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# Influence of $GA_3$ and boric acid foliar application on bioactive compounds and quality of pomegranate fruit (*Punica granatum* L.)

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## ABSTRACT

**Purpose:** The effect of foliar application of gibberellic acid and boric acid on bioactive compounds and quality of pomegranate fruit cv. Shishe-Kab was investigated. **Research Method:** This was accomplished through the field and laboratory experiments at the Faculty of Agriculture, University of Birjand, Iran, during 2017 and 2018 seasons. Gibberellic acid (50 and 150 mg $L^{-1}$) and Boric acid (200 and 600 mg $L^{-1}$) were applied three times at one-month interval; late in May, June, and July during growth and developmental stages of fruits. The experiment was set in a completely randomized block design. Fruits were harvested at full maturity stage late in October, and physicochemical properties were evaluated. **Findings:** Results showed that anthocyanin content and antioxidant activity significantly decreased while fruit firmness, ascorbic acid content, and fruit cracking increased in gibberellic acid treatments. Application of 50 mg $L^{-1}$ gibberellic acid significantly increased total soluble solids content and maturity index, but decreased titratable acidity in the fruits. However, foliar application of gibberellic acid and boric acid did not have significant effects on the pH and phenolic compounds of the fruit. **Research limitations:** Inability to examine different pomegranate cultivars in the investigation was a limitation. **Originality/Value:** Pre-harvest foliar use of gibberellic acid and boric acid showed positive and negative effects on postharvest quality attributes of Shishe-Kab pomegranate. Thus, further studies need for practical application.

## INTRODUCTION

Pomegranate from *Punicaceae* family is believed to have originated in north-eastern and the south Caspian areas (Zohary & Spiegel-Roy, 1975), which is grown extensively in arid and semi-arid regions worldwide (Sarkhosh et al., 2006). Pomegranate fruit forms as a large (5-12 cm) and fleshy berry containing many arils and seeds surrounded by pulp. Pomegranate fruit is a rich source of several high-value compounds like phenols, anthocyanins and ascorbic acid that make pomegranate fruit useful in human medicine (Lansky & Newman, 2007). Diabetes, dental conditions, erectile dysfunction, alzheimer's disease, male infertility, arthritis, and obesity are some of the pomegranate properties therapeutic (Dhineshkumar et al., 2015).

Foliar application is a technique to supply the required nutrient elements of plants with the benefit of low application rates, uniform distribution of fertilizer materials and quick response to applied nutrients (Umar et al., 1999). Boron is one of the essential mineral nutrients for normal growth and development of higher plants.

Cell wall strength and development, cell division, pollination, fruit and seed development, sugar transport, hormone development, the integrity of plasma membranes, phenol metabolism and nitrogen fixation are some of the main functions of boron in plants. Also, adequate boron nutrition is a requirement for anther, pollen and ovule normal development (Rasheed, 2009). According to Cakmak and Römheld (1997) study, boron deficiency increased the accumulation of phenolic compounds that result in reversible alteration in membrane permeability of higher plant (Goldbach et al., 1990). Asgharzade et al. (2012) reported that preharvest application of boric acid increased Brix index in apple fruit. Also, boron application improved color in apple fruit by increasing carbohydrate content (Wojcik et al., 2008). Besides, fruit production and fruit quality could be improved by using growth regulators (Khalil & Aly, 2013).

Plant growth regulators enhance rapid changes in physiological and biochemical characteristics of crops at low concentration (Kishor et al., 2017). Gibberellin or gibberellic acid ($GA_3$) has useful role in vegetative growth, flowering, fruiting and various disorders in many fruit crops (Paroussi et al., 2002). Increasing fruit production is one of the main functions of foliar application of gibberellic acid (Lombardo et al., 1978). It has been reported that foliar application of gibberellic acid improved post-harvest life and storage quality, increased fruit firmness and fruit cracking in sweet cherries (Cline & Trought, 2007). Tuan and Chung-Ruey (2013) reported that gibberellic acid application decreased acidity percentage by conversion of the organic acids to sugar during fruit ripening in wax apple.

Several authors have studied the effect of growth regulators and other chemicals on pomegranate fruit characteristics (Khalil & Aly, 2013; Kishor et al., 2017). Also, Khalil and Aly (2013) reported that applying 80 mg $L^{-1}$ gibberellic acid increased rate of total soluble solids (TSS), anthocyanin and acidity in pomegranate fruit. Boric acid sprayed on Manfalouty pomegranate increased percentage of TSS and reduced acidity (Ahmed et al., 2014). Belsare (2011) reported that both boric acid and gibberellic acid application increased ascorbic acid content in pomegranate fruit cv. G137. It is in the light of these that a study was designed to evaluate the effects of foliar application of gibberellic acid and boric acid on the quality of pomegranate fruit cv. Shishe-Kab which has a high potential for the export market but are often cracked at harvest.

## MATERIALS AND METHODS

This experiment was conducted on the research orchard of the Faculty of Agriculture, University of Birjand, in 2017 and 2018. Nine-year-old pomegranate trees of cv. Shishe-Kab, planted at a spacing of 3×3 m were sampled for the purpose. One-year-old shoots with the same length (45±5 cm), diameter (2±1 cm) and same flowering stage (first flowering stage of pomegranate trees) were sampled and tagged for data collection. Treatments were control (spray with distilled water), boric acid (200 and 600 mg $L^{-1}$) and gibberellic acid (50 and 150 mg $L^{-1}$). These concentrations were chosen after studying the results of previous workers. The foliar spray was applied three times at one-month interval, in 20$^{th}$ May, 20$^{th}$ June, and 16$^{th}$ July, during the fruit development that boron and $GA_3$ required more. Fruits were picked at commercial harvest and transported to the laboratory of the Department of Horticultural Science, University of Birjand, where they were processed into fruit juice for the determination of the following parameters:

**Titratable acidity (TA)**
Titratable acidity was determined by titration of 1 ml of juice with 0.1 N of NaOH and the results were calculated as a percentage of citric acid (Cochran et al., 1986).

**pH**
The pH of the juice was determined using a digital pH meter (Extech Co., USA).

**Total anthocyanin**
Total anthocyanin content of juice was determined by the pH-differential method using two buffer systems comprised of potassium chloride (pH 1, 0.025 M) and sodium acetate (pH 4.5, 0.4 M). One ml of juice sample was mixed with 10 mL of buffer, and the absorbance (A) was measured at 510 and 700 nm using a Unico 2100 spectrophotometer (Wagner, 1979).

**Total soluble solids (TSS)**
Total soluble solids in the extracted juice of fruit were measured by a hand-held refractometer (Extech Co., Model RF 10, °Brix, 0–32 %, USA), and the results were expressed as ºBrix.

**TSS/TA ratio**
The TSS/TA ratio was used as a maturity index.

**Ascorbic acid**
Ascorbic acid was determined by the indophenol method and the value expressed as mg of ascorbic acid/100 ml juice (Ranganna, 1977).

**Antioxidant activity**
Antioxidant activity of pomegranate juice was determined by the diphenylpicrylhydrazyl method described by Turkmen et al. (2005).

**Phenolic compounds**
The total phenolic content of juice was determined by the folin-cicoalteu method at a wavelength of 725 nm and expressed as a percentage of gallic acid (Chuah et al., 2008).

**Firmness**

Fruit firmness (N) was determined by using a digital penetrometer (Fruit Hardness Tester, Extech Co., FHT 200, USA).

**Fruit cracking**

The ratios of the cracked fruits were determined by dividing the affected fruits to the total number of fruits (Hegazi et al., 2014).

**Sensory evaluation**

A panel of four trained members did sensory evaluation of samples, based on a 5-point hedonic scale (1: very bad, 2: bad, 3: indecisive, 4: good, and 5: very good) that rated visual appearance, odour, and taste quality of arils (Stone & Sidel, 1985).

**Color measurements**

Color measurements were performed using a color meter (TES-135A. Taiwan) (Ergüneş & Tarhan, 2006).

Hue angle (h) = $\tan^{-1}(b/a)$.

Hue angle expresses the color nuance values which are defined as follows: red-purple = 0, yellow = 90, bluish-green = 180, and blue = 270 (Voss, 1992).

Chroma= $((a^2 + b^2)^{0.5})$.

Chroma is a measure of chromaticity (C*), which denotes the purity or saturation of the color. L = lightness. L ranges from Zero (L = 0, no reflection for black) to one hundred (L = 100, perfect diffuse reflection for white. The value ‘‘a’’ shows the redness, ranging from negative values (-a) for green to positive (+a) values for red. The value ‘‘b’’ is the yellowness, ranging from negative values (-b) for blue and positive values (+b) for yellow.

**Data analysis**

The experiment was set in a completely randomized block design with six replications for each treatment and three plants for each replication. Obtained data were analyzed by the Genstat program (Discovery Edition, Version 9.2, 2007, VSN International Ltd., UK) and mean values were compared at the level of 5% probability according to LSD test.

## RESULTS AND DISCUSSION

**Titratable acidity**

It is evident from Table 1 that foliar application of 50 mg $L^{-1}$ gibberellic acid significantly decreased titratable acidity content in pomegranate fruits compared to the control in 2017 and 2018. Similarly, foliar application of 40 mg $L^{-1}$ gibberellic acid decreased titratable acidity content of pomegranate fruit cv. Yousef khani (Jafari, 2014). These findings are similar to reports on aonla fruit by Yadav et al. (2010) who stated that mineral compounds reduce the acidity in fruits since it is neutralized in parts during metabolic pathways and, or used in the respiratory process as a substrate. Also, Shukla et al. (2011) reported that the acid content of fruits after application of a plant growth regulator is either converted into sugar and its derivatives by a reaction involving the reversal of glycolytic pathways or used in respiration or both.

**pH**

Results in Table 1 show that the pH of pomegranate fruit juice was not affected by foliar application of gibberellic acid and boric acid.

**Anthocyanin**

Anthocyanins are the most important pigments of the vascular plants; they are harmless and responsible of the pink, red, violet and blue colors in the flowers and fruits of some plants (Buchert et al., 2005). Table 1 shows that the control fruits have the highest anthocyanin content and the spraying of both concentrations of gibberellic acid and boric acid decreased anthocyanin content compared to the control. The lowest anthocyanin content was observed in treated fruit with 600 mg $L^{-1}$ boric acid in 2017 and treated fruit with 50 mg $L^{-1}$ gibberellic acid in 2018. These results are in agreement with findings of Selah Varzi et al. (2003), who indicated that spray of 150 mg $L^{-1}$ of gibberellic acid decreased anthocyanin content of pomegranate fruit cv. Shahnaz. Also, the application of 500 mg $L^{-1}$ boric acid reduced anthocyanin content of sweet cherry (*Prunus avium* L.) (Thurzo et al., 2008).

Boron decreases anthocyanin pigments in the fruit by increasing the absorption of oxygen that acts as a factor in the anthocyanin degradation and causes instability of this pigment. (O'Kelley, 1957; Wang et al., 2004). The decrease in anthocyanin content can be related to the role of GA in the inhibition of anthocyanin biosynthesis and reduction of fruit coloration (Laribi et al., 2013).

**Table 1.** Effect of foliar spray of $GA_3$ and boron on TA, pH, anthocyanin, TSS and TSS/TA content of pomegranate fruits in 2017 and 2018 production seasons

| Treatment | TA (g 100 $mL^{-1}$) | pH | Anthocyanin (mg $L^{-1}$) | TSS (%) | TSS/ TA |
|---|---|---|---|---|---|
| **2017** | | | | | |
| Control | $26.6^{a}$ | $3.5^{a}$ | $371.2^{a}$ | $18.5^{c}$ | $0.7^{a}$ |
| B 200 | $25.8^{a}$ | $3.7^{a}$ | $163.3^{c}$ | $19.8^{b}$ | $0.7^{a}$ |
| B 600 | $23.6^{ab}$ | $3.5^{a}$ | $100.2^{c}$ | $17.9^{c}$ | $0.7^{a}$ |
| $GA_3$ 50 | $19.9^{b}$ | $3.7^{a}$ | $278.8^{b}$ | $22.6^{a}$ | $1.1^{a}$ |
| $GA_3$ 150 | $26.1^{a}$ | $3.6^{a}$ | $307.5^{ab}$ | $19.0^{bc}$ | $0.7^{a}$ |
| **2018** | | | | | |
| Control | $23.1^{ab}$ | $3.5^{a}$ | $148.3^{a}$ | $17.5^{c}$ | $0.7^{c}$ |
| B 200 | $22.8^{b}$ | $3.5^{a}$ | $124.5^{b}$ | $19.0^{b}$ | $0.8^{b}$ |
| B 600 | $23.1^{ab}$ | $3.6^{a}$ | $110.5^{c}$ | $17.9^{bc}$ | $0.7^{bc}$ |
| $GA_3$ 50 | $20.1^{c}$ | $3.5^{a}$ | $45.7^{e}$ | $23.3^{a}$ | $1.16^{a}$ |
| $GA_3$ 150 | $24.3^{a}$ | $3.6^{a}$ | $60.1^{d}$ | $18.6^{bc}$ | $0.7^{bc}$ |

Treatments: Control (distilled water), BA 200= Boric acid 200 mg $L^{-1}$, BA 600= Boric acid 600 mg $L^{-1}$, $GA_3$ 50= Gibberellic acid 50 mg $L^{-1}$ and $GA_3$ 150= Gibberellic acid 150 mg $L^{-1}$, respectively. In each column, means with the same letter are not significantly different at 5% level of probability using LSD.

**Table 2.** Effect of foliar spray of $GA_3$ and boron on ascorbic acid, antioxidant activity, phenolic compounds, firmness and fruit cracking characteristics of pomegranate fruits in 2017 and 2018 production seasons

| Treatment | Ascorbic acid (mg AA100 $mL^{-1}$) | Antioxidant activity (%) | Phenolic compounds (mg GA $g^{-1}$ DM) | Firmness (N) | Fruit cracking (%) |
|---|---|---|---|---|---|
| **2017** | | | | | |
| Control | $17.7^{b}$ | $87.4^{a}$ | $63^{a}$ | $20.2^{d}$ | 10.6b |
| B 200 | $24.0^{b}$ | $85.4^{a}$ | $63^{a}$ | $25.0^{c}$ | 11.7b |
| B 600 | $41.5^{a}$ | $85.3^{a}$ | $63^{a}$ | $24.0^{c}$ | 11.2b |
| $GA_3$ 50 | $55.6^{a}$ | $83.5^{ab}$ | $63^{a}$ | $33.2^{a}$ | 10.7b |
| $GA_3$ 150 | $24.0^{b}$ | $80.05^{b}$ | $64^{a}$ | $26.9^{b}$ | 17.8a |
| **2018** | | | | | |
| Control | $15.0^{b}$ | $85.5^{a}$ | $63^{a}$ | $21.8^{b}$ | 25a |
| B 200 | $25.0^{ab}$ | $86.3^{a}$ | $63^{a}$ | $22.1^{b}$ | 23.7a |
| B 600 | $41.0^{a}$ | $86.8^{a}$ | $63^{a}$ | $23.1^{b}$ | 23.1a |
| $GA_3$ 50 | $40.3^{a}$ | $86.4^{a}$ | $63^{a}$ | $30.4^{a}$ | 25.0a |
| $GA_3$ 150 | $27.2^{ab}$ | $81.8^{b}$ | $63^{a}$ | $31.3^{a}$ | 25.0a |

Treatments: Control (distilled water), BA 200= Boric acid 200 mg $L^{-1}$, BA 600= Boric acid 600 mg $L^{-1}$, $GA_3$ 50= Gibberellic acid 50 mg $L^{-1}$ and $GA_3$ 150= Gibberellic acid 150 mg $L^{-1}$, respectively. In each column, means with the same letter are not significantly different at 5% level of probability using LSD.

**Total soluble solids (TSS)**

Results in Table 1 indicate that foliar application of 50 mg $L^{-1}$ gibberellic acid and 200 mg $L^{-1}$ boric acid significantly increased total soluble solids content of pomegranate fruits. Maximum total soluble solids was observed in fruits treated with 50 mg $L^{-1}$ gibberellic acid which was also significantly higher for both 2017 (22.6 %) and 2018 (23.3 %) production years. Khalil and Aly (2013) reported that spraying gibberellic acid and boric acid increased the total soluble solids content of pomegranate cv. Manfalouty. Gibberellins affect activation of the amylase enzyme, which is responsible for the conversion of starch into sugars that could increase TSS content (Shukla et al., 2011). Yadav et al. (2010) reported that the high amounts of soluble solids in aonla fruits treated with boric acid and gibberellic acid relate to the rapid transformation of complex carbohydrates to soluble sugars, as well as the rapid mobilization of metabolites from source to the reservoir.

**Maturity index (TSS/ TA)**

The maximum maturity index (1.1) was observed in fruits treated with 50 mg $L^{-1}$ gibberellic acid in 2017 and 2018 and also significantly higher among the other treament in the latter year of production (Table 1). In another study, spraying 50 and 75 mg $L^{-1}$ gibberellic acid increased maturity index of pomegranate cv. Bhagwa (Kishor et al., 2017). The fruit flavor is affected/influenced by the ratio of total soluble solids to titratable acidity. Fruit flavor and sweetness improve by reducing the amount of acid and increasing the soluble solids during the growing season. The ratio of total soluble solids to titratable acidity has been used as a qualitative criterion for determining harvest maturity. Fruits treated with 50 mg $L^{-1}$ gibberellic acid resulted in maximum maturity index (1.1) most probably because of the increase in soluble solids and the reduction in acidity in fruits of that treatment.

**Ascorbic acid**

Ascorbic acid or vitamin C is water-soluble compound and is one of the key antioxidant nutrients that play a crucial role in preventing losses and providing a decent level of antioxidants in our body (Yadav et al., 2016). Effect of various concentrations of gibberellic acid and boric acid on ascorbic acid of pomegranate fruit is shown in Table 2.

The minimum ascorbic acid content was recorded in control fruit in 2017 and 2018. The maximum ascorbic acid content was observed in fruit treated with 50 mg $L^{-1}$ gibberellic acid and 600 mg $L^{-1}$ boric acid in 2017 and 2018, respectively.

Similar results were reported by Kumar et al. (2016) that use of 2000, 4000 and 6000 mg $L^{-1}$ of boric acid significantly increased ascorbic acid in pomegranate cv. Jodhpur Red. In another study, application of 30 or 60 mg $L^{-1}$ gibberellic acid significantly increased ascorbic acid in pomegranate Malaseh Saveh cultivar (Karami, 2016). Arzani et al. (2008) stated that boric acid increases the amount of vitamin C in fruit flesh during growth and storage time. It has been reported that gibberellic acid not only stimulates ascorbic acid synthesis but also prevents its oxidation (Ouzounidou et al., 2010). In this study, the application of gibberellic acid and boron may have enhanced the processes of synthesis, translocation, and accumulation of TSS and other sugars following a strong source-sink relationship (Shukla et al., 2011).

**Antioxidant activity**

Halliwell (2007) reported that an antioxidant is "any substance that delays, prevents or removes oxidative damage to a target molecule even at relatively small concentration. Polyphenols, flavonoids, vitamins (C and E), and β-carotene are some of the antioxidants (Yadav et al., 2016). Results in Table 2 indicate that the foliar application of gibberellic acid at 150 mg $L^{-1}$ significantly decreased the antioxidant activity in the pomegranate fruit compared to control-treated fruits in both 2017 and 2018 production seasons. Davarpanah et al. (2016) reported that application of boric acid at 25 and 75 mg $L^{-1}$ did not have significant effects on antioxidant activity in pomegranate fruit cv. Ardestani. Ozturk et al. (2018) reported that application of gibberellic acid at 15 mg $L^{-1}$ significantly increased the antioxidant activity in jujube fruit. In this study, the decrease in antioxidant activity of the pomegranate fruit could be related to the direct role of gibberellic acid in the biosynthesis of phenolic compounds and anthocyanin (Sardoei et al., 2014). According to Tehranifar and Mahmoudi Tabar (2009), gibberellic acid application reduced the antioxidant activity of pomegranate fruits by decreasing the biosynthesis of anthocyanin, which has a high antioxidant capacity.

## Phenolic compounds

Results show that the application of gibberellic acid and boric acid at the different concentrations did not affect the content of phenolic compounds in the pomegranate fruit during the 2017 and 2018 production seasons (Table 2).

**Table 3.** Effect of foliar spray of $GA_3$ and boron on taste and appearance of pomegranate fruit arils in 2017 and 2018 production seasons

| Treatment | Taste | Appearance |
|---|---|---|
| | **2017** | |
| Control | 4.5[a] | 3.5[a] |
| B 200 | 4.6[a] | 3.0[b] |
| B 600 | 3.3[b] | 3.3[ab] |
| $GA_3$ 50 | 4.0[ab] | 3.6[a] |
| $GA_3$ 150 | 4.3[a] | 3.3[ab] |
| | **2018** | |
| Control | 3.6[a] | 4.4[a] |
| B 200 | 2.8[a] | 2.2[d] |
| B 600 | 4.2[a] | 3.2[bc] |
| $GA_3$ 50 | 4.2[a] | 2.6[cd] |
| $GA_3$ 150 | 4.2[a] | 3.8[ab] |

Treatments: Control (distilled water), BA 200= Boric acid 200 mg $L^{-1}$, BA 600= Boric acid 600 mg $L^{-1}$, $GA_3$ 50= Gibberellic acid 50 mg $L^{-1}$ and $GA_3$ 150= Gibberellic acid 150 mg $L^{-1}$, respectively. In each column, means with the same letter are not significantly different at 5% level of probability using LSD.

**Table 4.** The effect of foliar spray of $GA_3$ and boron on color attributes of pomegranate arils in 2017 and 2018 production seasons

| Treatment | *L** (lightness) | *a** (redness) | *b** (yellowness) | Hue (h°) | Chroma (*C**) |
|---|---|---|---|---|---|
| **2017** | | | | | |
| Control | 23.2[c] | 24.3[b] | 4.7[e] | 11.6[c] | 24.8[b] |
| B 200 | 20.4[d] | 26.4[b] | 6.1[d] | 13.0[bc] | 27.1[b] |
| B 600 | 41.6[a] | 21.6[b] | 10.7[b] | 28.3[a] | 24.4[b] |
| $GA_3$ 50 | 23.2[c] | 24.6[b] | 9.5[c] | 21.7[ab] | 26.5[b] |
| $GA_3$ 150 | 32.2[b] | 34.6[a] | 15.6[a] | 24.6[a] | 38.0[a] |
| **2018** | | | | | |
| Control | 16.2[ab] | 19.9[c] | 4.4[a] | 12.5[a] | 20.48[c] |
| B 200 | 16.4[ab] | 25.0[a] | 4.1[ab] | 9.3[b] | 25.4[a] |
| B 600 | 12.4[c] | 18.1[d] | 3.6[b] | 11.4[a] | 18.5[d] |
| $GA_3$ 50 | 16.9[a] | 20.9[bc] | 4.5[a] | 14.1[a] | 21.4[bc] |
| $GA_3$ 150 | 15.1[b] | 22.0[b] | 4.5[a] | 11.6[a] | 22.4[b] |

Treatments: Control (distilled water), BA 200= Boric acid 200 mg $L^{-1}$, BA 600= Boric acid 600 mg $L^{-1}$, $GA_3$ 50= Gibberellic acid 50 mg $L^{-1}$ and $GA_3$ 150= Gibberellic acid 150 mg $L^{-1}$, respectively. In each column, means with the same letter are not significantly different at 5% level of probability using LSD.

**Fruit firmness**

Fruit firmness is one of the most essential characteristics for a fresh market cultivar, and is related to stage of harvest maturity and the variety. For both the 2017 and 2018 production seasons, the application of gibberellic acid significantly increased the firmness of pomegranate fruit as compared to the other treatments (Table 2). Control treated fruits had the lowest fruit firmness record. The highest fruit firmness was recorded in fruits treated with 50 and 150 mg $L^{-1}$ gibberellic acid in 2017 and in 2018, respectively. Statistically, no significant difference was observed between fruits treated with 50 mg $L^{-1}$ gibberellic acid and fruits treated with 150 mg $L^{-1}$ gibberellic acid in the 2018 production season. Weksler et al. (2009) explained that pretreatment of gibberellic acid increased the amount of cellulose in the cell wall and therefore increased texture firmness in the treated fruits compared to the control treated fruits. Xuan et al. (2000) stated that boron plays a vital role in membrane integrity and intercellular defense mechanism. Khalaj et al. (2015) reported that spraying boric acid at 5 mg $L^{-1}$ significantly increased the firmness of pear fruit while Tehranifar and Mahmoudi Tabar (2009) reiterated that foliar application of boric acid at 1500 and 3000 mg $L^{-1}$ did not affect fruit firmness in pomegranate fruit cv. Shishe-Kab. This inconsistency might be due to the different crop species, different spraying times, and different boric acid concentrations administered at the time.

**Fruit cracking**

Fruit cracking causes a significant loss and lessens the marketability during the latter period of growth, which is a severe commercial loss to farmers. Fruit cracking was significantly increased by spraying 150 mg $L^{-1}$ gibberellic acid (Table 2).

Christensen (1972) described that fruits treated with $GA_3$ are more advanced in maturity, which could explain increased susceptibility to cracking. The application of gibberellic acid increases the rate of water uptake and transpiration that may change the cuticular and possibly epidermal properties of fruit and consequently weaken the fruit skin to cracking (Glenn, 1989). Cline and Trought (2007) reported that repeated or singular foliar applications at 10 and 40 mg $l^{-1}$ gibberellic acid, respectively, increased fruit cracking in Bing sweet cherries.

**Sensory evaluation**

Sensory evaluation determines the food quality characteristics by use of human senses. Boric acid at 600 mg $L^{-1}$ significantly decreased aril sensory scores compared to control in 2017 experiment. However, there was no significant difference among treatments in 2018 (Table 3). Application of boric acid at 200 mg $L^{-1}$ in both production seasons and gibberellic acid at 50 and 150 mg $L^{-1}$ in 2018 decreased aril appearance scores (Fig. 1). Results in Table 1 indicate that control samples scored the highest in terms of appearance quality. Exogenous use of growth regulators can change the chemical properties of fruits that may weaken or improve the taste (Arora & Singh, 2015). Phenolic compounds, anthocyanins, and tannins are responsible for the taste and color of the pomegranate fruit (Kulkarni & Aradhya, 2005). All these activities relate to the diversity of phenols and anthocyanins in pomegranate juice (Gil et al., 2000). As is shown in Table 1 and 2, foliar application of boric acid and gibberellic acid decreased the anthocyanin content and did not affect phenolic compounds in pomegranate fruits, which cause lower sensory scores compared to the control. Bhoyar and Ramdevputra (2016) reported that application of boric acid at 3000 mg $L^{-1}$ weaken the taste of guava fruit compared to the control treatment.

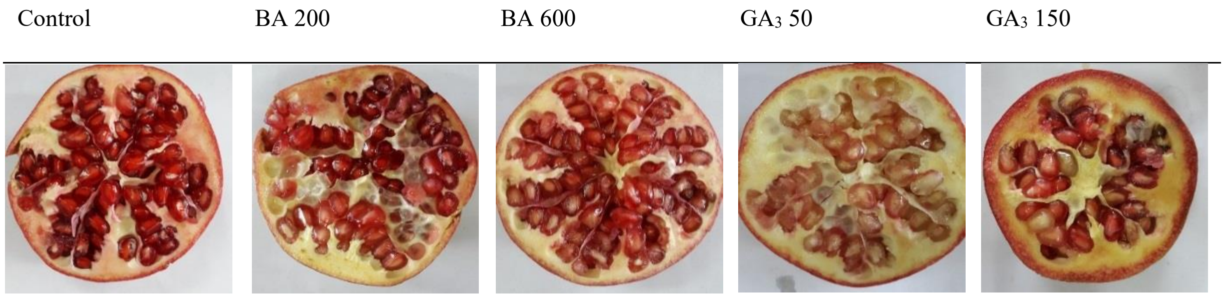


**Fig. 1**. Effect of foliar spray of $GA_3$ and boron on visual appearance of pomegranate fruit cv. Shishe-Kab in 2018 season. Treatments: Control (distilled water), BA 200= Boric acid 200 mg $L^{-1}$, BA 600= Boric acid 600 mg $L^{-1}$, $GA_3$ 50= Gibberellic acid 50 mg $L^{-1}$ and $GA_3$ 150= Gibberellic acid 150 mg $L^{-1}$.

### Aril color attributes

The color attributes of pomegranate fruit arils are presented in Table 4. Color parameters were significantly affected by experimental treatments. Foliar application of 200 and 600 mg $L^{-1}$ boric acid recorded the lowest lightness ($L*$) reading for the pomegranate fruit arils in the 2017 and 2018 production seasons, respectively. The lowest redness ($a*$) reading was observed in fruits treated with 600 mg $L^{-1}$ boric acid in 2017 and 2018. The highest yellowness ($b*$) reading was recorded in fruits treated with 150 mg $L^{-1}$ gibberellic acid in 2017.

Foliar application of 600 mg $L^{-1}$ boric acid and 50 mg $L^{-1}$ gibberellic acid in 2017 and 150 mg $L^{-1}$ gibberellic acid in both years significantly increased the chroma reading of pomegranate fruit arils. Besides, the application of gibberellic acid at both concentrations and boric acid at 600 mg $L^{-1}$ significantly increased hue reading of pomegranate fruit arils. Foliar application of 200 mg $L^{-1}$ boric acid decreased hue reading of pomegranate fruit arils in 2018. Safdary (2015) reported that spraying with gibberellic acid at 50 and 100 mg $L^{-1}$ two weeks after full bloom did not affect/influence the $L*$, $a*$, $b*$, hue, and chroma readings of grapevine cv. Siah-e-Samarghandi during experimentation. Different spraying times, different foliar application materials, and various crop species might be the reason for the inconsistencies in these present results. Treated fruits with 600 mg $L^{-1}$ boric acid had the lowest anthocyanin content in 2017. This could be the possible reason for increases in hue. The lowest and highest chroma readings were observed in fruits treated with 50 and 150 mg $L^{-1}$ gibberellic acid, respectively. According to Harminder et al. (2008), increasing hue reading indicates a decrease in red color intensity or content of anthocyanin pigments, and that gibberellic acid has been shown to decrease color development in fruits.

## CONCLUSION

Total soluble solids, titratable acidity, maturity index, and ascorbic acid content of pomegranate fruit cv. Shishe-Kab grown under Birjand condition were improved by preharvest foliar application of boric acid and gibberellic acid during the 2017 and 2018 production seasons while fruit firmness, cracking, anthocyanin content, appearance and antioxidant activity were negatively affected. It may be concluded that boron and gibberellin may be used for obtaining fruit with higher quality. Further studies should be done focusing on different concentrations, the number of applications, time of application, including the determination of the combined effect of both boric acid and gibberellic acid for the purpose.

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## CONFLICT OF INTEREST

The authors have no conflict of interest to report.

## REFERENCES

Ahmed, F., Mohamed, M., Abou El-Khashab, A., & Aeed, S. (2014). Controlling fruit splitting and improving productivity of Manfalouty pomegranate trees by using salicylic acid and some nutrients. *World Rural Observations*, *6*(1), 87-93.

Arora, R., & Singh, S. (2015). Effect of growth regulators on quality of ber (*Zizyphus mauritiana Lamk*) cv. Umran. *Agricultural Science Digest*, *34*(2), 102-106. https://doi.org/10.5958/0976-0547.2014.00024.X

Arzani, K., Khoshghalb, H., Malakouti, M. J., & Barzegar, M. (2008). Postharvest fruit physicochemical changes and properties of Asian (*Pyrus serotina* Rehd.) and European (*Pyrus communis* L.) pear cultivars. *Horticulture Environment and Biotechnology*, *49*(1), 244-252.

Asgharzade, A., Valizade, G. A., & Babaeian, M. (2012). Investigating the effect of boron spray on yield nutrient content, texture and brix index of apple (Sheikh Amir Variety) in Shirvan region. *African Journal of Microbiology Research*, *6*(11), 2682-2685. https://doi.org/10.5897/AJMR11.1163

Belsare, C. R. (2011). Effect of plant bio-regulators and nutrients on yield, fruit cracking and quality in pomegranate (*Punica granatum* L.) cv. G-137. (Doctoral dissertation, UHF, Nauni, Solan).

Bhoyar, M. G., & Ramdevputra, M. V. (2016). Effect of foliar spray of zinc, iron and boron on the growth, yield and sensory characters of guava (*Psidium guajava* L.) Cv. Sardar L-49. *Journal of Applied and Natural Science, 8*(2), 701-704. https://doi.org/10.31018/jans.v8i2.860

Buchert, J., Koponen, J. M., Suutarinen, M., Mustranta, A., Lille, M., Törrönen, R., & Poutanen, K. (2005). Effect of enzyme-aided pressing on anthocyanin yield and profiles in bilberry and blackcurrant juices. *Journal of the Science of Food and Agriculture*, *85*(15), 2548-2556. https://doi.org/10.1002/jsfa.2284

Cakmak, I., & Römheld, V. (1997). Boron deficiency-induced impairments of cellular functions in plants. *Plant and Soil*, *193*(1-2), 71-83. https://doi.org/10.1023/A:1004259808322

Christensen, J. V. (1972). Cracking in cherries: IV. Physiological studies of the mechanism of cracking. *Acta Agriculturae Scandinavica*, *22*(3), 153-162. https://doi.org/10.1080/00015127209433474

Chuah, A. M., Lee, Y.-C., Yamaguchi, T., Takamura, H., Yin, L.-J., & Matoba, T. (2008). Effect of cooking on the antioxidant properties of coloured peppers. *Food Chemistry*, *111*(1), 20-28. https://doi.org/10.1016/j.foodchem.2008.03.022

Cline, J., & Trought, M. (2007). Effect of gibberellic acid on fruit cracking and quality of Bing and Sam sweet cherries. *Canadian Journal of Plant Science*, *87*(3), 545-550. https://doi.org/10.4141/P06-132

Cochran, R., Adams, D., Wallace, J. & Galyean, M. (1986). Predicting digestibility of different diets with internal markers: evaluation of four potential markers. *Journal of Animal Science*, *63*(5), 1476-1483. https://doi.org/10.2527/jas1986.6351476x

Davarpanah, S., Tehranifar, A., Davarynejad, G., Abadía, J., & Khorasani, R. (2016). Effects of foliar applications of zinc and boron nano-fertilizers on pomegranate (*Punica granatum* cv. Ardestani) fruit yield and quality. *Scientia Horticulturae*, *210*, 57-64.

https://doi.org/10.1016/j.scienta.2016.07.003

Dhineshkumar, V., Ramasamy, D., & Srivastav, P, P. (2015). Modified atmosphere packaging of pomegranate arils: Review. *International Journal of Applied Engineering and Technology ISSN*. Vol. *5* (3), pp.8-24.

Ergüneş, G., & Tarhan, S. (2006). Color retention of red peppers by chemical pretreatments during greenhouse and open sun drying. *Journal of Food Engineering*, *76*(3), 446-452. https://doi.org/10.1016/j.jfoodeng.2005.05.046

Gil, M. I., Tomás-Barberán, F. A., Hess-Pierce, B., Holcroft, D. M., and Kader, A. A. (2000). Antioxidant activity of pomegranate juice and its relationship with phenolic composition and processing. *Journal of Agricultural and Food Chemistry*, *48*(10), 4581-4589. https://doi.org/10.1021/jf000404a

Glenn, G. M. (1989). Cuticular properties and postharvest calcium applications influence cracking of sweet cherries. *Journal of the American Society for Horticultural Science*, *114*, 781-788.

Goldbach, H. E., Hartmann, D., & Rötzer, T. (1990). Boron is required for the stimulation of the ferricyanide-induced proton release by auxins in suspension-cultured cells of Daucus carota and Lycopersicon esculentum. *Physiologia Plantarum*, *80*(1), 114-118. https://doi.org/10.1111/j.1399-3054.1990.tb04383.x

Halliwell, B. (2007). Biochemistry of oxidative stress. *35*, 1147-1150. https://doi.org/10.1042/BST0351147

Harminder, K., Arvinder, S., Monika, G., & Randhawa, J. S. (2008). Effect of NAA and gibberellic acid on pre-harvest fruit drop and quality of Satluj Purple plum. *Haryana Journal of Horticultural Sciences*, *37*(1/2), 31-32.

Hegazi, A., Samra, N., El-Baz, E., Khalil, B. M., & Gawish, M. (2014). Improving fruit quality of Manfalouty and Wonderfull pomegranates by using bagging and some spray treatments with gibberellic acid, calcium chloride and kaolin. *Journal of Plant Production Mansoura University. 5*(5), 779-792.

Jafari, S. 2014. Effect of growth regulators on seed firmness and some characteristics of pomegranate Yousef Khani cultivar. Master's Thesis. Faculty of Bu Ali Sina. Iran Hamedan. Iran.

Karami, K. 2016. Effects of gibberellic acid and zinc sulfate on control fruit cracking in pomegranate. Master's Thesis. Ilam University of Technology. Iran.

Khalaj, K., Ahmadi, N., & Souri M. K. (2015). Effect of calcium and boron foliar application on fruit quality in Asian pear cultivar 'KS10'. *Journal of Crop Production and Processing*, *4* (14) :89-97

Khalil, H. A., & Aly, H. S. (2013). Cracking and fruit quality of pomegranate (*Punica granatum* L.) as affected by pre-harvest sprays of some growth regulators and mineral nutrients. *Journal of Horticultural Science & Ornamental Plants*, *5*(2), 71-76.

Kishor, S., Maji, S., Meena, M., Deepa, H., Dwivedi, S. K., & Kumar, S. (2017). Effect of plant bio-regulators and chemicals on fruit physico-chemical traits of pomegranate (*Punica granatum* L.) cv. Bhagwa. *Journal of Pharmacognosy and Phytochemistry*, *6*(4), 1573-1575.

Kulkarni, A. P., & Aradhya, S. M. (2005). Chemical changes and antioxidant activity in pomegranate arils during fruit development. *Food Chemistry*, *93*(2), 319-324. https://doi.org/10.1016/j.foodchem.2004.09.029

Kumar, K., Joon, M., Yadav, R., & Daulta, B. (2016). Effect of Growth Regulators and Micronutrients on Fruit Quality in Pomegranate. *International Journal of Environment, Agriculture and Biotechnology*, *1*(4). https://doi.org/10.22161/ijeab/1.4.3

Lansky, E. P., & Newman, R. A. (2007). Punica granatum (pomegranate) and its potential for prevention and treatment of inflammation and cancer. *Journal of ethnopharmacology*, *109*(2), 177-206. https://doi.org/10.1016/j.jep.2006.09.006

Laribi, A., Palou, L., Intrigliolo, D., Nortes, P., Rojas-Argudo, C., Taberner, V., Bartual, J., & Pérez-Gago, M. (2013). Effect of sustained and regulated deficit irrigation on fruit quality of pomegranate cv.'Mollar de Elche'at harvest and during cold storage. *Agricultural Water Management*, *125*, 61-70. https://doi.org/10.1016/j.agwat.2013.04.009

Lombardo, G., Cargnello, G., Bassi, M., Gerola, F., & Carraro, L. (1978). Pollen ultrastructure in different vine cultivars with low productivity. *Vitis-Berichte ueber Rebenforschung mit Dokumentation der Weinbauforschung (Germany, FR).*

O'Kelley, J. C. (1957). Boron effects on growth, oxygen uptake and sugar absorption by germinating pollen. *American Journal of Botany*, *44*(3), 239-244. https://doi.org/10.1002/j.1537-2197.1957.tb08236.x

Ouzounidou, G., Ilias, I., Giannakoula, A., & Papadopoulou, P. (2010). Comparative study on the effects of various plant growth regulators on growth, quality and physiology of *Capsicum annuum* L. *Pakistan Journal of Botany*, *42*(2), 805-814.

Ozturk, B., Bektas, E., Aglar, E., Karakaya, O., & Gun, S. (2018). Cracking and quality attributes of jujube fruits as affected by covering and pre-harvest Parka and $GA_3$ treatments. *Scientia Horticulturae*, *240*, 65-71. https://doi.org/10.1016/j.scienta.2018.06.004

Paroussi, G., Voyiatzis, D., Paroussis, E., & Drogoudi, P. (2002). Growth, flowering and yield responses to GA3 of strawberry grown under different environmental conditions. *Scientia Horticulturae*, *96*(1-4), 103-113. https://doi.org/10.1016/S0304-4238(02)00058-4

Ranganna, S. (1977). Manual of analysis of fruit and vegetable products. New Delhi, Tata McGraw-Hill.

Rasheed, M. K. (2009). Role of boron in plant growth: a review. *Journal of Agricultural Research*, *47*(3), 329-338.

Safdary, A. J. (2015). Effects of gibberellic acid, 2, 4-diclorophenoxyacetic acid and potassium sulfate on fruit growth, shot berry and fruit quality of grapevine cv. Siah-e-Samarghandi. Master's thesis. Shiraz, Iran, Shiraz University.

Sardoei, A. S., Shahadadi, F., Vakili, M. A., & Gholamshahi, S. (2014). Effects of gibberellic acid (GA3) on phenolic compounds and antiradical activity of marigold (*Calendula officinalis*). *International Journal of Biosciences, 4*(3), 80-84.

Sarkhosh, A., Zamani, Z., Fatahi, R., & Ebadi, A. (2006). RAPD markers reveal polymorphism among some Iranian pomegranate (*Punica granatum* L.) genotypes. *Scientia Horticulturae*, *111*(1), 24-29. https://doi.org/10.1016/j.scienta.2006.07.033

Selah Varzi, Z,. Talai, A,. & Fatahi Moqadam, M. R. (2003). Investigation the effect of gibberllic acid on physicochemical properties and storage of pomegranate fruit cv. Shahnaz under low irrigation. *Horticulture Science*, *30,*- 2008-4730.

Shukla, H. S., Kumar, V., & Tripathi, V. K. (2011). Effect of gibberellic acid and boron on development and quality of aonla fruits' Banarasi'. *Acta Horticulturae*, *890*, 375-380.

Stone, H., & Sidel, J. L. (1985). Sensory evaluation practices. Academic Press. San Diego.

Tehranifar, A., & Mahmoudi Tabar, S. (2009). Foliar application of potassium and bron during pomegranate (*Punica granatum*) fruit development can improve fruit quality. *Horticulture, Environment, and Biotechnology*, *50*(3), 191-196.

Thurzo, S., Szabo, Z., Nyeki, J., Nagy, P. T., Silva, A. P., & Goncalves, B. (2008). Effect of boron and calcium sprays on photosynthetic pigments, total phenols and flavonoid content of sweet cherry (*Prunus avium* L.). *In VI International Symposium on Mineral Nutrition of Fruit Crops*, *868*, 457-462.

Tuan, N. M., & Chung–Ruey, Y. (2013). Effect of gibberellic acid and 2, 4-dichlorophenoxyacetic acid on fruit development and fruit quality of wax apple. *International Journal of Biology Food, Veterinary and Agriculture Engineering*, *7*(1), 28-36.

Turkmen, N., Sari, F., & Velioglu, Y. S. (2005). The effect of cooking methods on total phenolics and antioxidant activity of selected green vegetables. *Food Chemistry*, *93*(4), 713-718. https://doi.org/10.1016/j.foodchem.2004.12.038

Umar, S., Bansal, S., Imas, P., & Magen, H. (1999). Effect of foliar fertilization of potassium on yield, quality, and nutrient uptake of groundnut. *Journal of Plant Nutrition*, *22*(11), 1785-1795. https://doi.org/10.1080/01904169909365754

Voss, D. H. (1992). Relating colorimeter measurement of plant color to the Royal Horticultural Society Colour Chart. *Horticulture Science*, *27*(12), 1256-1260.

Wagner, G. J. (1979). Content and vacuole/extravacuole distribution of neutral sugars, free amino acids, and anthocyanin in protoplasts. *Plant Physiology*, *64*(1), 88-93.

Wang, Y., Lau, M., Tang, J. & Mao, R. (2004). Kinetics of chemical marker M-1 formation in whey protein gels for developing sterilization processes based on dielectric heating. *Journal of Food Engineering*. *64*(1), 111-118.

Weksler, A., Dagar, A., Friedman, H., & Lurie, S. (2009). The effect of gibberellin on firmness and storage potential of peaches and nectarines. *In VII International Peach Symposium*, *962* (pp. 591-595).

Wojcik, P., Wojcik, M., & Klamkowski, K. (2008). Response of apple trees to boron fertilization under conditions of low soil boron availability. *Scientia Horticulturae*, *116*(1), 58-64.

Xuan, H., Streif, J., & Bangerth, F. (2000). Effect of boron applications on physiological disorders in 'Conference'pears during CA-storage. *In IV International Conference on Postharvest Science*. *553* (pp. 249-254).

Yadav, A., Kumari, R., Yadav, A., Mishra, J. P., Srivatva, S., & Prabha, S. (2016). Antioxidants and its functions in human body-A Review. *Research in Environment and Life Science, 9*(11), 1328-1331.

Yadav, S., Shukla, H. S., & Ram, R. A. (2010). Studies on foliar application of NAA, GA3, Boric acid, and Ca (NO3) 2 on fruit retention, growth, yield and quality of Aonla (*Emblica officinalis Gaertn*.) cv. Banarasi. *Society for the Advancment of Horticulture*, *23*(2), 64-67.

Zohary, D., & Spiegel-Roy, P. (1975). Beginnings of fruit growing in the Old World. *Science*, *187*(4174), 319-327. https://doi.org/10.1126/science.187.4174.319