	10.08±0.36 n	10.38±0.75 mn	12.07±0.41 jkl	14.45±1.06 b-f
	1	0.5	12.87±0.21 g-k	12.66±0.16 il	13.91±1.09 d-i	15.13±0.45 bcd
	2	0.5	14.76±0.66 bcd	14.50±0.34 b-e	15.33±0.80 bc	15.66±0.72 b
	0	1	10.37±0.52 mn	10.58±0.21 mn	12.44±0.78 jkl	14.91±1.05 bcd
	1	1	13.40±1.43 e-j	13.13±0.24 f-j	14.19±0.33 c-f	14.91±1.06 bcd
	2	1	13.26±0.41 ej	13.19±0.61 ej	14.15±1.02 c-h	14.82±1.47 bcd

Mean values followed by the similar letters across treatment and storage time for each parameter are not significantly different from each other at $P \leq 0.05$ (Duncan's multiple range test). Values represent the mean ± SD.

3.2. Anthocyanin

The anthocyanin content of pomegranates declined during cold storage (Table 5). However, fruits of fertilized trees showed significantly more total anthocyanin content compared to unfertilized controls. At all sampling days, the maximum anthocyanin content was related to 2% K_2SO_4+0.5% $ZnSO_4$, which showed a significant difference compared to other treatments (Table 5).

Table 5 The interaction effect of fertilizer treatment and time on the anthocyanin and firmness of pomegranate fruits during cold storage

Parameter	Treatment		Storage day			
	K_2SO_4 (%)	$ZnSO_4$ (%)	0	30	60	90
Anthocyanin (mg 100 g^{-1})	0	0	6.48±0.12 f	5.80±0.20 j	4.22±0.17 qr	2.91±0.09 u
	1	0	6.87±0.10 cd	6.18±0.12 gh	4.93±0.07 m	3.90±0.10 s
	2	0	6.97±0.17 c	6.29±0.11 g	4.89±0.11 mn	3.94±0.06 s
	0	0.5	6.57±0.07 ef	5.91±0.09 ij	4.40±0.10 pq	3.13±0.07 t
	1	0.5	7.16±0.09 b	6.88±0.12 cd	5.31±0.09 l	4.20±0.05 r
	2	0.5	7.92±0.08 a	7.34±0.15 b	6.28±0.12 g	5.52±0.07 k
	0	1	6.70±0.10 de	6.02±0.13 hi	4.53±0.06 op	3.28±0.12 t
	1	1	7.31±0.09 b	6.94±0.14 c	5.75±0.10 j	4.71±0.08 no
	2	1	7.24±0.06 b	6.90±0.10 c	5.87±0.13 ij	4.65±0.05 o
Firmness (kg cm^{-2})	0	0	8.20±0.10 k	9.12±0.12 i	11.19±0.17 b	12.52±0.08 a
	1	0	7.80±0.07 lm	8.10±0.10 k	9.45±0.10 h	10.40±0.10 e
	2	0	7.60±0.06 n	7.90±0.10 l	9.33±0.07 h	10.37±0.13 ef
	0	0.5	8.20±0.09 k	8.96±0.12 ij	10.20±0.10 f	10.86±0.15 c
	1	0.5	7.40±0.07 o	7.77±0.12 lmn	8.80±0.20 j	9.92±0.07 g
	2	0.5	6.50±0.05 q	7.11±0.09 p	8.25±0.14 k	9.44±0.15 h
	0	1	7.88±0.08 lm	8.19±0.06 k	9.78±0.12 g	10.62±0.08 d
	1	1	7.70±0.07 mn	7.85±0.15 lm	9.37±0.12 h	9.89±0.10 g
	2	1	7.70±0.04 mn	7.92±0.10 l	9.30±0.10 h	9.94±0.06 g

Mean values followed by the similar letters across treatment and storage time for each parameter are not significantly different from each other at $P \leq 0.05$ (Duncan's multiple range test). Values represent the mean ± SD.

3.3. Firmness

The firmness of pomegranates increased significantly with increasing storage time (Table 5). This increase was significantly lesser in the fruits of fertilized trees than those unfertilized. At all sampling days, the lowest value of firmness was for 2% K_2SO_4+0.5% $ZnSO_4$, although no significant differences were found among 2% K_2SO_4+0.5% $ZnSO_4$, 2% K_2SO_4+0% $ZnSO_4$, 1% K_2SO_4+1% $ZnSO_4$, and 2% K_2SO_4+1% $ZnSO_4$ at days 30, and among 2% K_2SO_4+0.5% $ZnSO_4$, 1% K_2SO_4+1% $ZnSO_4$, and 2% K_2SO_4+1% $ZnSO_4$ at day 90 (Table 5).

3.4. Vitamin C

During cold storage, the vitamin C content of pomegranates declined, although this decline was less significant in fruits from fertilized trees (Table 6). On all sampling days, the highest vitamin C content of fruits was obtained with 2% K_2SO_4+0.5% $ZnSO_4$, which was significantly higher than most other treatments (Table 6).

Table 6 Effect of the fertilizer treatments on the vitamin C of pomegranate fruits during cold storage

Parameter	Treatment		Storage day			
	K_2SO_4 (%)	$ZnSO_4$ (%)	0	30	60	90
Vitamin C (mg 100 mL^{-1})	0	0	15.56±0.60 f	14.41±0.19 e	13.14±0.35 d	10.52±0.50 e
	1	0	16.41±0.06 e	15.50±0.15 d	14.45±0.45 c	12.41±0.40 c
	2	0	16.80±0.07 d	15.71±0.29 d	14.72±0.27 c	12.40±0.35 c
	0	0.5	15.70±0.10 f	14.65±0.33 e	13.52±0.50 d	11.01±0.48 de
	1	0.5	17.51±0.04 c	16.58±0.21 c	15.51±0.50 b	13.16±0.35 b
	2	0.5	19.09±0.07 a	18.24±0.25 a	17.07±0.45 a	15.13±0.37 a
	0	1	15.90±0.08 f	14.78±0.21 e	13.70±0.30 d	11.51±0.50 d
	1	1	18.41±0.07 b	17.25±0.25 b	16.02±0.28 b	13.79±0.21 b
	2	1	18.20±0.09 b	17.11±0.11 b	15.93±0.45 b	13.85±0.15 b

Mean values followed by the same letters are not significantly different from each other at $P \leq 0.05$ (Duncan's multiple range test). Significant differences were separately evaluated on days 0, 30, 60, and 90. Values represent the mean ± SD.

3.5. Sensory attributes

The sensory attributes of pomegranates decreased during storage, and the sensory attributes of fruits from fertilized trees were better than those from unfertilized trees (Table 7). No significant differences were observed in sensory attributes of the fruits from fertilized and unfertilized trees on days 0 and 30, among most fertilizers on days 60 and 90. After 60 and 90 days of cold storage, fruits of trees fertilized with 2% K_2SO_4+0.5% $ZnSO_4$ and 1% K_2SO_4+1% $ZnSO_4$ showed 87.96% and 225.56% greater sensory scores than the unfertilized control (Table 7).

Table 7 The interaction effect of fertilizer treatment and time on the sensory attributes and weight loss of pomegranate fruits during cold storage

Parameter	Treatment		Storage day			
	K_2SO_4 (%)	$ZnSO_4$ (%)	0	30	60	90
Sensory attributes	0	0	4.66±0.57 ab	4.33±0.57 abc	2.66±0.57 e	1.33±0.57 f
	1	0	5.00±0.00 a	4.66±0.57 ab	4.00±1.00 bc	2.66±0.57 e
	2	0	5.00±0.00 a	4.66±0.57 ab	4.33±0.57 abc	3.00±1.00 de
	0	0.5	5.00±0.00 a	4.66±0.57 ab	3.66±0.57 cd	2.33±0.57 e
	1	0.5	5.00±0.00 a	5.00±0.00 a	4.66±0.57 ab	3.66±0.57 cd
	2	0.5	5.00±0.00 a	5.00±0.00 a	5.00±0.00 a	4.33±0.57 abc
	0	1	5.00±0.00 a	4.66±0.57 ab	3.66±0.57 cd	2.33±0.57 e
	1	1	5.00±0.00 a	5.00±0.00 a	5.00±0.00 a	4.33±0.57 abc
	2	1	5.00±0.00 a	5.00±0.00 a	4.66±0.57 ab	3.66±0.57 cd
Weight loss (%)	0	0		4.62±0.24 n	10.83±0.15 h	17.25±0.15 a
	1	0		4.37±0.07 op	7.93±0.07 k	16.03±0.15 c
	2	0		4.29±0.11 pq	7.76±0.03 k	15.93±0.06 c
	0	0.5		4.50±0.05 no	8.30±0.08 i	16.55±0.15 b
	1	0.5		4.16±0.03 qr	7.44±0.06 l	15.52±0.07 d
	2	0.5		3.50±0.08 t	7.05±0.20 m	13.48±0.12 g
	0	1		4.40±0.08 op	8.11±0.11 j	16.40±0.12 b
	1	1		4.02±0.02 r	7.87±0.17 k	14.44±0.15 f
	2	1		3.80±0.04 s	8.21±0.11 ij	14.86±0.13 e

Mean values followed by the similar letters across treatment and storage time for each parameter are not significantly different from each other at $P \leq 0.05$ (Duncan's multiple range test). Values represent the mean ± SD.

3.6. Weight loss

The weight loss of pomegranates increased during cold storage. However, weight loss in fruits from fertilized trees was less than that from unfertilized trees. At all sampling days, the lowest weight loss was related to 2% K_2SO_4+0.5% $ZnSO_4$, which had a significant difference compared to other treatments (Table 7).

4. Discussion

Deficiency of nutrients, especially potassium and zinc, due to the calcareous nature of the soils, has been one of the main problems in the pomegranate-growing regions of Iran. The application of mineral fertilizers containing potassium and zinc to soils with high calcium carbonate content causes a reduction in yield, which can be due to the fixation of elements in the soil and also to the reduction in the availability of these elements. Foliar application of mineral fertilizers is a particularly useful alternative tool when soil conditions may limit the uptake of elements by plant roots. On the other hand, foliar application of mineral fertilizers is convenient, has good efficacy, and the plant responds quickly to it. In addition, foliar application of mineral fertilizers helps to prevent toxicity symptoms that may occur after soil application of fertilizers. In previous reports, foliar application of mineral fertilizers was found to significantly improve fruit quality and quantity (ValizadehKaji and Naeini, 2024).

The changes in TSS and TA in fruits during storage could be the result of the ripening process. Organic acids are the primary respiratory substrates of fruit during storage (ValizadehKaji and Almasian, 2025). Results are also in agreement with previous reports in Mandarin (ValizadehKaji and Ahmadi, 2025), in which TA reduced during cold storage, and the fertilizer treatments decreased its loss. Furthermore, starch degrades into soluble sugars during cold storage, increasing the TSS level (Sabır et al., 2011). Nevertheless, the lowest TSS recorded in fruits from fertilized trees (Table 3) can be related to a decrease in respiration rate by fertilizers. Moreover, the findings of this research confirm various previous works that foliar application of different fertilizers caused fewer changes in TSS, TA, and TSS/TA of fruits over post-harvest time (Mounika et al., 2021; Ziogas et al., 2022; Ghafouri et al., 2023; Abidi et al., 2023).

Similar to some previous works (Malekshahi and ValizadehKaji, 2021), the anthocyanin content of pomegranate fruits decreased during cold storage (Table 5). In addition, in accordance with our findings, an increase in the anthocyanin content of pomegranate fruits has been shown with the application of potassium and zinc (Maity et al., 2022; Al-Saif et al., 2022). In contrast, Davarpanah et al. (2016) showed that the application of zinc did not affect the anthocyanin content of pomegranate fruits. The positive effect of potassium on anthocyanin content is because potassium increases the transport of sugars from leaves to fruits and increases the activity of enzymes involved in the biosynthesis of anthocyanins (Delgado et al., 2006). Zinc is also vital for improving the efficiency of photosynthesis and sugar accumulation (Davarpanah et al., 2016), which leads to an increase in anthocyanin biosynthesis.

The findings of this study (Table 5) are consistent with the findings of other researchers (Malekshahi and ValizadehKaji, 2021; Ziogas et al., 2022) who showed that the firmness of pomegranate fruits increases significantly with increasing storage time. In addition, similar to our findings, Okba et al. (2021) showed that the firmness of apricot fruits from foliar-sprayed trees with potassium was significantly higher than that of the control during storage. The higher firmness in fruits from trees fed with potassium can be attributed to the effects of potassium on the accumulation of osmolytes and the increase in fruit potassium content, which leads to a higher fruit pressure potential. In addition, positive effects of preharvest application of other fertilizers on reducing fruit softening during storage have been reported (Zingwari et al., 2024; Moosavi-Nezhad et al., 2024).

Similar to the results of this study, a decrease in the vitamin C content of fruits with increasing storage time has been proven for grapes (Tavasolinasab et al., 2023) and mangoes (Khalil et al., 2022), which could be due to its consumption in the free radical detoxification process (Saki et al., 2019). Likewise, Abidi et al. (2023) showed that fruits of trees fertilized with potassium had greater vitamin C content than unfertilized ones. Furthermore, it was found that spraying mango trees with K_2SO_4 (Jakhar and Pathak, 2016) caused less reduction in the vitamin C content of fruits during storage, which is consistent with our findings (Table 6).

Consistent with the sensory attributes obtained in the present study (Table 7), other studies have reported that pre-harvest application of fertilizers maintains the sensory attributes of fruits during storage (Mohebbi et al., 2020; Souza et al., 2023). The maximum sensory attributes may be attributed to minimal water loss from the fruit surface and maintaining a better balance between sugars and acids in the fruit juice (ValizadehKaji and Ahmadi, 2025).

Water loss due to evapotranspiration is the main reason for the significant weight loss of fruits (Malekshahi and ValizadehKaji, 2021). In this regard, positive effects of potassium foliar application on reducing fruit weight loss have been obtained for peach and nectarine (Abidi et al., 2023), which could be related to reduced evapotranspiration in the fruit due to stomatal closure (El Kholy et al., 2018).

Conclusion

Pomegranate fruits of trees sprayed with different levels of K_2SO_4 and $ZnSO_4$ had higher values of TSS, TA, anthocyanin, firmness, vitamin C, and sensory attributes; however, fruits of fertilized trees showed lower values of weight loss and TSS/TA during cold storage. Therefore, foliar spraying of K_2SO_4 and $ZnSO_4$ has shown significant promising potential for maintaining quality characteristics and increasing shelf life of pomegranate fruits. On the other hand, foliar fertilization strategies can lead to increased efficiency in nutrient consumption, reduced negative impact on the environment, and potentially enhanced health benefits for consumers.

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