Erwerbs-Obstbau
https://doi.org/10.1007/s10341-018-0386-6

ORIGINAL ARTICLE

Reduction of Cracking in Pomegranate Fruit After Foliar Application of Humic Acid, Calcium-boron and Kaolin During Water Stress

Elmira Ghanbarpour[1] · **Mehdi Rezaei**[1] · **Shaneka Lawson**[2]

Received: 14 April 2017 / Accepted: 16 March 2018

Abstract

One of the primary physiological issues with cultivation of pomegranate (*Punica granatum* L. cv Post Sefid Darjazin) is excessive fruit cracking. Foliar applications of chemical and organic mixtures to limit or prevent pomegranate cracking were evaluated in this work. This 2 year study (2014–2015) was conducted in Darjazin, Iran and designed to evaluate the impacts of foliar application of 2 and 5 ml l^{-1} humic acid, 6% kaolin, and 3% Calcium-1% Boron (CB) separately or in combination. Pomegranate fruits were examined under two irrigation regimes at three time periods during the growing season. It was found that 14 day irrigation periods resulted in significantly more cracking in pomegranate than standard irrigation. Increased temperatures in 2015 contributed to higher percentages of fruit cracking as well. Foliar application of 6% kaolin significantly decreased cracking in 7 day irrigation studies while 2 ml l^{-1} humic acid, 6% kaolin, CB, and the combination of 6% kaolin/CB and 6% kaolin/2 ml l^{-1} humic acid reduced cracking under 14 day irrigation. Fruit weights significantly increased with 6% kaolin application and 7 d irrigation while 5 ml l^{-1} humic acid both increased pomegranate acidity and decreased the flavor index. Therefore, foliar application of kaolin and humic acid can reduce cracking in pomegranate fruit.

Keywords Calcium · Cracking · Humic acid · Irrigation · Kaolin · Pomegranate · *Punica granatum*

Reduzierung des Platzens von Granatapfelfrüchten nach Blattapplikation von Huminsäure, Calcium-Bor und Kaolin bei Wasserstress

Schlüsselwörter Calcium · Platzen · Huminsäure · Bewässerung · Kaolin · Granatapfel · Punica granatum

Introduction

Pomegranate, *Punica granatum* L., is classified in the family Punicaceae. Pomegranate shrubs have bushy irregular branches, malleable thorns, a short trunk, and a strong tendency to have suckers on the base (Holland et al. 2009; Stover and Mercure 2007). The Iranian plateau is known as the origin of pomegranate (Stover and Mercure 2007) although the fruit is cultivated extensively in many other Mediterranean countries. Regions where the bulk of pomegranate cultivation occurs, such as Iran, are arid/semiarid areas constantly facing water use restrictions. Pomegranate trees are moderately drought tolerant (Holland et al. 2009) however, under semiarid conditions the prevalence of fruit cracking is elevated with between 10–35% of fruits showing signs of cracking (Hiwale 2009; Khattab et al. 2012). These imperfect individuals are unsuitable for market and become sources of crop contamination as a variety of fungi immediately attack the cracked fruit. Fruit cracking rates can also be influenced by elements such as the environment, inherent morphology and physiology, and genetic factors (Galindo et al. 2014; Gharesheikhbayat 2006; Khadivi-Khub 2014).

The growth curve of pomegranate fruits is a single sigmoid pattern and about half of the fruit weight is seeds. The

✉ Mehdi Rezaei
mhrezaei@shahroodut.ac.ir

[1] Horticulture Department, Agriculture Faculty, Shahrood University of Technology, Shahrood, Iran

[2] USDA Forest Service, Northern Research Station, Hardwood Tree Improvement and Regeneration Center (HTIRC), FORS309, Department of Forestry and Natural Resources, Purdue University, 715 West State Street, West Lafayette, IN 47907, USA

Published online: 07 May 2018

edible juicy tissue of the seeds grow continuously from June to October whereas the internal stone tissue stop growing and hardened by the end of June (Shulman et al. 1984). Most known pomegranate cultivars will eventually split when they overripen however most Iranian pomegranate cultivars tend to split in much earlier stages of fruit development (Tabatabaei and Sarkhosh 2006). Deficiencies in nutrients such as calcium and boron in young fruit, drastic undulations in day and night temperatures, irregular watering regimes during fruit ripening, and long dry periods followed by heavy rains or irrigation are the primary contributors to cracking in pomegranate fruit (Galindo et al. 2014; Gharesheikhbayat 2006; Khalil and Aly 2013). There exists some research data that indicated spraying with gibberellic acid (GA3) or benzyl adenine (BA) could significantly reduce fruit cracking (Mohamed 2004; Yılmaz and Özgüven 2006). Other studies showed that application of boron and calcium chloride reduced fruit cracking (Khalil and Aly 2013; Sheikh and Manjula 2006; Singh et al. 2003). Calcium is an essential element for proper plant growth and development as it has metabolic functions in nutrient uptake and is involved in abiotic and biotic stress resistance. It was recently reported that deficiencies in calcium and boron caused cracking in apple, cherry, plum, and tomato (Khadivi-Khub 2014).

In recent years, different substances such as kaolin and humic acid have been used as foliar applicants to prevent injury to crops during abiotic and biotic stress conditions. Kaolin is a white, soft powder consisting principally of the mineral kaolinite. This powder reduces the surface temperature of leaves and fruits by reflecting ultraviolet and infrared light without interfering with stomatal functioning or photosynthetic properties (Colavita et al. 2010; Glenn and Puterka 2005). Treatment with kaolin can significantly reduce sun damage in pomegranate (Weerakkody et al. 2010) and has been shown to perform similarly in apple (Gindaba and Wand 2005; Wand et al. 2006). A previous study also noted that addition of kaolin decreased pomegranate fruit cracking (El-Rhman 2010).

Humic acids have recently been shown to improve soil fertility and increase plant growth and yield (Canellas et al. 2015). Humic acid is a complex organic material derived from the decomposition of plant matter that exists as a mixture of soluble substances. These organic supplements can be used to regulate hormone levels, improve nutritional uptake, and enhance stress tolerance (Khattab et al. 2012; Lotfi et al. 2015; Moghadam 2015). To our knowledge, this study is the first to examine the effects of humic acid on pomegranate fruit cracking.

Thus, the aim of this work was to gain insight on the effect of aqueous extracts of humic acid, 6% kaolin, 3% Calcium-1% Boron (CB) and various combinations of these on pomegranate fruit cracking under both standard irrigation (7 d) and water deficient conditions (14 d). The relationship between treatment and fruit sizes at eventual harvest was also addressed at the conclusion of the study.

Materials and Methods

Plant Materials

Twenty year old pomegranate (*Punica granatum* L. cv Post Sefid Darjazin) trees in a commercial orchard located in Darjazin, Semnan province, Iran were used for this study. The trees had been planted at 4 m × 2.5 m spacing and trained with three trunks. Field data were collected during the 2014 and 2015 growing seasons (February–September). Trees were maintained under the supervision of local management specialists.

Design and Treatments

A combined split-plot experiment was conducted based on a complete randomized block design with two trees in each plot. There were two irrigation treatments used in this study; a 7 day interval (standard irrigation) and a 14 day irrigation interval. The irrigation period was the primary factor for they study. The secondary factor was a combination of 12 foliar application treatments. Twelve treatments including 2 and 5 $ml\,l^{-1}$ of humic acid (Bio Green, Greensboro, GA, USA), 6% kaolin (Kaolin Khorasan Co. Mashad, Iran), and 3% Calcium-1% Boron (CB; Nambar Company, Mashad, Iran) separately or in combination were sprayed uniformly on the study trees. The controls were trees within the plots without any foliar application. Each experiment was repeated in triplicate.

Treatment Performance

Irrigation treatment started 2 week before first foliar application. Initial sprays were done 30 day after full bloom (mid-June) and these treatments were repeated twice more during the growing season at 30 day increments. Due to high volume of work, humic acid treatments were done in week 1, CB in week 2, and 6% kaolin in week 3. No treatments were applied in week 4. This treatment plan was repeated twice more in the growing season. The same schedule was followed each of the two growing seasons in the study and at end of each spraying plan, week 4, fruit cracking percent was measured. Foliar applications were applied during early morning or late evening to prevent exposure to high midday temperatures.

Table 1 Meteorological statistics for the 2014 and 2015 growing season

Growing Season	Month	Temperature (°C)	Relative Humidity (%)	Evaporation (mm)	Wind Speed (m/s)
2014	July	31.8	27	450.3	11
	August	31.9	27	424.4	10
	September	29.6	26	316.5	9
2015	July	33.2	21	501.7	10
	August	33	20	482.7	12
	September	29.5	21	346.6	9

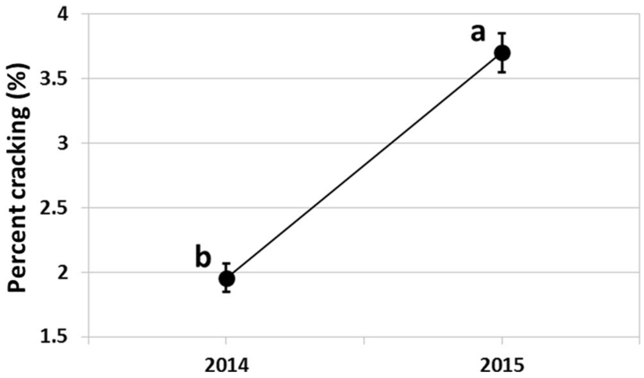

Fig. 1 Total yearly cracking. Percent pomegranate fruit cracked in 2014 and 2015. $p < 0.05$

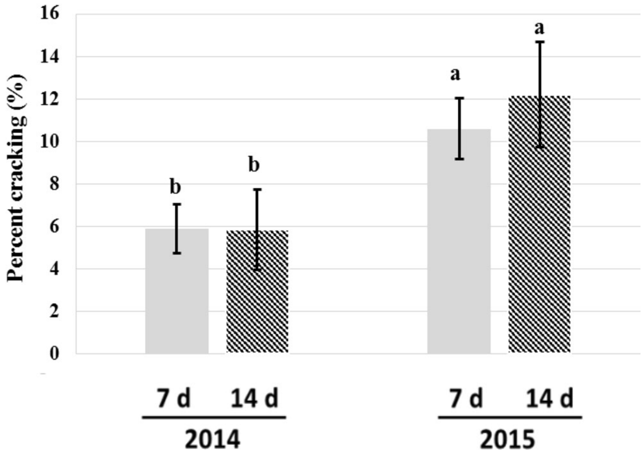

Fig. 2 Percent of treated pomegranate fruit cracked during 2014 and 2015 according to different irrigation regimes. $p < 0.05$

Cracking Assay

Cracking percentages for each tree were measured as the number of split fruit compared to total fruit on the tree. These data were collected in July, August, and September. Total cracking percentages were calculated from the combination of all three growing season measurements.

Fruit Quality and Quantity Assay

Fruit quality and quantity measurements were derived from a random selection of 15 commercially mature, market ready fruit randomly selected and harvested from each tree and harvested in late September. Average diameter (cm), length (cm), juice volume (%), and fruit weight (g) measurements were collected for each fruit. Total juice extracted and percent total soluble solids (TSS) were measured by a hand refractometer (ATAGO®, Minato-ku, Tokyo, Japan). Total acidity (TA) was determined by titration of 20 ml fruit juice with 0.2 *N* sodium hydroxide (NaOH) solution and expressed as percent citric acid (AOAC 2000). Fruit flavor index was described as TSS/TA.

Data Analysis and Sources

Statistical Analysis Software (SAS 9.1) was used for all statistical analyses. The presented results in figure are expressed as mean ± standard deviation. For all the parameters measured, an analysis of variance (ANOVA) was performed for foliar application treatments and least significant differences calculated using the general analysis of variance. All meteorological data was collected from the annual statistics reports from the Meteorological Office in Semnan, Iran (Table 1).

Results and Discussion

Fruit Cracking

Significantly more cracking was seen during the 14 day irrigation period (3.6%) compared to the 7 day treatment (2.15%) (Fig. 1). Percent cracking was significantly higher in 2015 than 2014 for both irrigation periods combined (Fig. 2). The percentage of cracked fruit increased as the growing season ended (Fig. 3).

Application of 6% kaolin and 5 ml l^{-1} of humic acid in July significantly reduced pomegranate fruit cracking under 7 day irrigation during both growing seasons. Foliar spraying of 6% kaolin in August was the most successful treatment although the other treatments such as CB, 2 or 5 ml l^{-1} humic acid, or combinations of these with kaolin added were not significantly different under a 7 day irrigation regime during either year (Table 2). The lowest percentages of fruit cracking were seen in September with the

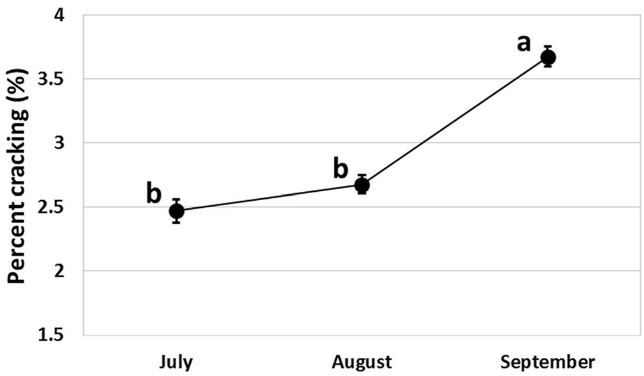

Fig. 3 Developmental times. Percent pomegranate fruit cracked during July, August and September. $p < 0.01$

application of 6% kaolin and 5 ml l^{-1} humic acid although cracking was also reduced with the applications of 2 ml l^{-1} of humic acid with CB and 6% kaolin in 2015. Foliar application of 6% kaolin or 5 ml l^{-1} of humic acid resulted in the least cracking at the close of the 7 day irrigation study (Table 2).

All foliar treatments caused a significant decrease in pomegranate fruit cracking during July and August under 14 day irrigation although the reduction rates varied. Foliar applications of 6% kaolin with 5 ml l^{-1} of humic acid and CB were least effective (Table 2). The lowest percentages of fruit cracking were recorded in September for the 14 day irrigation study. Treatment with 6% kaolin each year and with 2 ml l^{-1} of humic acid in 2015 were most effectual however, application of CB alone or CB with 2 ml l^{-1} of humic acid and 6% kaolin was also successful and displayed no significant difference. Foliar application of each treatment served to reduce cracking in pomegranate however some had better results than others (Table 2).

Cracking began during the early stages of fruit development in July and increased throughout the growing season. The least amount of cracking, 0.75%, was observed in 2014 during the 7 day irrigation period with the application of 6% kaolin. The greatest percentage of cracking was seen in 2015 during the 14 day irrigation period. Nearly 33% of the fruit were cracked in the control trees during the 14 day study (Table 2). The majority of cultivars are prone to cracking if overdeveloped and others split with greater frequency earlier in development (Holland et al. 2009).

Environmental conditions especially temperature and humidity have been shown to influence fruit cracking (Khadivi-Khub 2014). Abiotic stresses such as higher temperature, increased wind speed, and low humidity likely impacted fruit growth and development in 2015 (Table 1). There were greater percentages of cracked fruit during 2015 than throughout the entire 2014 growing season. Pomegranate trees under water stress (14 day irrigation) were more cracked than those on the standard schedule. Research has shown that regular irrigation, drip irrigation in particular, relieves water stress and reduces cracking (Prasad et al. 2003).

The rapid absorption of water when irrigation is resumed to severely stressed fruit leads to cracking of the skin as water is diverted to the aril and greater stress is placed on the water-deficient skin (Galindo et al. 2014; Lichter et al. 2002). It has also been suggested that asymmetrical stretching of the skin occurs as the aril fills with water. This leads to cracking on the same side of the swelling aril (Galindo et al. 2014).

Our data indicated that application of CB significantly reduced cracking at all time points with the exception of July (2014 and 2015) under standard irrigation (Table 2). Other studies have reported use of CB to reduce fruit cracking (Khalil and Aly 2013). Treatment with calcium likely contributes to the greater elasticity, strength, and thickness of epidermal cell walls. Calcium also assists with the deposition of pectin so that fruit are better able to resist cracking under the higher rates of turgor pressure exhibited during water stress (Choi et al. 2010).

When CB was combined with 6% kaolin under standard irrigation cracking was reduced however, cracking was increased with this same combination under 14 day irrigation (Table 2). We were unable to find accounts in the literature of other treatments where fruit cracking was increased however we believe that this is a prospective response to increased osmotic potential in the outer skin but this suggestion has not been corroborated. Kaolin application helped reduce pomegranate surface temperatures and fruit cracking by reflecting light away from the fruit thereby preventing sun-scorching of the pomegranate skin (Gindaba and Wand 2005; Yazici and Kaynak 2006). Undulations in fruit surface temperatures combined with increased water evaporation from the surface are known factors that induce pomegranate fruit cracking (Galindo et al. 2014). The presence of 6% kaolin significantly decreased cracking under standard irrigation 6.4% in 2014 and 7.1% in 2015. Reductions of 18 and 27% were recorded after 6% kaolin application during the 14 day irrigation schedule when compared to controls. In 2010, El-Rhman (2010) reported a 9% reduction in pomegranate fruit cracking after kaolin application during water stress and a 20% decrease under standard irrigation when compared to controls.

Humic acid, a byproduct of plant decomposition, has numerous bio-stimulatory properties that work to alleviate damage from abiotic stress (Canellas et al. 2015; Moghadam 2015). Humic acid is also able mediate shifts in primary and secondary metabolism processes to modulate growth and increase water-use efficiency (Canellas et al. 2015). Application of either 2 or 5 ml l^{-1} humic acid reduced fruit cracking. No other studies have been conducted

Table 2 Effect of foliar application treatments on pomegranate fruit cracking during July, August, and September for both 7 and 14 d irrigation periods in 2014 and 2015. Means with same letter in each column were not significantly different at the $p < 0.05$ level of probability

			July				August				September				Total fruit cracking (%)			
			2014		2015		2014		2015		2014		2015		2014		2015	
Irrigation period (day)			7	14	7	14	7	14	7	14	7	14	7	14	7	14	7	14
Foliar application																		
Hu (ml l^{-1})	CB (Ca + B%)	Ka (%)																
0	0	0	1.52 bc	2.06 b	2.73 bc	10.84 d	1.54 bc	3.66 bc	2.81 ab	8.72 c	4.08 ef	14.20 d	5.46 de	13.23 d	7.14 b	19.92 c	11.00 cd	32.79 e
		6	0.20 a	0.00 a	1.05 a	1.15 a	0.00 a	1.52 ab	0.85 a	3.08 ab	0.55 ab	0.50 a	1.72 a	1.51 a	0.75 a	2.02 a	3.83 a	5.74 ab
	3 + 1	0	3.18 cde	0.00 a	4.34 cde	1.41 a	0.30 ab	1.06 a	1.52 ab	2.51 ab	2.40 cde	1.43 ab	3.68 bc	2.96 ab	5.87 b	2.50 a	9.54 bcd	6.89 ab
		6	4.30 e	0.24 a	6.65 e	1.22 a	6.19 d	0.74 a	8.57 c	1.73 a	5.38 f	0.77 ab	8.18 f	2.37 ab	15.87 c	1.75 a	23.19 e	5.32 ab
2	0	0	2.38 bcd	0.70 a	4.33 cde	1.40 a	0.48 ab	1.24 a	2.53 ab	1.97 ab	2.94 def	0.72 ab	5.15 cde	1.45 a	5.81 b	2.66 a	12.01 d	4.83 a
		6	3.20 cde	0.92 ab	4.37 cde	2.15 a	1.50 bc	0.93 a	2.75 ab	2.21 ab	2.14 bcde	0.94 ab	3.45 b	2.24 ab	6.86 b	2.79 a	10.57 cd	6.61 ab
	3 + 1	0	3.69 de	1.04 ab	4.74 cde	3.12 ab	1.91 c	0.53 a	3.05 b	2.66 ab	1.05 abcd	2.65 abc	1.93 a	4.96 bc	6.65 b	4.23 a	9.51 bcd	10.74 c
		6	2.82 cde	0.65 a	3.84 cde	3.25 abc	1.52 bc	0.64 a	3.13 b	3.38 ab	0.8 abc	2.63 abc	1.91 a	5.45 bc	4.68 b	3.92 a	7.89 bc	12.08 c
5	0	0	0.00 a	0.00 a	1.62 ab	2.50 ab	1.22 abc	0.62 a	2.80 ab	3.23 ab	0.41 a	1.89 ab	1.70 a	4.56 bc	1.63 a	2.50 a	6.22 ab	10.29 bc
		6	0.90 ab	2.40 b	2.70 bc	5.69 bc	0.46 ab	2.52 c	2.30 ab	5.17 abc	4.11 ef	4.37 bc	6.16 ef	8.19 cd	5.47 b	9.33 b	11.16 cd	19.05 d
	3 + 1	0	1.47 bc	0.00 a	3.43 cde	2.51 a	1.49 bc	1.26 c	3.57 b	3.89 ab	1.51 abcd	1.90 ab	3.70 bc	4.61 bc	4.48 b	3.16 a	10.72 cd	11.01 c
		6	2.43 cde	5.88 c	5.67 de	6.86 cd	0.84 abc	4.17 d	2.17 ab	6.32 c	2.09 bcde	5.43 c	3.94 bcd	7.85 c	5.36 b	15.48 c	11.78 d	21.04 d

CB 3% Calcium-1% Boron, *Hu* Humic acid, *Ka* Kaolin 6%

Table 3 The effects foliar application treatment on average fruit length, width and weight in 7 and 14 d irrigation periods in 2014 and 2015. Means with same letter in each column were not significantly different at the $p < 0.01$ level of probability

			Fruit length (cm)				Fruit width (cm)				Fruit weight (g)			
			2014		2015		2014		2015		2014		2015	
Irrigation period (day)			7	14	7	14	7	14	7	14	7	14	7	14
Foliar application														
Hu (ml l^{-1})	CB (Ca + B%)	Ka (%)												
0	0	0	7.00 a	6.38 b	6.50 b	6.60 cd	7.67 a	6.68 a	7.20 cde	6.53 d	184.8 cde	155.2 e	172.4 de	134.8 e
		6	7.22 a	6.49 b	7.67 a	7.23 abcd	7.84 a	6.96 a	8.10 a	7.53 ab	243.7 a	158.9 de	222.7 a	147.5 bcde
	3 + 1	0	7.17 a	6.12 b	6.97 ab	6.73 bcd	7.37 a	6.71 a	7.00 de	7.23 abc	191.1 bcd	139.3 g	185.4 bc	143.9 cde
		6	6.72 a	6.50 b	6.83 ab	7.00 abcd	7.31 a	6.88 a	7.30 bcde	7.63 ab	187.5 bcde	154.4 e	181.7 bcd	146.1 bcde
2	0	0	6.56 a	6.80 ab	7.03 ab	7.27 abc	7.31 a	6.85 a	6.90 e	7.63 ab	178.8 def	175.9 bc	177.2 cde	156.4 bcd
		6	7.00 a	7.14 a	7.33 ab	7.57 a	7.18 a	7.12 a	7.73 ab	7.77 a	197.5 b	190.4 a	193.2 b	183.0 a
	3 + 1	0	6.80 a	6.42 b	7.07 ab	7.43 ab	7.58 a	6.72 a	7.53 bc	7.13 bc	178.7 defg	152.7 ef	168.3 ef	158.0 bc
		6	6.70 a	6.21 b	7.27 ab	6.50 d	6.98 a	7.26 a	7.46 bcd	7.47 ab	178.5 efg	161.9 de	159.6 fg	145.1 cde
5	0	0	6.36 a	6.33 b	6.93 ab	7.37 ab	6.92 a	6.88 a	7.10 cde	6.83 cd	165.9 g	143.5 fg	157.5 fg	143.6 de
		6	5.71 a	6.19 b	6.53 b	7.30 abc	6.68 a	6.77 a	7.10 cde	7.30 abc	167.0 gf	168.0 dc	151.9 g	145.2 bcde
	3 + 1	0	6.57 a	6.18 b	7.33 ab	7.27 abc	6.76 a	6.47 a	7.53 bc	7.70 a	167.7 gf	144.3 fg	160.4 fg	136.9 e
		6	6.55 a	6.80 ab	7.23 ab	7.20 abcd	7.26 a	7.94 a	7.2b cde	7.47 ab	188.8 bcde	184.8 ab	175.2 cde	159.3 b

CB 3% Calcium-1% Boron, *Hu* Humic acid, *Ka* Kaolin 6%

Table 4 Effect of foliar application treatments on total soluble solids (TSS), total acidity (TA), fruit flavor index (TSS/TA), and fruit juice percent for both 7 and 14 d irrigation periods in 2014 and 2015. Means with same letter in each column were not significantly different at the $p < 0.01$ level of probability

			TSS				TA (%)				TSS/TA				Fruit juice (%)			
			2014		2015		2014		2015		2014		2015		2014		2015	
Irrigation period (day) Foliar application			7	14	7	14	7	14	7	14	7	14	7	14	7	14	7	14
Hu (ml l^{-1})	CB (Ca+B%)	Ka (%)																
0	0	0	16.73 a	17.00 abcd	17.50 f	17.33 de	0.48 b	0.69 b	0.49 g	0.51 efg	35.72 a	25.30 bc	35.72 ab	34.25 bc	43.33 a	34.42 a	44.29 bc	43.77 b
		6	16.17 ab	17.33 abc	18.27 ef	17.50 de	0.51 b	0.61 b	0.52 g	0.68 bcd	32.01 ab	28.43 b	34.89 ab	25.80 e	38.81 a	38.76 a	41.25 cd	42.74 b
	3+1	0	16.00 ab	18.00 a	19.00 de	18.33 bc	0.44 b	0.62 b	0.69 de	0.70 bc	36.34 a	29.03 b	27.61 def	26.34 de	40.20 a	43.96 a	33.08 f	31.51 cd
		6	16.50 a	16.83 bcd	20.03 ab	19.33 a	0.53 b	0.78 b	0.69 d	0.63 cde	32.44 ab	21.49 cd	29.13 de	30.67 cd	36.63 a	36.06 a	19.85 g	29.68 d
2	0	0	15.67 ab	16.50 dc	20.17 a	18.67 ab	0.43 b	0.70 b	0.77 c	0.46 fg	36.30 a	15.55 de	26.10 ef	23.57 e	40.01 a	33.4 a	30.96 f	19.99 e
		6	15.83 ab	16.83 bcd	17.83 f	19.00 ab	0.54 b	0.79 b	0.61 ef	0.56 def	20.15 c	21.34 cd	29.42 dc	34.03 bc	33.52 a	38.63 a	37.55 de	18.65 e
	3+1	0	16.00 ab	17.83 ab	19.50 bcd	17.00 e	0.47 b	0.88 b	0.49 g	0.51 efg	34.15 ab	20.17 cd	37.01 a	33.69 bc	38.87 a	40.84 a	51.75 a	29.02 d
		6	14.83 b	16.00 d	18.27 ef	16.17 f	0.47 b	0.83 b	0.61 f	0.78 ab	31.85 ab	19.41 cd	32.63 bc	23.50 e	32.78 a	41.61 a	33.33 ef	38.05 b
5	0	0	16.67 a	17.50 abc	19.17 cde	17.83 cd	1.12 a	1.46 a	1.62 a	0.85 a	19.23 c	12.34 e	12.02 h	18.97 f	45.92 a	42.48 a	48.33 ab	31.01 d
		6	17.17 a	17.50 abc	19.55 bcd	17.67 cde	0.69 b	0.70 b	0.72 dc	0.76 abc	25.26 abc	25.03 bc	27.15 def	23.96 e	33.77 a	27.60 a	23.78 g	37.80 bc
	3+1	0	16.33 ab	17.17 abc	19.77 abc	17.83 cd	0.70 b	1.40 a	0.77 c	0.50 efg	23.42 bc	12.32 e	25.65 f	35.37 b	38.87 a	32.61 a	34.59 ef	50.90 a
		6	16.67 a	17.50 abc	19.50 bcd	17.33 de	0.71 b	0.49 b	0.86 b	0.43 g	24.04 bc	35.71 a	22.44 g	40.30 a	34.82 a	41.45 a	31.05 f	41.53 b

CB 3% Calcium-1% Boron, *Hu* Humic acid, *Ka* Kaolin 6%

that use this organic as a foliar applicant for pomegranate for comparison.

Fruit Quality and Quantity

A study by El-Rhman (2010), reported reductions in the proportions of seed to fruit but also noted increased fruit diameters, lengths, aril weights, juice percentages, TSS, and acidity after foliar application of kaolin. Application of 6% kaolin and 2 ml l^{-1} of humic acid together during the 14 day irrigation schedule resulted in the highest fruit weights while the lowest weights were recorded in fruit from the control trees (Table 3). No foliar applications in 2014 had a statistically significant impact to fruit length and width however, the greatest overall fruit sizes and weights were seen after 6% kaolin application under 7 d irrigation (Table 3).

Khattab et al. (2012) related that humic acid in irrigation water could improve fruit quality and quantity. Other researchers have shown that humic acid can improve yield, weight, and size of several other fruits such as kiwifruit (Mahmoudi et al. 2013) and apricot (Fathy et al. 2010; Mahmoudi et al. 2013). We have not found any reports thus far regarding the effects of CB on quantitative and qualitative characteristics of pomegranate however Huang and Snapp (2004) have used CB to improve marketability of tomato and work by Fernandez and Flore (1995) indicated that calcium treatments reduced size of cherry from 1.5 to 0.3 g.

Data generated in this work indicated that several of the foliar application combinations reduced TSS amounts in pomegranate. The combination of 2 ml l^{-1} of humic acid, CB, and 6% kaolin resulted in the lowest levels of TSS. However, in 2015, the lowest TSS levels were noted for 2 ml l^{-1} of humic acid and 6% kaolin without CB under standard irrigation. Application of 5 ml l^{-1} of humic acid increased the total acidity of the pomegranate fruit and resulted in the most dramatically decreased flavor indexes recorded during the study (Table 4). Juice content was not affected during 2014 however treatments with both 2 and 5 ml l^{-1} humic acid combined with CB significantly increased juice content under both irrigation systems (Table 4).

Conclusion

Fruit cracking in the pomegranate cultivar examined in this study was shown to be dependent on irrigation rate and abiotic factors. Our data indicated that the 14 day irrigation period, in combination with warmer temperatures, resulted in increased stress and subsequently greater percentages of cracked fruit. The application of 6% kaolin reduced cracking in pomegranate during water stressed and non-stressed time periods. Use of kaolin was also shown to positively affect fruit weights, reduce fruit skin temperature by reflecting sunlight, and improve the internal water balance within the fruit. Additional research is needed to determine the extent of these benefits. Foliar applications of humic acid also limited plant stress effects because of its biostimulatory properties. Although none of the treatments applied in this study were able to provide 100% protection against fruit cracking, several of these combinations were shown to significantly reduce percentages of cracking in pomegranate fruit during abiotic stress conditions.

Conflict of interest The authors announce that there is no conflict of interest.

References

AOAC (2000) Official methods of analysis, 17th edn. Assoc. Anal. Chem, Arlington

Canellas LP, Olivares FL, Aguiar NO, Jones DL, Nebbioso A, Mazzei P, Piccolo A (2015) Humic and fulvic acids as biostimulants in horticulture. Sci Hortic 196:15–27

Choi H-M, Son I-C, Kim D-I (2010) Effects of calcium concentrations of coating bag on pericarp structure and berry cracking in 'Kyoho'grape (Vitis sp.). Korean J Hortic Sci Technol 28:561–566

Colavita GM, Blackhall V, Valdez S (2011) Effect of kaolin particle films on the temperature and solar injury of pear fruits. Acta Hortic 909:609–615

El-Rhman IA (2010) Physiological studies on cracking phenomena of pomegranates. J Appl Sci Res 6:696–703

Fathy MA, Gabr MA, El Shall SA (2010) Effect of humic acid treatments on 'Canino' apricot growth, yield and fruit quality. N Y Sci J 3:109–115

Fernandez RT, Flore JA (1995) Intermittent $CaCl_2$ sprays during rain to prevent sweet cherry cracking. HortScience 30:793–793

Galindo A, Rodríguez P, Collado-González J, Cruz Z, Torrecillas E, Ondoño S, Corell M, Moriana A, Torrecillas A (2014) Rainfall intensifies fruit peel cracking in water stressed pomegranate trees. Agric For Meteorol 194:29–35

Gharesheikhbayat R (2006) Anatomical study of fruit cracking in pomegranate CV. Malas-e-Torsh. Pajouhesh Va Sazandegi J 18:10–14

Gindaba J, Wand SJ (2005) Comparative effects of evaporative cooling, kaolin particle film, and shade net on sunburn and fruit quality in apples. HortScience 40:592–596

Glenn DM, Puterka GJ (2005) Particle films: a new technology for agriculture. Hortic Rev (Am Soc Hortic Sci) 31:1–44

Hiwale SS (2009) The pomegranate. New India Publishing, Delhi

Holland D, Hatib K, Bar-Ya'akov I (2009) Pomegranate: botany, horticulture, breeding. Hortic Rev (Am Soc Hortic Sci) 35:127–191

Huang J-S, Snapp SS (2004) The effect of boron, calcium, and surface moisture on shoulder check, a quality defect in fresh-market tomato. J Am Soc Hortic Sci 129:599–607

Khadivi-Khub A (2014) Physiological and genetic factors influencing fruit cracking. Acta Physiol Plant 37:1–14. https://doi.org/10.1007/s11738-014-1718-2

Khalil HA, Aly HS (2013) Cracking and fruit quality of pomegranate (Punicagranatum L.) as affected by pre-harvest sprays of some growth regulators and mineral nutrients. J Hortic Sci Ornam Plants 5:71–76

Khattab MM, Shaban AE, El-Shrief AH, Mohamed AED (2012) Effect of humic acid and amino acid on pomegranate trees under deficit

irrigation. I: growth, flowering, and fruiting. J Hortic Sci Ornam Plants 4:253–259
Lichter A, Dvir O, Fallik E, Cohen S, Golan R, Shemer Z, Sagi M (2002) Cracking of cherry tomatoes in solution. Postharvest Biol Technol 26:305–312
Lotfi R, Gharavi-Kouchebagh P, Khoshvaghti H (2015) Biochemical and physiological responses of Brassicanapus plants to humic acid under water stress. Russ J Plant Physiol 62:480–486. https://doi.org/10.1134/S1021443715040123
Mahmoudi M, Samavat S, Mostafavi M, Khalighi A, Cherati A (2013) The effects of proline and humic acid on quantitative properties of kiwifruit. Int Res J Appl Basic Sci 6(8):1117–1119
Moghadam Tohidi HR (2015) Humic acid as an ecological pathway to protect corn plants against oxidative stress. Biol Forum 7(1):1704–1709
Mohamed A (2004) Effect of gibberellic acid (GA3) and benzyl adenine (BA) on splitting and quality of Manfalouty pomegranate fruits. Asian J Agric Sci 35:11–21
Prasad RN, Bankar GJ, Vashishtha BB (2003) Effect of drip irrigation on growth, yield and quality of pomegranate in arid region. Indian J Hortic 60:140–142
Sheikh M, Manjula N (2006) Effect of chemicals on control of fruit cracking in pomegranate (Punicagranatum L.) var. Ganesh. ISHS, 1st Int. Symp., Pomegranate and Minor Mediterranean Fruits, pp 16–19 (Abstracts contributed papers)
Shulman Y, Fainberstein L, Lavee S (1984) Pomegranate fruit development and maturation. J Hortic Sci 59:265–274
Singh D, Sharma B, Bhargava R (2003) Effect of boron and GA3 to control fruit cracking in pomegranate (Punica granatum). Curr Agric 27:125–127
Stover E, Mercure EW (2007) The pomegranate: a new look at the fruit of paradise. HortScience 42:1088–1092
Tabatabaei S, Sarkhosh A (2006) Analysis and comparison of salinity tolerance among 10 Iranian commercial pomegranate cultivars. ISHS 1st Int. Symp. Pomegranate and Minor Mediterranean Fruits, pp 16–19 (Abstracts contributed papers)
Wand SJ, Theron KI, Ackerman J, Marais SJ (2006) Harvest and postharvest apple fruit quality following applications of kaolin particle film in South African orchards. Sci Hortic 107:271–276
Weerakkody P, Jobling J, Infante MMV, Rogers G (2010) The effect of maturity, sunburn and the application of sunscreens on the internal and external qualities of pomegranate fruit grown in Australia. Sci Hortic 124:57–61
Yazici K, Kaynak L (2009) Effects of kaolin and shading treatments on sunburn on fruit of hicaznar cultivar of pomegranate (Punica granatum L. Cv. Hicaznar). Acta Hortic 818:167–174
Yılmaz C, Özgüven A (2006) The effects of some plant nutrients, gibberellic acid and pinolene treatments on the yield, fruit quality and cracking in pomegranate. Acta Hortic 818:205–212