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ORIGINAL PAPER

Exogenous Pre-harvest Application of Abscisic and Jasmonic Acids Improves Fruit Quality by Enhancing Sugar Synthesis and Reducing Acidity in Pomegranate (*Punica granatum* L. cv. Wonderful)

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Abstract

One of the major issues with pomegranate production in arid and semi-arid climate is the white arils of fruit. The known plant regulators abscisic and jasmonic acids play a variety of roles in plant growth and the reduction of abiotic stresses. However, little is known about their application to improve the quality of pomegranate fruit, particularly white arils, in semi-arid environments. Herein, the experiments, in this study, were performed in two consecutive seasons 2020 and 2021 on 10-year-old Wonderful pomegranate trees to spotlight the improvement of the aril coloration and fruit quality by spraying with abscisic and jasmonic acids under semi-arid climatic conditions. Fifteen Wonderful pomegranate trees were subjected to five treatments (three replications for each). The tested treatments included abscisic acid (ABA) at the concentrations of 600 and 800 μg^{-1} mL, jasmonic acid (JA) at the concentrations of 10 and 15 Mm, and the control treatment (distilled water). The physical and chemical characteristics of the fruit quality of Wonderful pomegranate improved significantly when the trees were treated with abscisic or jasmonic acids. The foliar addition of ABA at 600 and 800 μg^{-1} mL increased the anthocyanin index by 96.74 and 114.75%, respectively, in the first year and by 49.48 and 67.62% in the second year, in comparison with the control. The foliar addition of ABA at 800 μg^{-1} mL was more effective than jasmonic acid in enhancing most of the chemical fruit properties, especially the anthocyanin index. The high level of ABA (800 μg^{-1} mL) gave the minimum fruit acidity and the highest fruit quality. Abscisic acid induces the fruit acidity and enhances the aril coloration in Wonderful pomegranate. In semi-arid conditions, it is recommended to spray the Wonderful pomegranate trees with abscisic acid at 800 μg^{-1} mL to improve the fruit quality and to increase the aril coloration.

Keywords Anthocyanin · Aril color · Plant growth regulators · Fruit quality · Post-harvest

1 Introduction

Worldwide, 6.3 million tons of pomegranate fruit are produced from a total area of half a million hectares (Sarkhosh et al. 2020). Essentially, pomegranate arils contain a substantial amount of sugars, organic acids, vitamins, polysaccharides, and essential minerals (Guillén et al. 2019; Tadayon and Hosseini 2021). Accordingly, pomegranate is well-known as "Super fruit" in the global functional food market for their numerous therapeutic uses such as cardiovascular diseases, type II diabetes, and anti-cancerogenic (Ramezanian et al. 2009; Mayuoni-Kirshinbaum and Porat 2014). Manfaloty and Wonderful are considered the major pomegranate cultivars that grown in Egypt (Hegazi et al. 2014). The cultivated area of pomegranate in Egypt is 33,816 ha, with a production of 672,064 tons in 2020, and this acreage is on the increase (Yearly Book of Statistics and Agricultural Economic Department 2020).

One of the major issues with pomegranate production is the lack of essential compounds, such as anthocyanin, which reduces the fruit's health-promoting qualities and affects the fruit's quality and marketability (Borochov-Neori et al. 2013). Latterly, researchers have exhibited an increased interest in enhancing pomegranate fruit quality and quantity

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by utilizing some growth regulators such as jasmonic and abscisic acids (Farag et al. 2018; García-Pastor et al. 2020; Asghari et al. 2020). Pomegranate producers in Upper Egypt suffer from a variety of production challenges, like fruit splitting, sunburn damage, and poor discoloration of arils and fruit skin (Attia 2017). Pomegranate fruit splitting is a common problem in other areas, including India, Iran, Tunisia, Turkey, Afghanistan, Greece, and Morocco (Salih 2018). Discoloration of the fruit skin is a consumer purchase incentive, and non-invasive measures for its determination are underway (Czieczor et al. 2018). Increasing the temperature of the skin and the inner fruit reduces the formation of anthocyanins and abscisic acid concentrations (Kataoka et al. 1984; Farag et al. 2018). Once the temperature rises, constitutive photomorphogenic 1 (COP1) is transported to the nucleus and destabilizes hypocotyl 5 (HY5), reducing anthocyanin biosynthesis (Liu et al. 2021).

Jasmonic acid (JA) is a plant hormone involved in various physiological and biochemical processes in plants, specifically seed germination, root growth, senescence, tendril coiling, phenolic production, pollen viability, tuber formation, organogenesis, male fertility, defense responses, fruit ripening, and ethylene production (An et al. 2019; Asghari et al. 2020; Abeed et al. 2021). Plus, it is considered a safe compound with no restrictions on its use to promote the quality of food crops (McCarthy 2013; Asghari et al. 2020). Exogenous methyl jasmonate boosts the biosynthesis of ethylene, anthocyanins, carotene, ascorbic acid, and also antioxidant activity in many types of fruits, resulting in a favorable impact on quality attributes (Wei et al. 2017). Jasmonic acid mitigated the aging effects that are characterized by a severe loss of chlorophyll, rises in respiratory rate, and peroxidase and protease activities (Koda 1992). In addition to that, jasmonic acid contributes significantly to the color of grape berries by raising the transcription levels of various color-associated genes (Jia et al. 2016). The commercial formulation of JA is registered almost worldwide to enhance the coloration of red grapes (Jia et al. 2016; Wei et al. 2017).

Abscisic acid (ABA) is a plant growth regulator (PGR) that plays an essential role in regulating environmental stress responses and plant growth and development, as well as fruit ripening (Chen et al. 2020). In this interim, a few studies focused on ABA effects on pomegranate fruit quality attributes and coloration (Attia 2017; Farag et al. 2018). The primary roles that ABA affects fruit maturity are by closing stomata and influencing the amount of carbohydrates in plants (Bound 2022). The main function of abscisic acid in promoting fruit ripening is due to increasing sugar content and reducing indole-3-acetic acid levels (Jia et al. 2017). Raised levels of abscisic acid cause remarkable increases in total soluble solids, anthocyanins, and sugars during fruit maturation (Owen et al. 2009). Treating of grape vines with abscisic acid accelerated both the accumulations of fructose and glucose in grape clusters (Murcia et al. 2016). Abscisic acid stimulates the genes responsible for sugar and anthocyanin formation, i.e., VvHT6 and VvHT2, as well as improves the leaf sucrose content and phloem area (Jeong et al. 2004; Murcia et al. 2016). ABA increases the color appearance of fruits and is used routinely in different grapevine cultivars (Lurie et al. 2009; Balbontínet al. 2018).

High temperatures during the pomegranate fruit's formation in arid and semi-dry environments degrade the fruit's quality, particularly the coloration of the arils (Joshi et al. 2021).

Although abscisic and jasmonic acids are known as plant growth regulators, not much information is available about the use of them in improving the fruit quality of pomegranate in semi-arid conditions. Thus, this study spotlighted on the improvement of the aril coloration and fruit quality of Wonderful pomegranate under semi-arid climatic conditions by spraying with abscisic and jasmonic acids. The current study hypothesizes that spraying pomegranate fruits with abscisic and jasmonic acids will influence the formation of anthocyanin pigments and improve the fruits' quality by controlling their acidity.

2 Materials and Methods

2.1 Experimental Site and Field Trials

The field experiments were performed in two consecutive seasons of 2020 and 2021 on 10-year-old pomegranate (*Punica granatum* L. cv. Wonderful). The orchard is located at the experimental station of Assiut University, Faculty of Agriculture, Assiut, Egypt (27° 11′ 02″ N, 31° 09′ 42″ E m above sea level). The trees were grown in a clay loam soil at 5 × 5 m apart and acquired the optimal horticultural practices that were adopted in the orchard. According to Assiut Agrometeorological Station, Assiut, Egypt, the experimental site is characterized by a hot, dry climate in summer and a cold climate in winter without rainfall and a relative humidity of 40–45%. The maximum and minimum temperatures of the experimental site range between 28–34 and 15–20 °C, respectively. Figure 1 A and B show the main climatic conditions of the experimental site during 2020 and 2021. The soil of the experimental site is clay loam and classified as Entisols: Typic Torri Fluvents (Soil Survey Staff 2014).

The trial consisted of five treatments of foliar spraying with abscisic and jasmonic acid and was conducted in a completely randomized block design (CRBD) with three replicates. Fifteen Wonderful pomegranate trees (five treatments × three replications), which were uniform in vigor and growth, were designated for this investigation. The examined treatments were as follows: control (distilled water), abscisic acid (ABA) at 600 and 800 μg^{-1} mL, and jasmonic acid (JA) at 10 and 15 mM. The spraying solutions of abscisic and jasmonic acids were prepared by dissolving the weight of each

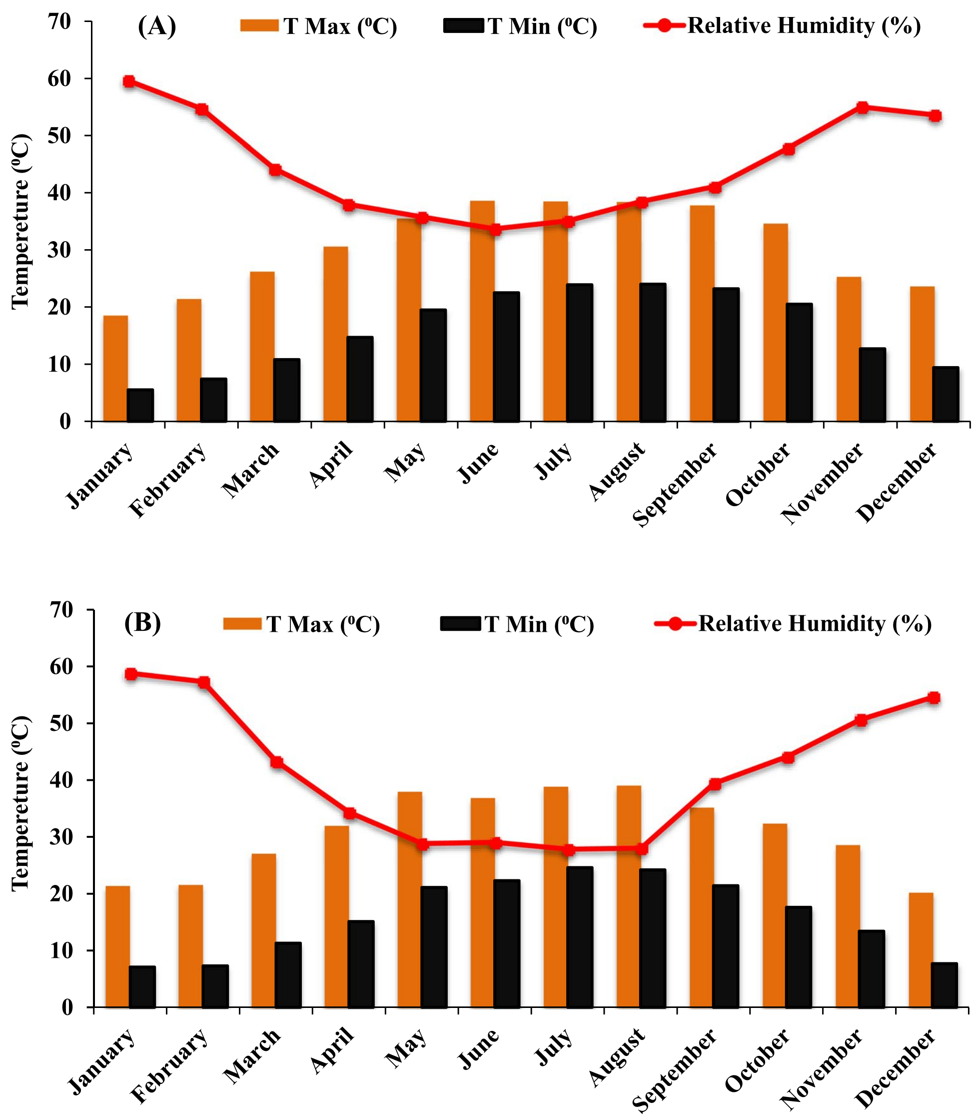


Fig. 1 Climatic conditions of the experimental site according to Assiut Agrometeorological Station, Assiut, Egypt. **A** The first season (2020) and **B** the second season (2021). T Max and T Min are the maximum and minimum temperature, respectively

treatment in the distilled water with the addition of Tween-20 (2 mL L^{-1}) to the foliar solution to help it pass through the leaf stomata. A hand-held sprayer was used to apply 4 L $tree^{-1}$ of the spraying solution to the plants 3 weeks before fruit harvest, which was done on 15th of October each year.

2.2 Physical and Chemical Fruit Properties

At harvest, a sample of five fruits/tree from each replication was randomly collected in both studied seasons and then transferred to the laboratory of Pomology Department, Faculty of Agriculture, Assiut University, Egypt, to assess the specific physical and chemical fruit properties as follows: fruit weight (g) was determined; fruit length and diameter (mm) by using a digital vernier caliper; fruit L/D ratio was calculated by dividing fruit length on fruit diameter, aril weight (g), and fruit peel percentage (%). Plus, the anthocyanin index in the aril was determined based on the method described by Onayemi et al. (2006). Five grams of each aril sample was ground in 20 mL of methanolic HCL (85 parts of 99.9% methanol and 15 parts of 1.5 N HCL), and these extracts were held in the deep freeze for 48 h. After 48 h, the extracts were supplemented to a volume of 50 mL with solvent, and the anthocyanin content was measured by a spectrophotometer (Unico 1200-USA) at 530 nm. The total soluble solids percentage (TSS %) was recorded by using a manual refractometer (model N-1E, Atago, Japan, 0–32% range) according to Chen and Mellenthin (1981). Moreover, total acidity (%) was assessed and then expressed as citric acid (as the dominant organic acid in pomegranate) based on A.O.A.C. (1995). It was specified by titrating 5 mL of clear pomegranate juice with a 0.1 M NaOH solution after adding a few drops of phenolphthalein as an indicator, and TSS/acid ratio was calculated by dividing. The pH of fruit juice was recorded by using a portable digital pH meter, according Saeed and Al-Tinawi (2010).

2.3 Statistical Analysis

Data presented in this study was statistically pooled and analyzed according to Snedecor and Cochran (1980), and the mean values were compared using the least significant differences (L.S.D.) at 5%. Principal component analysis (PCA) and correlation matrix analysis between traits were run by Past software version 4.06.

3 Results

3.1 Physical Fruit Properties

The effects of the two plant growth regulators, i.e., abscisic acid (ABA) and jasmonic acid (JA), were assessed on certain physical fruit properties of Wonderful pomegranate (*Punica granatum* L.) and the data are shown in Table 1 and Fig. 2. The results shown in Fig. 2 illustrated that ABA and JA treatments significantly increased the fruit weight compared to the control. Data presented in Table 1 revealed that, in 2020, exogenous application of ABA at 800 μg^{-1} mL and JA at 15 mM significantly increased the fruit length as compared to the untreated fruits (control). In contrary, all the different treatments had a positive impact and increased the fruit length significantly as compared with the control during 2021 season.

The results in Table 1 exhibited that ABA at 800 μg^{-1} mL significantly increased the fruit diameter over the control during the first season of 2020. The increment percentage of fruit diameter over unsprayed trees (control) was 12% as a result of spraying ABA at 800 μg^{-1} mL. However, in 2021, all of the spraying treatments significantly increased the fruit diameter as compared to the control. Moreover, in 2021, fruit treated with ABA at 800 μg^{-1} mL, JA at 15 mM, and ABA at 600 μg^{-1} mL exhibited 70%, 70%, and 64% higher aril weight than the control, respectively.

Data in Table 1 revealed that peel weight was increased statistically over the control by all the sprayed treatments during both seasons (Table 1). The highest peel weight value was gained from ABA at 600 μg^{-1} mL (160 g) treatment in 2020 season. Meanwhile, in 2021, the highest peel weight value was noticed with ABA at 800 μg^{-1} mL (158 g) treatment. In general, the lowest value of this parameter was

Table 1 Effect of abscisic acid (ABA) and jasmonic acid (JA) on fruit weight, fruit length, fruit diameter, aril weight, and peel weight of Wonderful pomegranate during 2020 and 2021 seasons. Means (± SD) with similar letters are not significantly different based on the least significant differences (L.S.D.) at 5%. The spraying was done 3 weeks before fruit harvest

Treatments	Fruit length (mm)		Fruit diameter (mm)		Aril weight (g)		Peel weight (g)	
	2020	2021	2020	2021	2020	2021	2020	2021
ABA 600 μg^{-1} mL	84.4 ± 2.5AB	74.5 ± 2.6B	91.9 ± 2.8A	84.1 ± 2.9B	251 ± 18A	200 ± 22A	160 ± 12A	105 ± 10C
ABA 800 μg^{-1} mL	85.6 ± 3.1A	80.6 ± 3.5A	94.0 ± 3.2A	92.7 ± 2.6A	279 ± 22A	207 ± 16A	149 ± 17A	158 ± 12A
JA 10 mM	83.6 ± 2.2AB	74.3 ± 3.5B	91.4 ± 2.6A	82.1 ± 3.7B	249 ± 16A	165 ± 12B	151 ± 16A	128 ± 6B
JA 15 mM	85.3 ± 2.5A	80.3 ± 3.2A	92.4 ± 2.7A	85.5 ± 2.0B	264 ± 15A	207 ± 16A	151 ± 12A	148 ± 9A
Control	76.4 ± 2.7 B	64.9 ± 2.5C	84.0 ± 2.4B	72.9 ± 3.0C	217 ± 16B	122 ± 12C	89 ± 6B	73 ± 5D

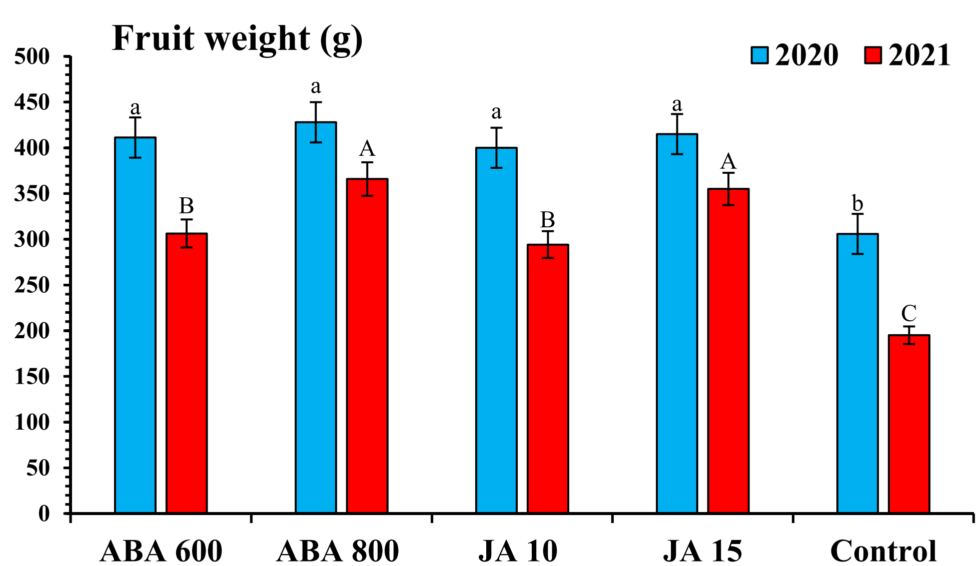


Fig. 2 Effect of abscisic acid (ABA at 600 and 800 μg^{-1} mL) and jasmonic acid (JA, 10 and 15 mM) on fruit weight of Wonderful pomegranate during 2020 and 2021 seasons. Means (± SD) with similar letters are not significantly different based on the least significant differences (L.S.D.) at 5%. The spraying was done 3 weeks before fruit harvest

figured out by the control in both seasons (89 g and 73 g, respectively). In general, spraying of pomegranate fruit with abscisic and jasmonic acids enhanced the physical fruit characteristics.

3.2 Chemical Fruit Properties

The total soluble solids (TSS) and total acidity (TA) in pomegranate fruit responded to the foliar application of abscisic and jasmonic acids (Table 2). Data revealed that all the spraying treatments increased the TSS compared to the control during the two studied seasons, and ABA at 800 μg^{-1} mL was the best treatment in this respect, followed by ABA at 600 μg^{-1} mL and JA at 15 mM, respectively. ABA at 800 μg^{-1} mL increased the TSS by over the control 11 and 15%, respectively, in the first and second year. The total acidity decreased significantly as a result of the spraying with ABA (Table 2). The data illustrated that ABA at 800 μg^{-1} mL presented the highest value of TSS/TA, followed by ABA at 600 μg^{-1} mL, while the control treatment was the lowest value. The values of these treatments were 19:1, 15:1, and 12:1 as an average of the two seasons, respectively. The data of the pH of the fruit juice (Fig. 3) stated ABA at 800 μg^{-1} mL gave the highest pH values (3.67 and 3.77), followed by ABA at 600 μg^{-1} mL which gave (3.57 and 3.70), while the lowest values were gained from the control treatment (3.47 and 3.57) during the two seasons, respectively.

The anthocyanin index in Wonderful pomegranate fruit was significantly affected by the exogenous application of abscisic and jasmonic acids (Fig. 4). According to anthocyanin values, the results revealed that ABA at 800 μg^{-1} mL surpassed most of the other spraying treatments. The foliar addition of ABA at 600 and 800 μg^{-1} mL increased the anthocyanin index by 97 and 115% and 50 and 68%, respectively, in the first and second year, in comparison with the control. The foliar addition of ABA at 600 and 800 μg^{-1} mL is more effective than jasmonic acid in enhancing most of the chemical fruit properties, especially the anthocyanin index.

3.3 Correlation Analysis Among the Measured Results

According to the correlation matrix (Fig. 5) and principal compound analysis (Fig. 6), the total acidity (TA) had a significant negative correlation with the fruit weight (FW),

Table 2 Effect of abscisic acid (ABA) and jasmonic acid (JA) on total soluble solids (TSS), total acidity (TA), and total soluble solids/acid ratio (TSS/TA) of Wonderful pomegranate during 2020 and 2021 seasons. Means (±SD) with similar letters are not significantly different based on the least significant differences (L.S.D.) at 5%. The spraying was done 3 weeks before fruit harvest

Treatments	TSS%		TA%		TSS/TA	
	2020	2021	2020	2021	2020	2021
ABA 600 μg^{-1} mL	16.1 ± 1.1AB	18.6 ± 1.2A	0.98 ± 0.05B	1.34 ± 0.08C	16.8 ± 0.2AB	14.0 ± 0.8AB
ABA 800 μg^{-1} mL	16.7 ± 1.5A	18.9 ± 1.0A	0.76 ± 0.08C	1.24 ± 0.12D	21.9 ± 0.2A	15.5 ± 1.1A
JA 10 mM	15.9 ± 0.5AB	17.1 ± 0.6B	1.07 ± 0.15AB	1.54 ± 0.09B	14.8 ± 0.1B	11.2 ± 1.5B
JA 15 mM	15.9 ± 0.6AB	17.5 ± 1.1B	1.02 ± 0.18AB	1.35 ± 0.08C	15.9 ± 0.2B	13.6 ± 1.1AB
Control	15.1 ± 0.6B	16.4 ± 0.8B	1.17 ± 0.08A	1.60 ± 0.12A	13.7 ± 0.1B	10.7 ± 1.2B

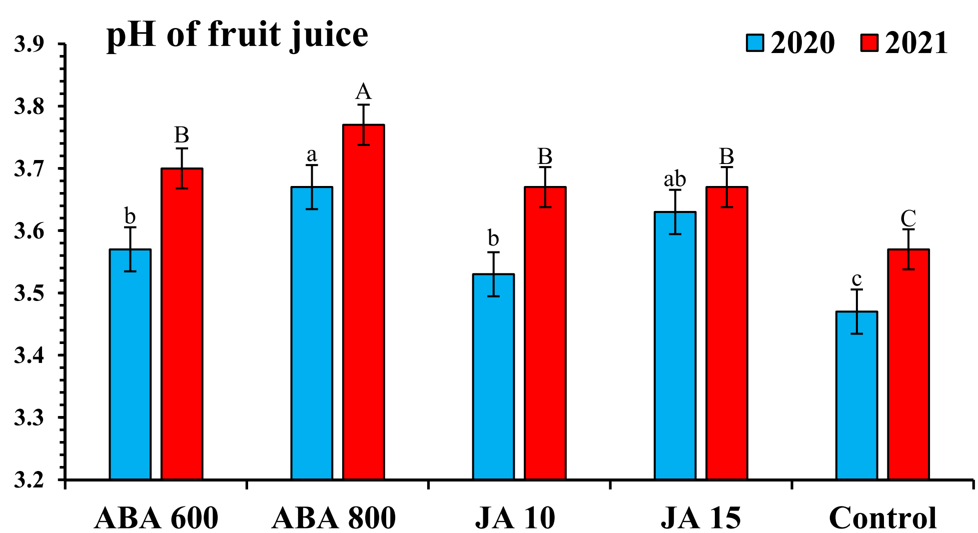


Fig. 3 Effect of abscisic acid (ABA at 600 and 800 μg^{-1} mL) and jasmonic acid (JA, 10 and 15 mM) on pH of Wonderful pomegranate fruit during 2020 and 2021 seasons. Means (±SD) with similar letters are not significantly different based on the least significant differences (L.S.D.) at 5%. The spraying was done 3 weeks before fruit harvest

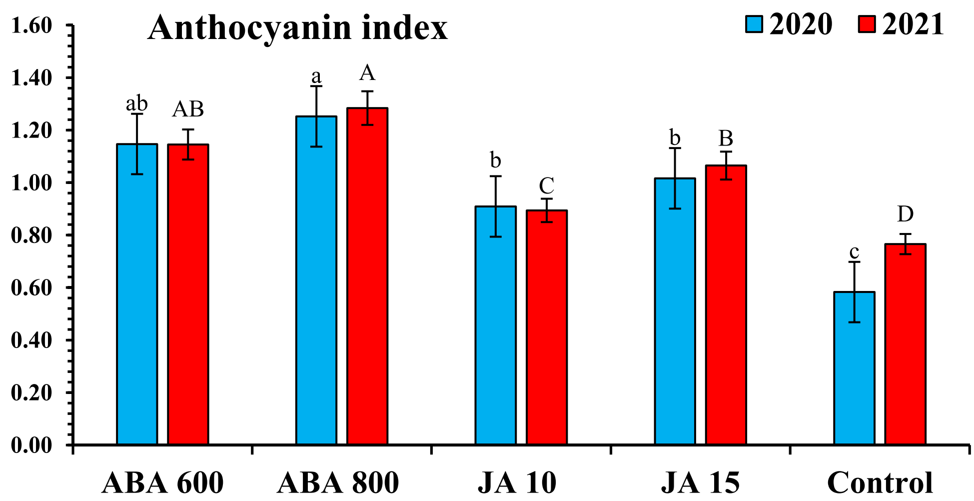
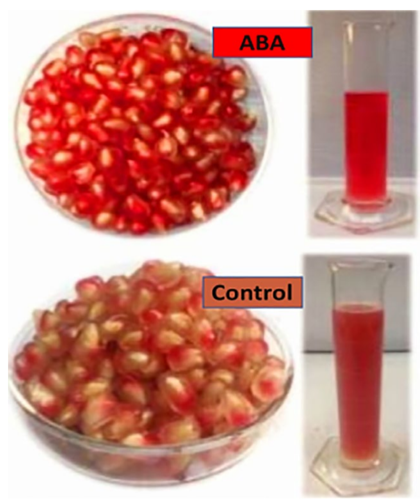


Fig. 4 Effect of abscisic acid (ABA at 600 and 800 μg^{-1} mL) and jasmonic acid (JA, 10 and 15 mM) on anthocyanin index of Wonderful pomegranate during 2020 and 2021 seasons. Means (± SD) with similar letters are not significantly different based on the least significant differences (L.S.D.) at 5%. The spraying was done 3 weeks before fruit harvest



fruit diameter (FD), fruit length (FL), and aril weight (AW). Anthocyanin index (AI) was affected negatively by increasing the TA, while it was increased positively with increasing the pH, TSS/TA, PW, FD, AW, and FW.

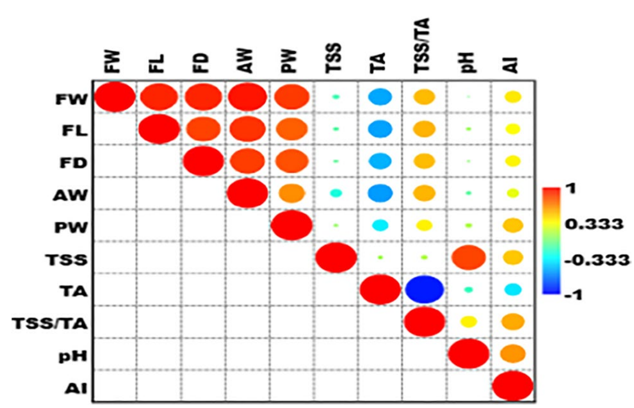


Fig. 5 Correlation matrix between some plant traits. FW, fruit weight; FL, fruit length; FD, fruit diameter; AW, aril weight; PW, peel weight; TSS, total soluble solids; TA, total acidity; TSS/TA, total soluble solids/acid ratio; pH, pH; AI, anthocyanin index

4 Discussion

In general, the results clearly illustrated that abscisic acid (ABA) application specifically at 800 μg^{-1} mL increased the fruit weight, aril, and peel weight, plus the fruit dimensions of pomegranates. The addition of ABA to Seedless grapes, increased the berry weight, length, and diameter (Peppi and Fidelibus 2008; Lurie et al. 2009). In agreement with our findings, Farag et al. (2018) stated that the application of ABA individually on Wonderful pomegranates led to a significant increase in the fruit weight, fruit length and diameter, peel weight, and granule weight. The effects of ABA on the fruit weight depend on timing, dose, and kind of fruit (Balbontín et al. 2018). The increases in the fruit yield component were directly related to water accumulation in the

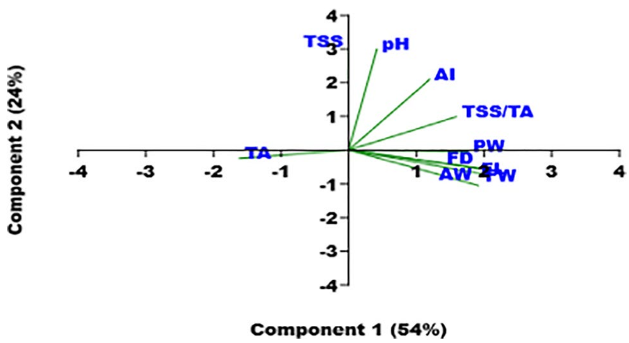


Fig. 6 Principal component analysis (PCA) between some plant traits. FW, fruit weight; FL, fruit length; FD, fruit diameter; AW, aril weight; PW, peel weight; TSS, total soluble solids; TA, total acidity; TSS/TA, total soluble solids/acid ratio; pH, pH of the juice; AI, anthocyanin index

fruits as a result of the application of ABA (Mohamed et al. 2019). However, ABA has not been elucidated to directly affect the fruit dimensions but rather to maintain cell turgor pressure, which increases the available water that could be used to raise the photosynthetic capacity and carbohydrate distribution in fruit (Farag et al. 2018).

It is clear from our results that abscisic acid had demonstrated a positive effect on the fruit quality of Wonderful pomegranates. In order to produce pomegranates with a higher sensory quality, it is necessary to have lower total acid levels and higher soluble solid levels, which enhance the fruit sweetness (Reynolds et al. 2013; Wang et al. 2016; Attia 2017; Neto et al. 2017). Plus, fruits of the pomegranate with a higher total soluble solids/acid ratio value have a sweeter flavor and are also favored by consumers, leading to greater marketability (Fawole and Opara 2013; Asghari et al. 2020). ABA improved the fruit qualitative attributes, i.e., TSS, TSS/TA, and total anthocyanin content, as well as increased productivity. These effects of ABA could be due to its crucial role in promoting fruit ripening and anthocyanin content (Agarwal et al. 2005). Besides, the increment in TSS in the fruits is also an outcome of the increased rate of photosynthesis (Wang et al. 2009). Furthermore, the increasing concentration of anthocyanin was an outcome of improved phenylalanine ammonia lyase (PAL) activity and UFGT expression (Peppi et al. 2008).

Our findings revealed that jasmonic acid (JA) enhanced the quantitative parameters of Wonderful pomegranate fruit as well as its dimensions. It has been revealed that JA, particularly in pomegranates, plays a vital role in various development and growth processes, leading to increased fruit growth processes as a result (Asghari et al. 2020). Fruit aril and peel weight increases emphasized that a rise in fruit peel diameter in a clear response to JA application did not occur at the expense of a reduction in pomegranate yield, and it appears here that this might be due to an increase in photosynthetic capacity in plants (Asghari et al. 2020). Water plays an important role in photosynthesis and cell division; the fruit's growth rate and productivity are reduced by any water shortages during the stages of growth (Asghari et al. 2020). Furthermore, JA plays essential roles in closing the stomata, increasing production of the cuticle and peel, and providing an efficient protection system versus water stress, particularly under stressed-out conditions such as those in pomegranate production regions (De Ollas et al. 2015; Asghari 2019). Stomatal closure occurs immediately after water stress in plants with higher jasmonate content, owing to the impact on the mechanism of calcium signaling (Mayuoni-Kirshinbaum and Porat 2014). Additionally, an increase in the fruit peel and cuticle actually results in the constraint of gas interchange among the fruit and its surrounding environment, leading to a reduction in the rate of respiration and water loss (Fawole and Opara 2013).

Importantly, jasmonates can stimulate biosynthesis of phytochemical, enhance fruit quality, activate the concerned genes, and interpose abscisic acid impacts (De Ollas et al. 2015; Balbontín et al. 2018; Asghari et al., 2020). In this interim, these findings are consistent with those found by Avanci et al. (2010) and Soltekin et al. (2015), who exhibited that the rise in bunch weight as a result of using jasmonic acid may be due to increases in plant hormones and carbohydrates, as well as being reflected on its length. Plus, Sabry et al. (2011) declared that spraying berries with jasmine oil at 0.2% resulted in the highest values of physical characteristics. Furthermore, Rudell et al. (2005) confirmed that the fruit size in apples with the application of JA increased through promoting cell division. Our results correspond in harmony with data claimed by Asghari et al. (2020) on the Rabab pomegranate cultivar. They concluded that methyl jasmonate had positive effects on increasing the fruit fresh weight and aril and peel weight. Literally, it was noticed that the response of the fruit to JA treatment may be attributed to the variations in fruit developmental stages (Fan et al. 1997). Furthermore, pre-harvest parameters, for instance, genotype, agro-climate and seasonal variation, cultural practice, and maturity stage at harvest, have an impact on the content of bioactive chemicals (Mphahlele et al. 2014). In this regard, the impacts of JA on the fruiting of pomegranate trees in this study are consistent with those obtained by Asghari et al. (2020) and Garcia-Pastor et al. (2020). They reported that spraying JA boosted the fruit quality of different pomegranate cultivars. JA improved the retention of quality attributes of pomegranates and delayed the development of senescence (Guillén et al. 2019). On the other hand, similar results were attained with these by Mirdehghan et al. (2012) and Vatanparast et al. (2012) that stated that JA improved TA, pH, and aril color of pomegranate fruit, but the differences were not significant as compared with control, while application of JA at the fruit color change stage reduced the SSC/TA ratio, which is consistent with other studies in peach and sweet cherry (Ziosi et al. 2008; Saracoglu et al. 2017).

The high level of ABA gave the lowest value of the fruit acidity (TA) and significantly improved the other fruit quality indexes. The obtained results revealed that ABA induced the fruit acidity which controls the other fruit quality indicators. According to the principal component analysis (PCA), increasing the total acidity decreased the other fruit quality parameters. In this interim, the decrease in the acidity can also be considered a sequence of the entry of organic acids as respiratory components and the dilution process used to increase the cellular juice inside the fruits (McCollum et al. 1988; Mphahlele et al. 2016; Abu-Goukh and Almahi 2017; Enaru et al. 2021; Liu et al. 2021). Additionally, the anthocyanins had the highest value when the amount of ABA was high, and the PCA analysis showed that the anthocyanins were adversely affected by the total acidity of the fruit. Anthocyanins can combine with other cellular components, and such combinations may explain some of the impacts of color in fruits (Liu et al. 2021). Moreover, the presence of an acidic taste at the stage of full maturity is due to the high acidity of the juice. Under high acidity, the stability of anthocyanins decreases, and in alkaline solutions, their color turns blue and colorless (Abu-Goukh and Almahi 2017; Enaru et al. 2021; Liu et al. 2021; McCollum et al. 1988 and Mphahlele et al. 2016).

5 Conclusion

Pomegranate production in arid and semi-arid regions faces difficulty due to high air temperatures and needs agricultural treatments that improve the quality of the fruits under these harsh climatic conditions. Abscisic acid is able to improve the fruit quality of pomegranate. Abscisic acid controls the acidity of the fruit and enhances the coloration of the arils of pomegranate fruit. To sum up, it could be concluded that spraying of abscisic acid at 800 μg^{-1} mL 3 weeks before harvest was effective in improving fruit weight, quality, and aril coloration of Wonderful pomegranate cultivar under semi-arid climatic conditions. Therefore, further studies should be conducted to define the influence of abscisic acid and jasmonic acid treatments on aril coloration and the quality of pomegranate fruit with regard to varieties and to identify the optimum application time and concentrations of abscisic acid and jasmonic acid.

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Declarations

Conflict of Interest The authors declare no competing interests.

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