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Yield and Fruit Quality Response of Pomegranate (*Punica granatum*) to Foliar Spray of Potassium, Calcium and Kaolin

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Abstract: To study the effect of potassium nitrate, calcium nitrate and kaolin (Aluminum silicate) on pomegranate cv. Wonderful, this study was conducted during 2020–2021 to investigate the possibility of minimizing the percentages of sunburn and fruit cracking and ameliorating the yield and fruit quality of pomegranate during the aforementioned period. Four sprays consisting of potassium nitrate at 1%, 2% and 3%, calcium nitrate at 2%, 3% and 4%, kaolin at 2%, 4% and 6% and water only (control) were sprayed on pomegranate trees during May, July, and August. The results showed that through spraying the fruit at set percentages, fruit yield was greatly increased through the spraying of potassium nitrate, calcium nitrate and kaolin, particularly the application of potassium nitrate at 3% and 4% and kaolin at 6% as opposed to than the other percentages. In addition, the percentages of fruit cracking and sunburn were markedly lessened by the application of calcium nitrate at 4% and 6% and also by kaolin at 6%. Moreover, the fruit content from TSS, total sugars and anthocyanin, was improved through the spraying of potassium nitrate at 2% and 3%, whereas the fruit weight and firmness were improved by the application of calcium nitrate at 4% and kaolin at 6%.

Keywords: potassium nitrate; sunburn; fruit quality; pomegranate

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1. Introduction

In tropical and sub-tropical regions, pomegranate (*Punica granatum* L., Punicaceae) has been cultivated for five thousand years in a wide range of countries such as Morocco, Spain, and Egypt, where it is valued for its antioxidative and nutritional value [1,2]. There are numerous and well-known cultivars of pomegranate such as the "Wonderful" variety, which is cultivated for fresh eating or for commercial juice production [3]. Moreover, it also characterized by its high productivity, favorable taste, big fruit, red aril, high juice percentage, bright appearance, high content from soluble solids, and anthocyanin [4].

When the temperature in the Summer season increases to above 45 °C, it causes sunburn damage to the fruit, which results in losses up to 40% from the total yield [5,6]. On the opposite side, the decrease in the leaf temperature perhaps ameliorates the net photosynthesis by minimizing the time of closing for the stomata and the respiration rate during the daytime, particularly in hot dry climates [7]. The combined effect of high solar radiation, high temperatures and low humidity causes the physiological disorder sunburn that leads to a decrease in fruit yield and quality through burning of the fruit surface and alteration of the peel color by the formation of large black spots on the fruits' skin [8]. Thus, it leads to a reduction in the fruits' appearance quality and consequently great economic losses [9]. One of the most common physiological problems is fruit cracking, which is caused as a result of moisture imbalances, and micronutrient deficiency [10,11]. Samra et al. [12] and Melgarejo et al. [6] stated that pomegranates are susceptible to being injured by sunburn because their fruits are on the end of the branches, which are usually thin and droop with the increasing weight of fruits.

Pre- and post-spraying of calcium can protect pomegranates from physiological deterioration, delaying maturity and ameliorating the fruit quality [13], regulating the plant root water absorption and reducing the cracking in pomegranates [14], raising the nutritional status, its productivity and its fruit quality [15]. Spraying calcium chloride improved the plant height, weight, preservation, size, length, diameter and number of fruits, yield, grain weight and grain–fruit ratio, marketable fruits, soluble solids, total acidity and TSS-acid ratio, anthocyanin content in juice and peel, whereas it decreased the fruit cracking and sunburn in pomegranates [16–19].

Spraying pomegranates with kaolin as an antitranspirant increased leaf relative turgidity, total chlorophyll, fruit weight, size, total soluble solids, total sugar and reducing sugars, grains and juice percentages, juice anthocyanin content, moisture percentage of peel and seeds, VC, aril wight and size, whereas it minimized the fruit skin thickness and non-edible parts [20]. Potassium plays important roles in plants; photosynthesis, respiration, ion absorption and transport, protein synthesis and enzyme activation [21], progressing the percentages of fruit set and reservation, fruit yield and its quality of pomegranates [22]. The spraying of potassium nitrate at 250 mg/L on pomegranates increased juice percentage, fruit weight, soluble solids and VC, whereas it decreased aril length and diameter [23]. Treating pomegranate 'Kandhari' with four levels of K_2O at 20, 40 and 60 g per tree increased productivity, weight, fruit size, and grain juice percentage [24]. Davarpanah et al. [25] documented that sprays of potassium on 'Malas-e-Saveh' pomegranate at 0, 500, 1000 and 2000 mg/L increased fruit yield, fruit no. and fruit size, TSS, juice volume, anthocyanin index and total anthocyanin. Therefore, this experiment was carried to investigate the role of potassium nitrate, calcium nitrate and kaolin as effective tools to provide physical protection, reduce the fruit drop, sunburn and cracking and improve the fruit yield and quality of 'Wonderful' pomegranate.

2. Materials and Methods

During the 2020–2021 seasons to investigate the influence of the spraying of potassium nitrate, calcium nitrate and kaolin, the research was performed on eight-year-old 'Wonderful' pomegranate trees. The pomegranate trees were grown on sandy loam soil in a private orchard located at Burg El-Arab, Alexandria Governorate, Egypt at 4 × 4 m apart and irrigated by a drip irrigation system and subjected to the same practical horticultural practices applied in the orchard as the untreated trees. The soil analysis is shown in Table 1.

Table 1. Physicochemical analysis of the soil being studied.

pH	$CaCO_3$ %	EC dS/m	O.M	Textural Class	Sand %	Silt %		Clay %	
8.2	40.5	1.74	1.32	Sandy Loam	74.5	12.2		13.3	
Nutrients (mg/kg)			Soluble Anions (meq/L)			Soluble Cations (meq/L)			
P	K	N	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
64.30	75.5	30.72	3.8	9.4	4.20	6.75	2.66	5.64	2.35

The experiment was composed of ten treatments, which were arranged in a completely randomized block design, where each treatment was applied on ten replicates (ten trees). The trees were sprayed four times: the first was in May (during the time of flowering), and the other sprays were started from the middle of July, with two-week intervals (during the period of fruit growth). The trees were completely covered by the solution by calcium nitrate at 2, 3 and 4% (20, 30 and 40 g/L), kaolin (Aluminum silicate) at 2, 4 and 6% (20, 40 and 60 g/L), and potassium nitrate at 1, 2 and 3% (10, 20 and 30 g/L), and control (not treated trees) and each tree was sprayed with 4 L.

2.1. Fruit Set, Drop and Fruit Yield

Fruit set (%): Two months after flowering, the final fruit set was calculated according to this formula:

$$\text{Fruit set }(\%) = \frac{\text{Number of fruitlets}}{\text{Number of perfect flowers}} \times 100 \quad (1)$$

Fruit drop (%) was measured as the number of dropped fruits from the middle of June until the time of harvest under experimental conditions according to the next equation:

$$\text{Fruit drop}(\%) = \frac{\text{Number of fruit at harvest time}}{\text{Number of fruit set}} \times 100 \quad (2)$$

Fruit cracking (%) was counted on each tree and the percentage of spilt fruit was calculated according to the equation:

$$\text{Fruit cracking }(\%) = \frac{\text{Number of cracked fruits}}{\text{Total number of fruits}} \times 100 \quad (3)$$

Fruit Sunburn (%)was calculated as a percentage from the total number of fruits on each tree before the time of harvest [26] according to this formula:

$$\text{Fruit sunburn}\% = \frac{\text{Number of sunburned fruits}}{\text{Total number of fruits}} \times 100 \quad (4)$$

Yield (kg/tree): At harvest time (start of October), the yield was calculated as the weight of the fruit in kg and by multiplying it * by the number of trees in each hectare, which gave the yield in ton per hectare.

Marketable fruit number = Total fruit number—(sunburned fruit number + fruit cracking number).

Marketable fruit yield (kg/tree) = Marketable fruit number * by the average fruit weight.

2.2. Fruit Quality

At harvest time (during October 2020–2021), five fresh fruits from each tree/replicate were collected randomly once they had reached the ripening stage and full color and were directly transferred to the lab to estimate their physical and chemical characteristics:

2.2.1. Physical Fruit Characteristics

The physical fruit characteristics were determined as the fruit weight (g), grains' weight (g), peel weight (g), fruit length and diameter (cm), and fruit volume (cm^3). Fruit firmness (Ib/inch2) was determined using a pressure tester (mod. FT 327 (3-27 Ibs.Made in Italy) with a 7/18-inch plunger [27]. The grains' juice percentage was estimated by taking 100 g of grains per replication of each treatment, weighing them and then grinding them in a Waring blender. The crushed material was filtered through the muslin cloth and the results were expressed in percentage using the following formula:

$$\text{Juice }(\%) = \frac{\text{weight of juice}}{\text{grain weight}} \times 100 \quad (5)$$

2.2.2. Chemical Fruit Characteristics

The total soluble solids (TSS%) measured in the fruit juice was measured by using hand refractometers (ATAGrO Co. LTD, Tokya, Japan). Total acidity (%)was determined by direct titration of 0.1 N sodium hydroxide using phenolphthalein 1% as an indicator and was expressed as citric acid percentage [28]. The TSS-acid ratio was calculated for each replicate of the applied treatments. Anthocyanin content (mg/100 g F.W.) was determined (mg/100 g fresh weight) according to Nangle et al. [29]. Vitamin C (mg/100 mL Juice) as ascorbic acid was determined by titration with 2,6 dichloro phenol-indo-phenol [30] and calculated as mg/100 mL juice. Total, reduced and non-reduced sugars percentages were assessed by using phenol and sulfuric acid [31], while reducing sugars were determined by the Nelson arsenate–molybadate colorimetric methods [32], and non-reducing sugars are the difference between them.

2.3. Leaf Nutritional Status

30 leaves were collected from the middle part of the sprayed shoots in the middle of October in accordance with Pal [33] to estimate their mineral content after their digestion by H_2SO_4-H_2O_2 until the solution became obvious [34]. The prepared solution was put in a 100 mL volumetric flask and was completed to 100 mL by distilled water. The Micro–Kjeldahl method was used to measure nitrogen percentage [35], and phosphorus was measured by the method of Vanadomolybdate [36]. Potassium was determined using a flame photometer (SKZ International Co., Ltd., Jinan, China) [37]. Calcium was determined using PerkinElmer Atomic Absorption Spectrometer 3300 (Manufacturer: PerkinElmer, Ontario, Canada) according to Carter [38]. Boron was calorimetrically determined using the carmine method according to [39].

2.4. Statistical Analysis

Data were statistically analyzed by one-way analysis of variance (ANOVA), and by use of the Least Significant Difference test at 0.05, and the comparison among means of the treatments was performed according to Snedecor and Cochran [40] by use of the the statistical software 'Statistix v8.1′, CoHort Software (Pacific Grove, CA, USA).

3. Results

3.1. Fruit Set, Drop and Fruit Yield

According to the results in Table 2, the foliar application of calcium nitrate, kaolin and potassium nitrate improved the fruit set, and reduced the percentages of fruit drop, fruit cracking and fruit sun burn in comparison with the control in the two seasons. The most positive influence in markedly improving the fruit set percentages was noticed with the foliar application of potassium nitrate at 3 and 2%, kaolin at 4 and 6% and calcium nitrate at 3 and 4% over untreated trees in the two seasons. On the opposite side, the percentages of fruit drop were minimized by the application of calcium nitrate at 3 and 4%, kaolin at 6 and 4% and by potassium nitrate at 3 and 2%, in the two seasons compared with the untreated trees. Fruit sunburn was significantly reduced by the spraying of potassium nitrate at 2 and 3%, kaolin at 4 and 6% and by calcium nitrate at 3 and 4% compared with the untreated trees in the two seasons, respectively. Fruit cracking percentages were markedly reduced by the spraying of potassium nitrate at 2 and 3%, kaolin at 4 and 6% and calcium nitrate at 3 and 4% as compared to the untreated trees in the two seasons.

The results demonstrated in Table 3 made it clear that the foliar application of potassium nitrate, calcium nitrate and kaolin significantly reduced the number of sunburned fruits and the most obvious influence was through the application of kaolin at 6 and 4% (3.61 and 3.63; 360 and 3.68) compared with the other applied treatments or the control (4.72 and 5.02) in the first and second season, respectively. The fruit cracking number was significantly reduced by the spraying of calcium nitrate at 4 and 3% (3.08 and 3.14; 3.01 and 3.10) compared with the other treatments and the control, which gave the highest number (4.69 and 4.86) in the first and seasons season. The highest number of marketable fruit was obtained by the spraying of potassium nitrate at 3% (52.18 and 56.15), kaolin at 6% (45.89 and 5179) and calcium nitrate at 4% (49.17 and 53.90) compared with the other treatments and the control, which gave the lowest number (28.82 and 32.30) in the first and second seasons. Marketable fruit weight was significantly increased by the spraying of potassium nitrate at 3 and 2% (28.55 and 22.01; 32.10 and 25.29 kg/tree), calcium nitrate at 4% (22.68 and 26.08 kg/tree) and kaolin at 6% (20.79 and 24.08 kg/tree) compared with the other treatments and the control, which gave the lowest values (10.98 and 12.84 kg/tree) in the first and second season respectively.

Table 2. The effect of the foliar application of potassium nitrate, calcium nitrate and kaolin on the fruit set, drop, sun burn and cracking percentages of 'Wonderful' pomegranate during the 2020 and 2021 seasons.

Treatment		Fruit Set%		Fruit Drop%		Sunburn%		Fruit Cracking%	
		2020	2021	2020	2021	2020	2021	2020	2021
Control	0	7.83 f	8.8 e	12.42 a	12.49 a	12.35 a	11.9 a	12.30 a	11.55 a
Calcium nitrate	2%	9.11 de	9.92 de	10.66 b	10.67 b	9.7 b	9.32 b	8.28 b	7.89 bc
	3%	10.86 c	12.54 c	7.85 f	7.67 ef	8.04 cd	7.58 c	6.19 e	5.58 fg
	4%	12.62 b	14.46 b	6.96 g	6.78 f	7.14 e	6.30 d	5.57 f	5.08 g
Kaolin	2%	8.74 ef	9.29 de	12.03 a	12.16 a	9.56 b	9.06 b	8.55 b	8.36 b
	4%	12.39 b	13.57 bc	9.29 d	9.68 bc	7.49 de	7.04 c	7.16 cd	6.58 de
	6%	12.67 b	14.55 b	8.49 e	8.85 cd	6.82 e	6.12 d	6.60 de	5.90 ef
Potassium nitrate	1%	9.99 cd	10.55 d	10.03 c	9.84 bc	9.69 b	9.31 b	8.33 b	8.14 bc
	2%	12.89 ab	14.69 b	7.99 ef	8.15 de	8.20 c	7.52 c	7.64 c	7.33 cd
	3%	13.92 a	15.95 a	7.05 g	6.83 f	6.96 e	6.26 d	6.57 de	6.51 e
$LSD_{0.05}$		1.16	1.20	0.57	1.03	0.65	0.59	0.62	0.78

The letters make it clear that there is no significant difference among treatments in the same column. Data are mean values of 10 replicates (10 trees).

Table 3. The effect of the foliar application of potassium nitrate, calcium nitrate and kaolin on the numbers of fruit sunburned, fruit cracking and marketable fruit of the 'Wonderful' pomegranate variety during the 2020 and 2021 seasons.

Treatment		Sunburned Fruit Number		Fruit Cracking Number		Marketable Fruit Number		Marketable Yield (kg/Tree)	
		2020	2021	2020	2021	2020	2021	2020	2021
Control	0	4.72 a	5.02 a	4.69 a	4.86 a	28.82 g	32.30 g	10.98 g	12.84 f
Calcium nitrate	2%	3.88 bc	4.04 bcde	3.32 cd	3.43 cde	32.80 ef	3593 f	13.73 ef	15.13 de
	3%	4.00 bc	4.09 bcd	3.08 d	3.01 e	42.59 d	46.74 cd	18.55 d	21.16 c
	4%	4.02 bc	3.83 cde	3.14 d	3.10 de	49.17 b	53.90 ab	22.68 a	26.08 b
Kaolin	2%	3.76 bc	3.89 cde	3.37 cd	3.59 cd	32.21 f	35.45 f	13.19 f	14.56 ef
	4%	3.63 c	3.68 de	3.48 cd	3.44 cde	41.39 d	45.11 d	18.15 d	20.40 c
	6%	3.61 c	3.60 e	3.5 cd	3.47 cde	45.89 c	51.79 b	20.79 c	24.08 b
Potassium nitrate	1%	4.21 b	4.40 b	3.62 bc	3.86 bc	35.67 e	39.07 e	14.98 e	16.86 d
	2%	4.23 b	4.28 bc	3.95 b	4.17 b	43.48 cd	48.42 c	22.01 bc	25.29 b
	3%	4.19 b	4.03 bcde	3.96 b	4.18 b	52.18 a	56.15 a	28.55 a	32.10 a
$LSD_{0.05}$		0.43	0.42	0.41	0.46	2.98	2.79	1.51	1.93

The same letters make it clear that there are no significant difference among treatments in the same column. Data are mean values of 10 replicates (10 trees).

Data in Figure 1 exhibited that the foliar application of potassium nitrate, kaolin and calcium nitrate remarkably increased the fruit number and fruit weight compared with the control during our study seasons. The highest increments in fruit weight were noticed by the spraying of potassium nitrate at 3 and 2% (165.67 and 125; 173.83 and 124.89 gm), kaolin at 6% (71.67 and 67.21 gm) and by calcium nitrate at 4 and 3% (80.34 and 54.34; 86.34 and 55.24 gm) in the first and second season, respectively, compared with the untreated trees. Moreover, the highest increments in fruit number were noticed by the spraying of potassium nitrate at 2 and 3%, kaolin at 6% and by calcium nitrate at 3 and 4% compared with control in both seasons. Fruit yield in kg per tree was enhanced by the application of potassium nitrate at 2 and 3% (11.59 and 18.44; 12.94 and 20.02 kg), by kaolin at 4 and 6% (6.7 and 9.44; 6.85 and 10.6 kg) and by calcium nitrate at 2 and 3% (7.07 and 11.42; 7.61 and 12.67 kg) over untreated trees in the two seasons, respectively. Regarding the fruit yield in ton per hectare, this was obviously enhanced by the spraying of potassium nitrate at 2 and 3% (7.19 and 11.43; 8.02 and 12.41), by kaolin at 4 and 6% (4.15 and 5.86; 4.25 and 6.57) and by calcium nitrate at 2 and 3% (4.38 and 7.08; 4.71 and 7.85) as compared to the control in the two seasons, respectively.

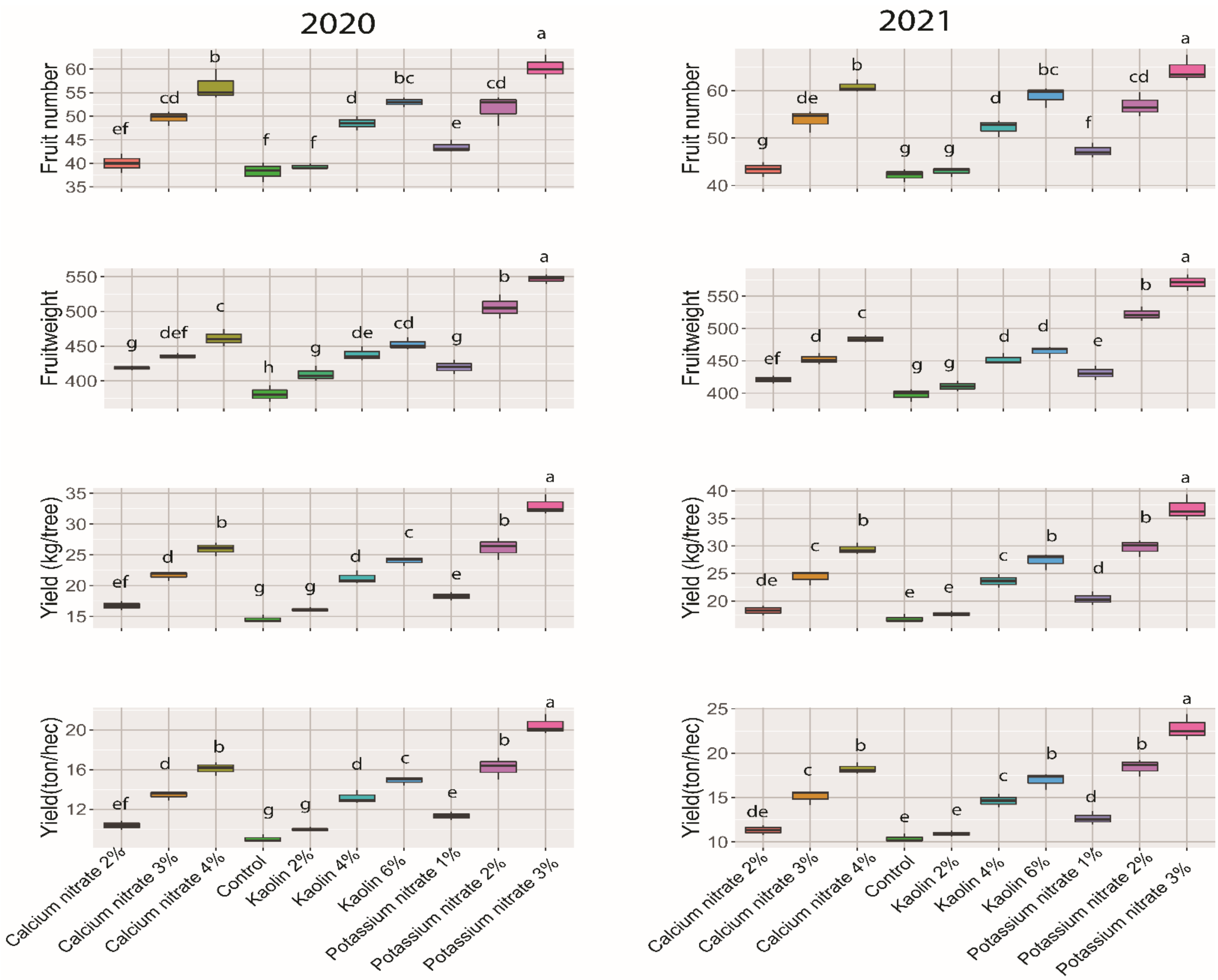

Figure 1. The of the foliar application of potassium nitrate, calcium nitrate and kaolin on the fruit number, fruit weight, fruit yield (kg/tree) and fruit yield (ton/hectare) of 'Wonderful' pomegranates during the 2020 and 2021 seasons. The same letters make it clear that there is no significant difference among treatments in the same column. Data are mean values of 10 replicates (10 trees).

3.2. Fruit Quality

Fruit volume, length and diameter were improved by the spraying of potassium nitrate, calcium nitrate, as well as by the foliar application of kaolin on pomegranate trees in comparison to the control (Table 4). Additionally, the highest increments in fruit volume were noticed by the spraying of potassium nitrate at 3 and 2% (150. 33 and 129.33; 150.33 and 177.67 cm^3), kaolin at 6 and 4% (62 and 46.66; 74.33 and 62.67 cm^3) and calcium nitrate at 4 and 3% (91.66 and 67.66; 93 and 59 cm^3) over untreated trees in the first and second seasons, respectively. Fruit length was obviously increased by the spraying of potassium nitrate at 3 and 2% (2.41 and 1.85; 2.52 and 2.33 cm), by kaolin at 6 and 4% (1.42 and 1.11; 2.04 and 1.59 cm) and by calcium nitrate at 4 and 3% (1.84 and 1.7; 1.84 and 1.52 cm) in comparison with the control in the first and second season, respectively. Regarding fruit diameter, this was increased by the foliar application of potassium nitrate at 3 and 2% (2.98 and 251; 247 and 2.25 cm), by kaolin at 6 and 4% (2.45 and 1.81; 1.57 and 1.36 cm) and by calcium nitrate at 4 and 3% (2.15 and 1.91; 1.94 and 122 cm) over untreated fruits in both the first and second season. Fruit firmness was improved markedly by the application of calcium nitrate at 3 and 4% and also by the application of kaolin at 6% in comparison with untreated trees in both seasons.

Table 4. The effect of the foliar application of potassium nitrate, calcium nitrate and kaolin on the fruit volume, length, diameter and fruit firmness of 'Wonderful' pomegranates during the 2020 and 2021 seasons.

Treatment		**Fruit Volume (cm^3)**		**Fruit Length (cm)**		**Fruit Diameter (cm)**		**Fruit Firmness (Ib/inch^2)**	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Control	**0**	407.67 f	414.00 g	7.69 f	7.67 f	7.6 f	8.41 d	20.00 e	21.00 f
Calcium nitrate	**2%**	445.00 de	443.67 ef	8.70 de	8.33 e	9.22 d	8.52 d	25.00 cd	27.00 d
	3%	475.33 c	473.00 d	9.39 bc	9.19 cd	9.51 cd	9.63 c	32.33 a	35.33 ab
	4%	499.33 b	507.00 c	9.53 ab	9.51 bcd	9.75 bc	10.35 ab	33.00 a	37.00 a
Kaolin	**2%**	426.00 ef	436.67 f	8.19 ef	8.85 de	8.25 e	9.44 c	24.33 cd	26.67 de
	4%	454.33 cd	476.67 d	8.80 cde	9.26 cd	9.41 cd	9.77 c	27.67 bc	32.00 c
	6%	469.67 c	488.33 d	9.11 bcd	9.71 abc	10.05 b	9.98 bc	31.00 ab	32.67 bc
Potassium nitrate	**1%**	442.67 de	455.67 e	8.72 de	8.91 de	9.39 cd	9.63 c	2267 de	23.67 ef
	2%	537.00 a	543.67 b	9.54 ab	10.00 ab	10.11 b	10.66 a	23.67 cde	24.33 de
	3%	558.00 a	591.67 a	10.10 a	10.19 a	10.58 a	10.88 a	24.00 cd	26.33 de
$LSD_{0.05}$		22.36	15.97	0.58	0.62	0.45	0.55	3.54	2.80

The same letters make it clear that there is no significant difference among treatments in the same column. Data are mean values of 10 replicates (10 trees).

The foliar application of potassium nitrate, calcium nitrate and kaolin dramatically ameliorated the grain weight, peel weight and fruit juice content with respective to the control (Table 5). Moreover, the highest grain weight resulted from the application of potassium nitrate at 2 and 3% (345 and 362 g) and (350 and 357 g) in the 2020–2021 seasons, respectively. Peel weight was increased greatly by the application of 3% potassium nitrate (184.33 and 214.31) in the 2020 and 2021 seasons. Fruit juice content was statistically increased by the spraying of potassium nitrate at 2 and 3%, kaolin at 4 and 6% and calcium nitrate at 4% compared with the untreated trees in during the 2020 and 2021 seasons.

Results in Table 6 exhibited that TSS content in pomegranate fruit was significantly increased as a result of spraying potassium nitrate at 2 and 3% (2.57 and 1.94; 2.2 and 2%) and by kaolin at 6% (1.8 and 1.33%) over untreated trees in both seasons, respectively. The total sugars fruit content was raised by the foliar application of potassium nitrate at 3 and 2% (3. 4 and 2.64; 3.1 and 2.22%) and by kaolin at 6% (2.26 and 1.97%) as opposed to the non-treated fruits in the two seasons. Reduced sugars percentages were increased by the spraying of potassium nitrate at 3 and 2% (1.8 and 1.68; 1.36 and 1.23%) and by kaolin at 6% (1.32 and 1.09%), and non-reduced sugars fruit content was enhanced by the spraying of potassium nitrate at 3 and 2% (1.6 and 0.95; 1.74 and 0.99%) and by kaolin at 6% (0.94 and 0.88%) over the control in the two seasons.

Table 5. The effect of the foliar application of potassium nitrate, calcium nitrate and kaolin on the grain weight, peel weight and fruit juice percentage of 'Wonderful' pomegranates during the 2020 and 2021 seasons.

Treatment		**Grain Weight (g)**		**Peel Weight (g)**		**Juice %**	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**
Control	0	245.33 f	253.67 f	136.00 cd	143.81 cd	64.07 d	71.45 c
Calcium nitrate	2%	273.67 d	264.67 e	145.00 bcd	156.27 bc	68.82 c	73.49 bc
	3%	292.67 c	301.67 c	143.00 bcd	151.05 c	71.65 bc	75.07 b
	4%	333.00 b	330.67 b	128.67 d	153.15 c	73.54 ab	76.42 ab
Kaolin	2%	259.33 e	279.67 d	150.33 bcd	131.09 d	68.53 c	73.95 bc
	4%	275.00 d	280.67 d	163.33 ab	171.45 b	73.14 ab	74.34 bc
	6%	295.00 c	305.67 c	158.00 bc	159.02 bc	73.47 ab	76.51 ab
Potassium nitrate	1%	293.67 c	301.67 c	126.33 d	129.59 d	72.34 bc	75.34 b
	2%	345.00 b	350.33 a	161.33 ab	172.03 b	73.83 ab	76.67 ab
	3%	362.67 a	357.00 a	184.33 a	214.31 a	76.68 a	78.68 a
$LSD_{0.05}$		13.16	9.86	22.39	15.51	3.69	2.86

The same letters make it clear that there are no significant differences among treatments in the same column. Data are mean values of 10 replicates (10 trees).

Table 6. The of the foliar application of potassium nitrate, calcium nitrate and kaolin on the fruit content from TSS %, and total reduced and non-reduced sugars of 'Wonderful' pomegranates during the 2020 and 2021 seasons.

Treatment		**TSS %**		**Total Sugars %**		**Reduced Sugars %**		**Non-Reduced Sugars %**	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Control	0	14.93 e	16.3 d	10.08 h	10.75 g	5.99 f	6.50 e	4.09 b	4.25 c
Calcium nitrate	2%	15.8 d	17.17 c	11.08 fg	11.45 ef	6.35 ef	6.54 e	4.73 b	4.91 bc
	3%	15.93 d	17.30 bc	11.26 efg	11.97 de	6.39 e	7.10 cd	4.87 ab	4.87 bc
	4%	15.98 cd	17.50 bc	11.80 cde	12.5 bcd	6.83 d	7.17 c	4.96 ab	5.33 ab
Kaolin	2%	15.62 de	17.13 c	10.73 g	10.98 fg	6.39 e	6.82 de	4.34 b	4.16 c
	4%	15.82 d	17.27 bc	11.56 def	11.49 ef	6.95 cd	6.53 e	4.61 b	4.96 bc
	6%	16.73 bc	17.63 b	12.34 bc	12.72 bc	7.31 bc	7.59 ab	5.03 ab	5.13 b
Potassium nitrate	1%	16.31 bcd	17.50 bc	12.06 bcd	12.04 cde	7.13 cd	7.49 b	4.93 ab	4.55 bc
	2%	16.87 ab	18.30 a	12.72 b	12.97 b	7.67 ab	7.73 ab	5.04 ab	5.24 ab
	3%	17.50 a	18.50 a	13.48 a	13.85 a	7.79 a	7.86 a	5.69 a	5.99 a
$LSD_{0.05}$		0.72	0.34	0.63	0.65	0.37	0.31	0.84	0.75

The same letters make it clear that there is no significant difference among treatments in the same column. Data are mean values of 10 replicates (10 trees).

Spraying potassium nitrate at 3 and 2% on pomegranate trees increased the fruit anthocyanin content by 0.37 and 0.31; 0.38 and 0.33%, VC% by (8.71 and 6.98; 8.91 and 7.3%) and TSS-Acid ratio by (9.92 and 7.57; 10.31 and 9.07) as opposed to the other applied treatments during the 2020 and 2021 seasons (Table 7). Moreover, application of kaolin at 6% also raised the fruit content from VC by 6.84 and 7.17% and TSS-Acid ratio by 6.28 and 6.56% as compared to the untreated trees in both seasons. On the other hand, fruit acidity was obviously lowered by the spraying of potassium nitrate at 2 and 3% (0.35 and 0.3; 0.37 and 0.34%), which gave the most positive influence as compared t the other treatments in both seasons.

Table 7. The effect of the foliar application of potassium nitrate, calcium nitrate and kaolin on the fruit content from anthocyanin, acidity, TSS-Acid ratio and vitamin **C** of 'Wonderful' pomegranates during the 2020 and 2021 seasons.

Treatment		**Anthocyanin (mg/100 mg)**		**Acidity %**		**TSS-Acid Ratio**		**VC (mg/100 mL)**	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Control	0	0.50 f	0.50 h	1.10 a	1.11 a	13.53 g	14.70 g	10.87 f	11.16 e
Calcium nitrate	2%	0.56 e	0.61 g	1.06 a	1.06 b	14.93 f	16.15 f	13.83 e	14.96 d
	3%	0.59 de	0.65 efg	0.95 b	0.89 cd	16.84 e	19.46 e	15.43 d	16.34 c
	4%	0.62 cd	0.67 def	0.85 cd	0.85 de	18.81 cd	20.61 cd	15.86 cd	16.78 c
Kaolin	2%	0.63 cd	0.63 fg	0.87 c	0.90 c	18.03 de	18.97 e	14.03 e	14.25 d
	4%	0.64 cd	0.69 de	0.85 cd	0.87 cde	18.61 cd	19.92 de	16.6 c	16.97 c
	6%	0.67 c	0.70 d	0.85 cd	0.83 e	19.81 bc	21.26 c	17.71 b	18.33 b
Potassium nitrate	1%	0.77 b	0.76 c	0.84 cd	0.85 de	19.50 c	20.68 cd	15.08 d	16.06 c
	2%	0.81 b	0.83 b	0.80 d	0.77 f	21.10 b	23.77 b	17.85 b	18.46 b
	3%	0.87 a	0.88 a	0.75 e	0.74 f	23.45 a	25.01 a	19.58 a	20.07 a
$LSD_{0.05}$		0.05	0.04	0.05	0.04	1.32	1.00	0.87	0.85

The same letters make it clear that there are no significant differences among treatments in the same column. Data are mean values of 10 replicates (10 trees).

Spraying pomegranate trees with potassium nitrate, calcium nitrate and kaolin greatly increased the leaf and fruit content from nutrients (Figure 2). Spraying pomegranate trees with 2 and 3% potassium nitrate increased the leaf content from nitrogen, phosphorous and potassium and boron in comparison to the rest of the treatments in the two seasons. Moreover, the application of kaolin at 4 and 6% also gave increments in the leaf mineral content from nitrogen, phosphorous, and potassium during the seasons of our experiment. The calcium content was significantly enhanced by the application of calcium nitrate, whereby it gave the highest values (1.07 and 1.23; 1.13 and 1.31) in in the 2020 and 2021 seasons.

3.3. Principal Component Analysis

Principal component analysis (PCA) was conducted to delineate the concentration-dependent effects of potassium, calcium and kaolin on the yield and fruit quality variables of pomegranates (Figure 3). Based on the highest squared cosine values corresponding to factors F1 or F2, measured attributes were clustered around potassium, calcium and kaolin treatments. Factor F1, covering 78.52% variability in the data (eigenvalue 21.986), showed clustering of fruit set, number of fruits, fruit weight, fruit yield, fruit length, fruit diameter, fruit volume, grain weight, peel weight, TSS, TTA, TSS-TTA ratio, vitamin C, total sugar, reducing sugar, non-reducing sugar, anthocyanin, juice percentage, leaf N, P and B with 2–3% potassium nitrate, 2% calcium nitrate, and 4–6% kaolin, suggesting its positive influence on these parameters. While another cluster in opposite quadrant showed the association of fruit drop, fruit crack, and sunburn with the control. A second factor, covering 11.95% variability in the data (eigenvalue 3.345), showed clustering of leaf calcium, and fruit firmness with 3–4% calcium nitrate. Thus, principal component analysis helped to delineate the individual roles of potassium, calcium and kaolin concentrations in regulating the yield and fruit quality of pomegranates (Figure 3).

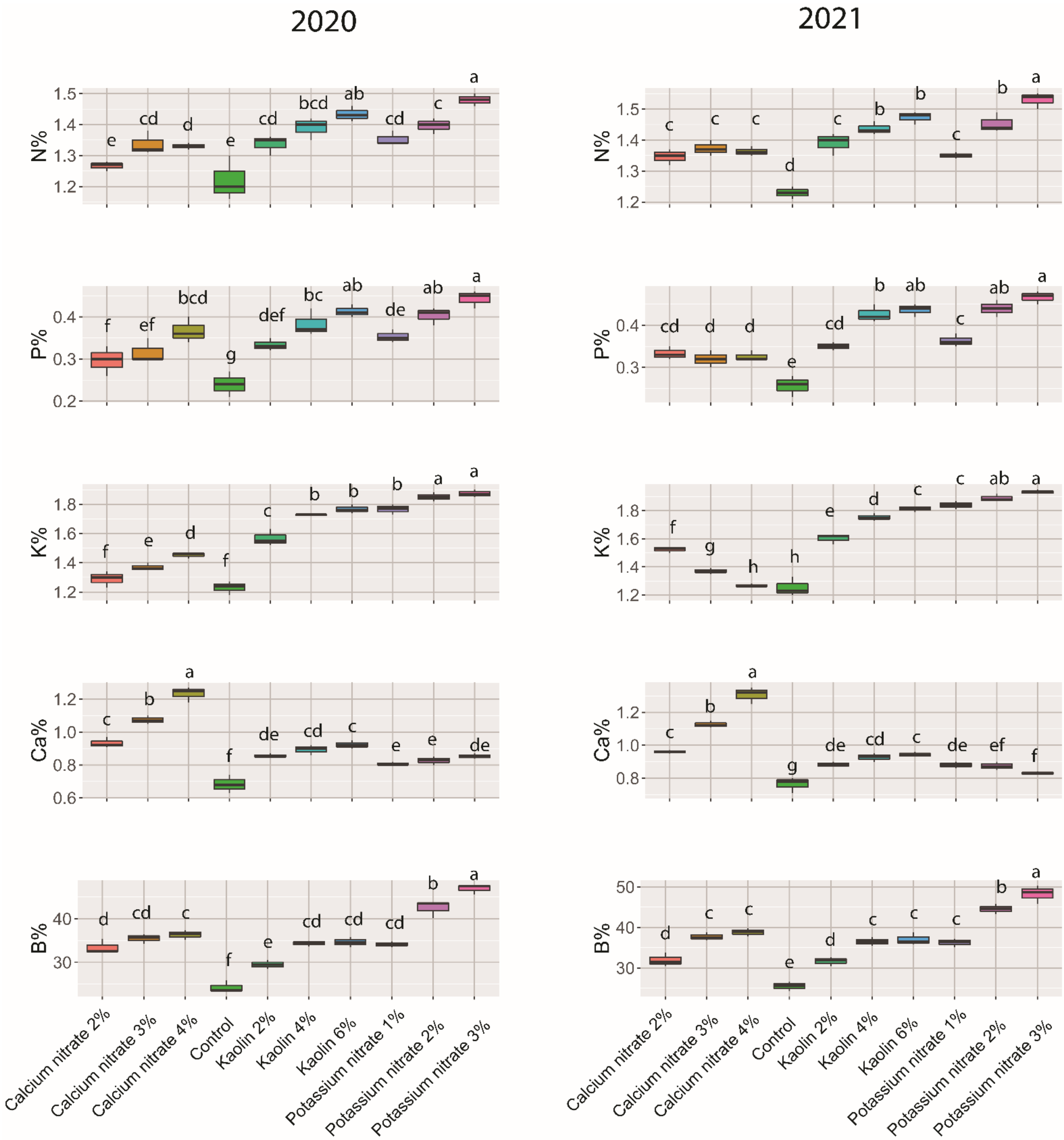

Figure 2. The effect of the foliar application of potassium nitrate, calcium nitrate and kaolin on the fruit content from nitrogen, phosphorous, potassium, calcium and boron of 'Wonderful' pomegranates during the 2020 and 2021 seasons. The same letters make clear that there is no significant difference among treatments in the same column. Data are mean values of 10 replicates (10 trees).

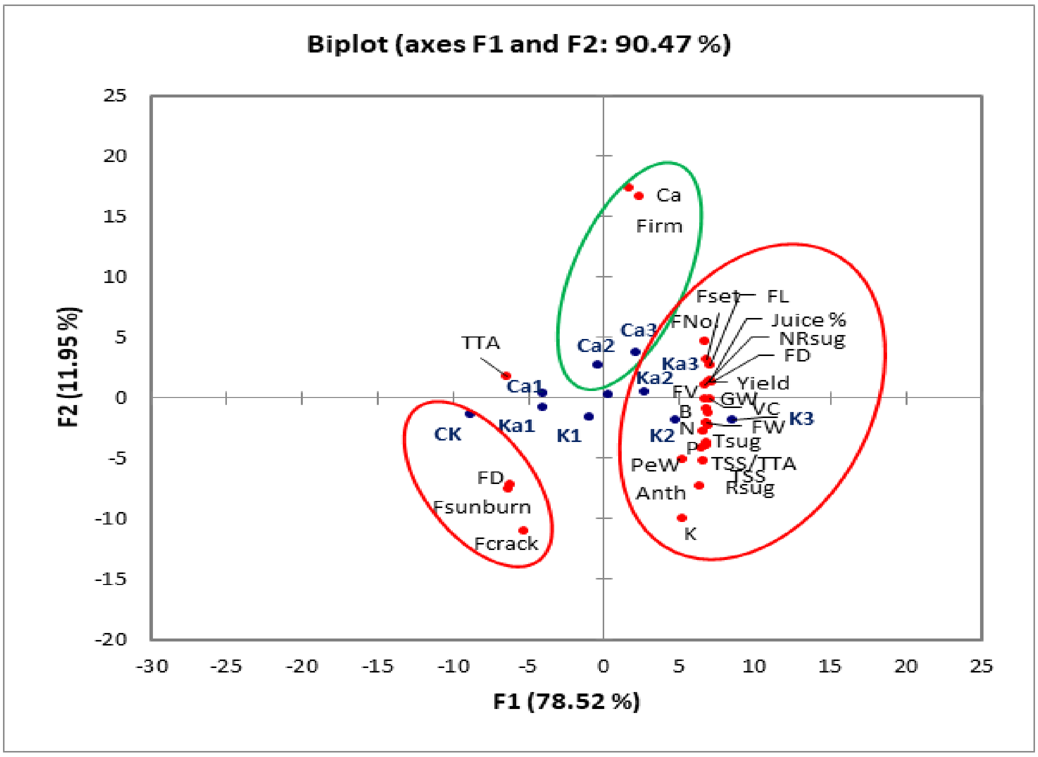

Figure 3. Principal component analysis "PCA" among potassium, calcium and kaolin treatments and fruit quality attributes of pomegranate. Clustering of treatments and measured attributes into groups "colored circles" is based on their highest squared cosine values corresponding to the factors F1 (red) or F2 "green". Abbreviations: CK control K1 "1%" potassium nitrate; K2 "2%" potassium nitrate; K3—3% potassium nitrate; Ca1—2% calcium nitrate; Ca2 "3%" calcium nitrate; Ca3 "4%" calcium nitrate; Ka1 "2%" kaolin; Ka2 "−4%" kaolin; Ka3 "6%" kaolin; FW "fruit weight"; FL—fruit length; FD—fruit diameter; TSS—soluble solid contents; TTA "total titratable acidity"; TSS-TTA—sugar-acid ratio; Fset—fruit set %; Fdrop—fruit drop %; Fcrack "fruit crack %"; Fsunburn"fruit sunburn (%)"; Firm "fruit firmness"; FNo. "number of fruits"; Yield "fruit yield"; FV "fruit volume"; GW—grain weight; PeW—peel weight; VC—vitamin C; Tsug "total sugars"; Rsug "reducing sugars"; NRsug "non-reducing sugars"; Anth "anthocyanin"; N "leaf nitrogen"; P "leaf phosphorus"; K "leaf potassium"; Ca "leaf calcium"; B "leaf boron".

4. Discussion

The results demonstrated the effect of spraying calcium nitrate on the productivity and quality of pomegranates. These results were previously explained by White and Broadley, [41], who reported that calcium is a very important element for the structure of the cell wall and cell membranes, it is an adverse cation for inorganic and organic anions in the vacuole, and it is an obligate intracellular messenger coordinating responses to numerous developmental cues and environmental challenges. Moreover, Elmer et al. [42] reported that calcium has an essential role in cell structure stability and mechanical strength. Moreover, the application of calcium to fruit provides protection against physiological deterioration and retardation of maturity and improves fruit quality [13,43]. Moreover, the results are in parallel with the previous findings by Sharma and Belsare [14], who found that calcium may organize the absorption of water and reduce cracking in pomegranate. In addition, calcium may minimize fruit cracking in pomegranate by cohesion of cell walls and reacting with pectic acid [18]. Calcium regulates water intake by plant roots and assists in linking the tissues, especially in the middle lamella and reduces fruit cracking [44,45]. Treating 'Wonderful' pomegranates with calcium chloride at 0.5% significantly improved the growth of shoots, fruit length, weight and aril weight, whereas it reduced fruit splitting, fruit sunburn, peel anthocyanin compared with the untreated trees [46]. Calcium is involved in various plant physiological processes; plant growth and development, cell division, cytoplasmic streaming and photosynthesis [47]. Spraying calcium chloride at 1 and 2% on 'Ardestani' pomegranate cultivar increased fruit length, TSS%, whereas it decreased in total phenols [48]. Calcium is an essential element, which is required for the development of plants under both non-stressed and stress conditions. It is an important factor for cell wall and membrane stability, serving as a second messenger in many developmental and physiological processes [49]. Treating 'Bhagwa' pomegranate cultivar with 3 and 5% calcium remarkably enhanced the fruit volume, specific gravity, TSS, total sugars and reducing sugar [50].

The results of the current study showed that kaolin improved the fruit set, yield and fruit quality of pomegranates. These results were previously explained by Jifon, and Syvertsen [51], they reported that kaolin had an effective influence on improving the water-use efficiency in grapefruit. Moreover, the application of kaolin greatly improved fruit soluble solids because of its reflective effect, which lessened the temperature of the leaf surface, respiration rate leading to increasing the accumulation of sugars and the anthocyanin dye [52]. Kaolin can reduce the temperature stress and solar injury effect to the entire tree canopy, leaf, and fruit [53,54]. Therefore, it could minimize the sun damage in pomegranates and in apples [55–57] and enhance the leaf water potential [58]. Moreover, the kaolin impact on fruit color might be great because of its influence on reducing the fruit temperature [59]. Ergun [60] documented that kaolin can minimize the fruit damage caused by sunburn because of its reflective influence to UV. Moreover, it minimized the leaf and fruit surface temperatures by reflecting ultraviolet and infrared light without affecting the stomatal or photosynthetic conductance [61,62]. Under water shortage, it was noticed that the utilization of kaolin could improve the photosynthetic rate in olive plants [63]. Kaolin spraying increased fruit weight and yield in 'Wonderful' pomegranates [12]. Spraying Manfaloty and Wonderful pomegranate trees with kaolin at 2.5 or 5% increased fruit weight, fruit number and yield, marketable fruits, fruit length and diameter, soluble solids, total acidity and soluble solids–acidity ratio, and anthocyanin content in juice and peel, whereas they decreased the fruit cracking and sunburn [64]. Spraying apples with kaolin at 2, 4, and 6% increased photosynthesis processes, whereas it lessened the leaf temperature and transpiration rate [65]. Treating kaolin played an important role in improving the plant height, plant dry weight, water-use efficacy, and increased stomatal conductance in water-stressed plants, whereas it can decrease the transpiration rates, leaf temperature, and leaf thickness [66].

Spraying potassium increased the synthesis of anthocyanin by raising the transporting of sugars inside the fruits [67]. The application of potassium increased the water absorption and plant dry mater and leaf area [68], and is required for enzyme activation, photosynthesis processes, osmotic pressure organizing, stomata movement, protein synthesis, phloem transport, energy transporting, and cation-anion balance in soil [69]. Spraying K_2 SO_4 and KNO_3 on olive and date palms increased the level of N, P, K and Fe [70], whereas treating olives, mangos and oranges with KH_2 PO_4 improved the leaf mineral composition of nitrogen, phosphorous and potassium [71]. The foliar application of potassium on pomegranates and oranges improved their fruit volume [23] and both quantitative and qualitative characteristics of 'Sultana' grapevines [72]. Potassium could be involved in the transportation and accumulation of sugars in fruit [73], and it is important in the regulation the osmotic pressure, preserving the cell membrane's turgidity and its potential protein synthesis [74]. Potassium is one of the vital elements because it is a constituent of the plant structure and has regulatory functions: protein synthesis, carbohydrate metabolism, enzyme activation, stomatal regulation, photosynthesis, increases in abiotic stress tolerance, membrane potential regulation, transport of sugars, stress acclimatization and plant growth [75–77]. Under salinity conditions, K^+ sustains ion homeostasis and controls the osmotic balance [78,79] and manages the stomatal opening under drought conditions and assists plants to acclimate under water stress [80]. The role of the element potassium is essential in increasing the fruit size because it preserves cell water contents and it is considered as a co-factor in chlorophyll production, photosynthesis processes and improving the peel color of fruits. $K_2 SO_4$ application on pistachios at 1 and 2% improved the fruit yield, fruit quality and leaf mineral content from P, K, Mg, Zn, Mn and Fe [81]. It was noticed that potassium has an effective role in plants such as inducing flower formation, and initiation, fruit set, carbohydrates and phytohormones [82]. Treating 'Royal' apricot cultivar with potassium increased the shoot length, as well as surface area and total chlorophyll content of leaves [83]. Spraying potassium nitrate 1% or 2% on apricot cv. Shahroudi significantly increased the length, width, and weight of apricot fruit and maintained total phenol content, vitamin C, and titratable acidity, fruit width, fruit length, and fresh fruit weight, fruit firmness, and fruit yield [84].

5. Conclusions

From the results of the current study, it could be concluded that using potassium nitrate, calcium nitrate and kaolin is considered as an effective way to reduce fruit cracking and fruit sunburn percentages and thus improve the fruit quality, fruit yield and consequently the income of the farmers. In both study seasons, the application of 2 and 3% potassium nitrate, 4% calcium nitrate and 4 and 6% kaolin were the best treatments, whereby they gave the highest increments in fruit set percentages, fruit yield, fruit chemical and physical quality attributes as compared to the other applied treatments. Moreover, they also decreased the percentages of fruit cracking and fruit sunburn.

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