Effect of climatic factors, gibberellic acid, mineral nutrients concentration on fruit splitting of Washington Navel orange and pomegranate (Punica granatum L.) in Egypt

تأثير العوامل المناخية ، و حمض الجبرلين ، و تركيز العناصر الغذائية على تشقق الثمار فى محصولى البرتقال "ابوسرة واشنطن " و الرمان فى مصر

By

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Abstract

A field experiment was conducted during the 2019–2020 and 2020–2021 seasons in private orchards of Washington Navel orange (*C. sinensis*) budded on sour orange (*C. aurantium*) rootstocks (20 years old) in Al-Dakahlia Governorate and Wonderful pomegranate (10 years old) in Al-Behera Governorate, Egypt. At the start of the study, the percentage of fruit splitting was assessed in four directions (north, east, west, and south) and at three canopy positions (upper, middle, and lower). Samples of Washington Navel orange and Wonderful pomegranate fruits, with and without splitting symptoms, were collected to determine calcium (Ca) and boron (B) content in the fruit peels. The experiment aimed to evaluate the effects of calcium chloride, boric acid and gibberellic acid on fruit splitting and fruit quality. Twenty-five trees of each fruit species were divided into five groups, and each group was sprayed three times at full bloom, 30 days and 60 days after full bloom with one of the following treatments: 150 ppm GA_3, 2.0% calcium chloride ($CaCl_2 \cdot 2H_2O$), 0.3% boric acid (H_3BO_3) and 150 ppm GA_3 + 2.0% $CaCl_2 \cdot 2H_2O$ + 0.3% boric acid. The results revealed that the highest rates of fruit splitting occurred in July, coinciding with high temperatures, intense solar radiation, and low relative humidity. Fruit splitting was more prevalent on the southern side and the lower canopy portion. Higher concentrations of calcium and boron were detected in the peels of non-split fruits compared to split ones. The combined treatment of 150 ppm GA_3, 2.0% $CaCl_2 \cdot 2H_2O$, and 0.3% boric acid was the most effective in reducing fruit splitting and enhancing yield and fruit quality of Washington Navel oranges and Wonderful pomegranates.

Therefore, this treatment is recommended to reduce fruit splitting and improve yield and quality parameters of Washington Navel orange and Wonderful pomegranate under experiment conditions.

Key words: climatic factors, gibberellic acid, calcium, boron, splitting, Washington' Navel orange, pomegranate

المستخلص:

أجريت تجربة حقلية خلال الموسمين ٢٠١٩-٢٠٢٠ و٢٠٢٠-٢٠٢١ في بساتين خاصة مزروعة باشجارالبرتقال ابوسرة واشنطن (عمر٢٠ سنة) (*C. sinensis*) مطعم على أصول البرتقال البلدى المالح (*C. aurantium*) بمحافظة الدقهلية، و الرمان وندرفل (عمر ١٠ سنوات) بمحافظة البحيرة، مصر. قبل البدء فى التجربة تم تقديرنسبة تشقق الثمار في الأربعة اتجاهات للشجرة (الشمال، الشرق، الغرب، الجنوب) وفي الثلاثة أجزاء موضعية (أعلى، وسط، وأسفل) للشجرة. تم اخذ عينات من ثمار البرتقال سرة واشنطن والرمان وندرفل مع وبدون أعراض للتشقق وذلك لتقديرمحتوى قشرتها من الكالسيوم والبورون. لدراسة تأثير الرش بالكالسيوم ، والبورون، و GA_3 على الاصابة بالتشقق وانتاجية وجودة ثمار البرتقال ابو سرة واشنطن والرمان وندرفل. خمسة وعشرين شجرة من البرتقال ابو سرة واشنطن والرمان وندرفل اختيرت عشوائياً و قسمت الى خمس مجموعات كل مجموعة رشت ثلاث مرات (عند الإزهار الكامل ، بعد ٣٠ و ٦٠ يومًا من الإزهار الكامل) بالماء المقطر(الكنترول)، و حمض الجبرليك بتركيز ١٥٠ جزء فى المليون، و كلوريد الكالسيوم بتركيز ٢ % ، و حمض البوريك بتركيز ٠.٣ % ، و١٥٠ جزء في المليون من حمض الجبريليك + ٢ % كلوريد الكالسيوم + ٠.٣ % حمض البوريك. اوضحت النتائج ان اعلى نسبة تشقق لثمار البرتقال ابوسرة و الرمان وندرفل كانت فى شهر يوليو عند ارتفاع درجة حرارة الهواء و الإشعاع الشمسي، وانخفاض الرطوبة النسبية. كما اضهرت النتائج ان اعلى نسبة تشقق قد سجلت فى الجهة الجنوبية من الشجرة عن الجهات الاخرى، و فى الجزء السفل من الشجرة خاصة فى المترالاول من الكانوبى كانت اعلى منها فى الجزء العلوى من الشجرة. قشرة الثمار السليمة (بدون أعراض للتشقق) احتوت على تركيزات أعلى من الكالسيوم و البورون في مقارنة بقشرة الثمار المصابة بالتشقق. ادى الرش بالمعاملة التى استخدم فيها ١٥٠ جزء في المليون من حمض الجبريليك + ٢ % كلوريد الكالسيوم + ٠.٣ % حمض البوريك تقليل الاصابة بتشقق الثمار كما حسنت إنتاجية وجودة الثمار مقارنة

بالمعاملات الاخرى. لذلك يوصى برش أشجار برتقال سرة واشنطن والرمان الوندرفل بالمعاملة السابقة لمنع حدوث التشقق و تحسين انتاجية و جودة الثمار.

الكلمات المفتاحية: العوامل المناخية، حمض الجبريليك، الكالسيوم، البورون، التشقق، برتقال ابو سرة واشنطن ، الرمان.

Introduction

Fruit splitting or cracking is a major pre-harvest physiological disorder affecting the Washington Navel orange (*Citrus sinensis* L. (Osbeck) and pomegranate (*Punica granatum* L.) industries, resulting in significant economic losses and reducing commercial value. This issue can lead to annual yield reductions of up to 30% (El-Sayed, 2016 and El-Akkad *et al.*, 2016). Factors contributing to fruit splitting include environmental factors, nutritional deficiencies, and imbalances in plant growth regulators (Abdelrahman, 2010; Singh *et al.,* 2020; Krajewski *et al.,* 2022). Environmental factors such as high temperatures, intense soil radiation, elevated transpiration rates, low relative humidity, and significant day-night temperature fluctuations during fruit development are closely linked to splitting (Abdelrahman, 2010, Khub, 2014 and Li and Chen, 2017).

Nutritional deficiencies, particularly in calcium (Ca) and boron (B), are directly associated with fruit splitting in oranges and pomegranates (Singh *et al.*, 2020 and Krajewski *et al.*, 2022). Calcium and boron play essential roles in maintaining cell wall integrity and plasma membrane function by interacting with pectic polymers in the cell wall matrix (Singh et al., 2012). Fruits with higher calcium and boron levels in their peel exhibit greater firmness, stronger cell walls, and reduced susceptibility to splitting (Masoud *et al.,* 2019 and Morwal and Das, 2021).

Additionally, endogenous plant growth regulators influence fruit splitting. Studies by Peng *et al.* (2001) and Sekse *et al.* (2005) indicate that gibberellic acid (GA_3) can mitigate fruit splitting by delaying fruit maturity, enhancing peel elasticity, increasing the deposition of stratum corneum components, reducing the activity of pectin methylesterase (PME) and polygalacturonase (PG), and improving cell wall plasticity and fruit hardness. The combined application of GA_3, calcium, and boron has been found effective in reducing fruit splitting severity in several crops, including litchi (*Litchi chinensis* Sonn.) (Singh *et al.,* 2022), lemon (*Citrus limon* L. cv. Eureka) (Devi *et al.,* 2018), sweet cherry (*Prunus avium* L.) (Dong *et al.,* 2019), grapes (*Vitis vinifera* L. cv. Muscat Hamburg) (Parthiban *et al.,* 2021), mandarin (*Citrus reticulata*) (Kaur *et al.,* 2024), 'Okitsu no. 58' citrus fruit (Wang *et al.,* 2024), and Lane Late Navel orange (Shi *et al.,* 2024).

Given the severity of the problem, this study aimed to evaluate the individual and combined effects of calcium, boron fertilization, and gibberellic acid treatment on fruit splitting, yield, and quality in Washington Navel orange and Wonderful pomegranate, two of Egypt's most commercially significant fruit crops.

Material and methods

A field experiment was conducted during the 2019–2020 and 2020–2021 seasons in private orchards of Washington Navel orange (*Citrus sinensis*) trees budded onto sour orange (*Citrus aurantium* L.) rootstocks (20 years old) located in Al-Dakahlia Governorate, Egypt (31.15° N latitude, 31.49° E longitude, 2.89 m altitude) and Wonderful pomegranate (*Punica granatum* L.) trees (10 years old) were studied in Al-Behera Governorate, Egypt (30.47° N latitude, 30.09° E longitude, 94.5 m altitude). The planting distances were 5 m × 5 m for the orange trees and 4 m × 4 m for the pomegranate trees. In both orchards, the experimental trees were managed under uniform fertilization, irrigation, and pest control practices as recommended by the

Egyptian Ministry of Agriculture and Land Reclamation. Details of the soil's physicochemical properties at the experimental sites are provided in Table 1.

Table (1): Physical and chemical characteristics of orange and pomegranate orchards soil.

Soil attributes	Orange	Pomegranate
Sand (%)	25.00	90.50
Silt (%)	25.50	2.700
Clay (%)	49.500	6.8
Soil texture	clay/ loamy	Sandy
Field capacity (%)	36.00	16.00
Saturation (%)	72.00	32.00
Organic matter (g/kg)	13.50	2.90
pH	7.90	8.00
EC, dS/m	2.99	1.34
Available N (mg/kg)	53.60	23.20
Available P (mg/kg)	11.40	3.50
Available K (mg/kg)	224.90	112.50

Agro-meteorological data, such as maximum and minimum temperatures (°C), relative humidity (%), and solar radiation (MJ/m²/day), were collected from January to December during the 2020 and 2021 seasons from weather stations situated in the Al-Dakahlia and Al-Behera governorates.

At the beginning of the experiment, 10 trees were randomly selected from each orchard. Five branches on each tree were marked in four directions, and the number of split fruits on these branches was recorded and expressed as a percentage. The tree canopy was divided into three sections (upper, middle, and lower), and the percentage of fruit splitting was calculated for each section. To analyze calcium and boron content in the fruit peels, 50 commercially mature Washington Navel orange and Wonderful pomegranate fruits, both with and without splitting symptoms, were collected. Calcium (Ca) content was analyzed using an atomic absorption spectrophotometer (Perkin Elmer - 3300) following the method of Chapman and Pratt (1961). Boron (B) content was measured photometrically using the azomethine color reaction, based on the method of Banuelos *et al.* (1992) with modifications by Liakopoulos *et al.* (2005).

For the experiment, 25 trees of Washington Navel orange and Wonderful pomegranate with similar yields, canopy sizes, and vigor were selected. These trees were divided into five groups, each receiving one of the following treatments applied as sprays at full bloom (FB), and 30 and 60 days after full bloom: gibberellic acid (GA_3) (ACG-EGYPT ®), calcium chloride ($CaCl_2·2H_2O$), and boric acid (H_3BO_3), either individually or in combination. The treatments were: control (distilled water), 150 ppm GA_3, 2.0 % $CaCl_2·2H_2O$, 0.3 % H_3BO_3 and 150 ppm GA_3 + 2.0 % $CaCl_2·2H_2O$ + 0.3 % H_3BO_3. Each treatment had five replicates (trees).

The following parameters were measured:

Leaf calcium and boron content

Leaf samples were collected in July during both seasons from Washington Navel orange and Wonderful pomegranate trees to determine calcium and boron contents, following the methods described earlier.

Percentage of fruit splitting

The incidence of fruit splitting was evaluated monthly until the ripening stage. Split-affected fruits on each tree were counted, and the data were expressed as a percentage of split-affected fruits. The total percentage of fruit splitting was calculated using the formula:

Fruit splitting (%) =Total number of split fruits \ Total number of fruits ×100

Yield and Fruit Quality Parameters

At the ripening stage, all fruits from each treatment were harvested separately. Measurements included fruit weight (g), yield (kg/tree), fruit diameter (cm), fruit firmness (kg/m²), total soluble solids (TSS) (%), titratable acidity (TA) (%), ascorbic acid (vitamin C) content, and reducing sugars (%).

Fruit diameter (cm) and skin thickness (mm) were measured using a vernier caliper.

Fruit firmness (kg/m²) was determined using a handheld fruit firmness tester (Penetrometer, Model FT 327, QA Supplies, Norfolk, VA, USA).

TSS (%) was measured using a hand refractometer (0–32 °Brix) with temperature correction at 20°C (Chawla *et al.*, 2018).

TA (%) was determined by titration with 0.01 N NaOH using phenolphthalein as an indicator, and results were expressed as citric acid percentage (El-Sisy, 2013).

Ascorbic acid content (vitamin C) was determined in fruit juice via oxidation with 2,6-dichlorophenol-indophenol dye, with results expressed in mg ascorbic acid per 100 mL of juice (El-Sisy, 2013).

Reducing sugars (%) were analyzed using the phenol-sulfuric acid method and the 3,5-dinitrosalicylic acid (DNS) method (Lam *et al.*, 2021).

Statistical Analysis

The experiment was conducted using a completely randomized block design with three replications. Data from each season were analyzed using analysis of variance (ANOVA) with SPSS 17.0 software (Statistical Packages for the Social Sciences, Inc., Chicago, USA). Treatment differences were assessed using the least significant difference (LSD) test at a 5% significance level (Steel et al., 1997).

Results and discussion

Splitting as affected by fruit position on the tree

As shown in Tables 2 and 3, fruit splitting in Washington Navel orange and Wonderful pomegranate was significantly affected by the fruit's position on the tree (p ≤ 0.05). Table 2 indicates that fruits located on the southern side of the tree canopy exhibited a higher percentage of splitting compared to other sides in both seasons. Similarly, Table 3 emphasizes the impact of fruit position within the tree canopy. The highest splitting rates were observed in the lower canopy (1 m height), followed by the middle canopy (2 m height) and the upper canopy (3 m height) across both seasons. Fruits in the lower canopy exhibited significantly more splitting than those in higher sections. These results are consistent with the findings of El-Sammak (2010), El-Sayed (2016), Saffari and Akhavan (2018), and Mandal and Mitra (2018), who linked increased splitting in the southern and lower canopy areas to higher temperatures, greater light intensity, and lower relative humidity in these regions.

Table 2. Effect of fruit position and distribution on fruit splitting percentage of Washington navel orange and Wonderful pomegranate grown under Al-Dakahlia and Al-Behera governorates climatic conditions in 2020 and 2021 seasons.

Season	Washington navel orange					Wonderful pomegranate				
	Fruit position					Fruit position				
	North	South	East	West	Total	North	South	East	West	Total
2020	3.50 d	13.70 a	4.30 c	9.50 b	31	1.5 d	9.3 a	2.3 c	5.9 b	19
2021	4.5 d	15.2 a	5.7 c	10.8 b	36.2	2.5 d	11.5 a	5.7 c	3.8 b	23.5

Values in the column followed by the same letter(s) are not significantly different at a 5 % level of probability.

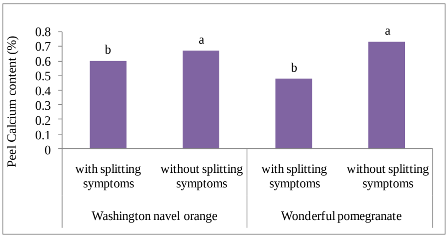
Table 3. % fruit splitting at different position of Washington navel orange and Wonderful pomegranate grown under Al-Dakahlia and Al-Behera governorates climatic conditions in 2020 and 2021 seasons.

Season	Washington navel orange				Wonderful pomegranate			
	Tree high				Tree high			
	Lower part(1m)	Medium part (2 m)	Higher part(3m)	Total	Lower part(1m)	Medium part (2 m)	Higher part(3m)	Total
2020	19.5 a	9.5 b	2 c	31	11.5 a	5.6 b	1.9 c	19
2021	23.3 a	10.2 b	2.7 c	36.2	13.5 a	7.6 b	2.4 c	23.5

Values in the column followed by the same letter(s) are not significantly different at a 5 % level of probability.

Relationship between fruit splitting and calcium and boron content in Peel

Significant differences ($p \leq 0.05$) were found in the calcium (Ca) and boron (B) content of the peel between split and non-split fruits of Washington Navel orange and Wonderful pomegranate. A negative correlation was observed between the levels of Ca and B in the fruit peel and the occurrence of splitting. Fruits without splitting symptoms showed higher concentrations of Ca and B in their peels, as illustrated in Figure 1. Similarly, earlier research on litchi (*L. chinensis*) has demonstrated that split fruits had notably lower levels of calcium and boron in the peel compared to non-split fruits of the same variety (Lin, 2001; Huang *et al.*, 2004).



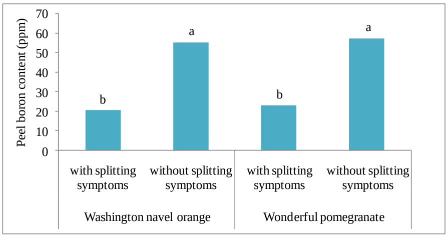


Figure 1. Relationship between peel Calcium (Ca) and boron (B) content and fruit splitting presence. Values in the bar followed by the same letter(s) are not significantly different at a 5 % level of probability.

Effect of Climatic conditions on fruit splitting in Washington Navel orange

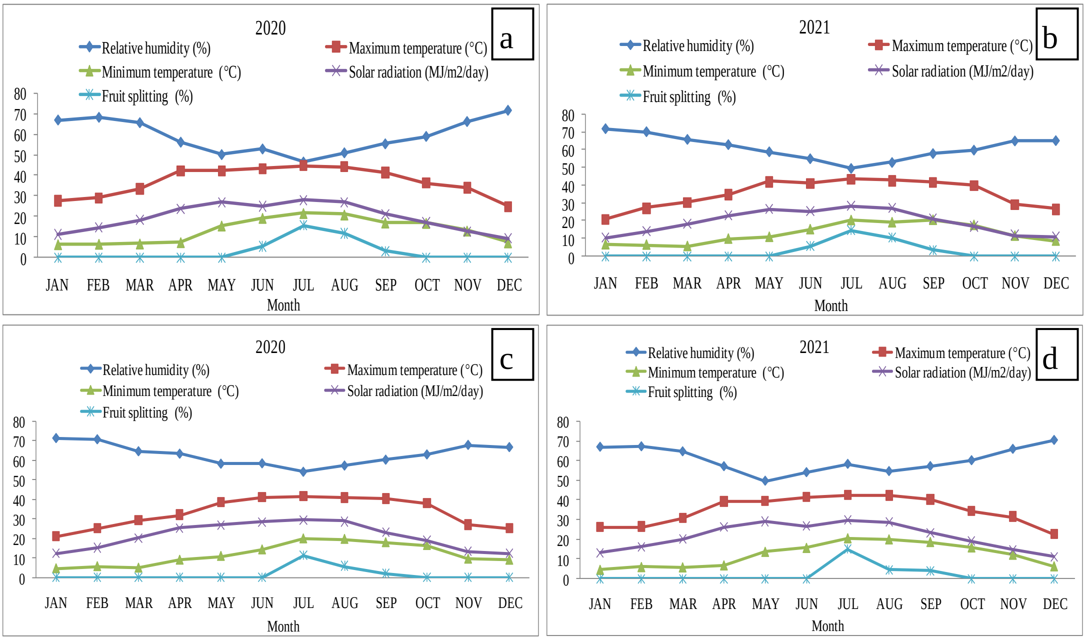
The data presented in Figure 2 (a, b, c, d) illustrate that climatic factors, particularly air temperature, relative humidity, and solar radiation, significantly affect fruit splitting in Washington Navel orange and Wonderful pomegranate. The occurrence of fruit splitting began to appear slightly in June and July, peaking in July for both fruit types.

Air temperature was positively correlated with fruit splitting. Higher maximum temperatures ($r^2 = 0.615$ for orange and 0.519 for pomegranate) and minimum temperatures ($r^2 = 0.752$ for orange and 0.685 for pomegranate) were linked to increased fruit splitting (Figure 2 a, b). These findings are consistent with those of Bolaños *et al.* (2017), who reported a similar trend in litchi (*L. chinensis*). Extreme temperature fluctuations can cause carbohydrate accumulation, lowering the osmotic potential of the fruit and increasing water absorption, which accelerates growth and heightens the risk of splitting (Wang and Camp, 2000).

Relative humidity showed a negative correlation with fruit splitting in both crops ($r^2 = -0.692$ for orange and -0.656 for pomegranate). The highest percentage of split fruits occurred during periods of low relative humidity (Figure 2 a, b). This aligns with research by Li et al. (2006) and Kaur *et al.* (2022), as well as Bolaños *et al.* (2017), who found that low relative humidity coupled with high temperatures promotes splitting in litchi.

Moreover, solar radiation was positively correlated with the percentage of split fruits. High solar radiation periods had a significant impact on fruit splitting, with correlation values of $r^2 = 0.645$ for orange and 0.545 for pomegranate (Figure 2 a, b). These results support the findings of Bolaños *et al.* (2017), who noted that increased solar radiation contributes to fruit splitting. The effect of solar radiation may be due to elevated external fruit temperatures, which create stress conditions, making fruits more vulnerable to splitting (Mitra *et al.*, 2010).

Figure 2. Splitting fruit incidence (%) in (a, b) Washington Navel orange and (b, c) Wonderful pomegranate fruits and its relation with air maximum and minimum temperatures (T °C), relative humidity (%) and solar radiation. Study period from January to December 2020-2021.



Effect of foliar application of gibberellic acid, calcium, and boron on fruit splitting and quality

Nutritional status (leaf mineral composition)

The nutritional status of Washington Navel orange and Wonderful pomegranate trees, as indicated by the leaf contents of N, P, K, Ca, Mg, and B, was evaluated in response to various treatments during the 2019–2020 and 2020–2021 seasons. The compiled data are presented in Tables 2 and 3.

As shown in Tables 4 and 5, all treatments significantly ($p \leq 0.05$) increased leaf nutrient contents (N, P, K, Ca, Mg, and B) compared to the control. Among the treatments, the combination of GA_3 (150 mg/L) + $CaCl_2.2H_2O$ (2.0%) + boric acid (0.3%) proved to be the most effective, resulting in the highest nutrient concentrations in the leaves. The GA_3 (150 mg/L) foliar spray alone ranked as the second most effective treatment.

Table 4. Effect of gibberellic acid, calcium and boron treatments on N, P, K, Ca, Mg and B content in leaves dry weight of Washington navel orange, plodded data of two seasons 2019 - 2020 and 2020 - 2021.

Treatments	Washington navel orange					
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)
Control (distilled water)	1.90 e	0.07 e	0.35 e	1.50 e	0.14 e	8.91e
GA_3 (150 mg/l)	2.77 b	0.19 b	0.95 b	3.05 b	0.34 b	50.70 b
$CaCl_2$ (2.0 %)	2.56 c	0.17 c	0.55 c	2.93 c	0.20 c	41.05 d
Boric acid (0.3%)	2.00 d	0.11 d	0.47 d	2.02 d	0.16 d	43.05 c
GA_3 (150 mg/l) + $CaCl_2.2H_2O$ (2.0 %) + Boric acid (0.3 %)	2.85 a	0.21 a	1.13 a	3.40 a	0.38 a	76.33 a

Values in the column followed by the same letter(s) are not significantly different at a 5 % level of probability.

Table 5. Effect of gibberellic acid, calcium and boron treatments on % N, P, K, Ca, Mg and B elements uptake in leaves dry weight of Wonderful pomegranate, plodded data of two seasons 2019 - 2020 and 2020 - 2021.

Treatments	Wonderful pomegranate					
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)
Control (distilled water)	1.44 e	0.11 e	0.74 e	2.33 e	0.20 e	10.01e
GA_3 (150 mg/l)	1.90 b	0.19 b	0.91 b	2.77 b	0.25 b	42.44 b
$CaCl_2$ (2.0 %)	1.70 c	0.16 c	0.85 c	2.57 c	0.23 c	33.57 d
Boric acid (0.3%)	1.11 d	0.13 d	0.79 d	2.07 d	0.18 d	37.55 c
GA_3 (150 mg/l) + $CaCl_2.2H_2O$ (2.0 %) + Boric acid (0.3 %)	2.33 a	0.24 a	0.98 a	2.90 a	0.27 a	68.23 a

Values in the column followed by the same letter(s) are not significantly different at a 5 % level of probability.

All treatments, whether applied individually or in combination, significantly ($p \leq 0.05$) reduced fruit splitting in Washington Navel orange and Wonderful pomegranate. Among the treatments, the combination of GA_3, calcium, and boron was the most effective, resulting in the lowest fruit splitting rates, while the untreated control trees displayed the highest rates of splitting (Table 6).

The effectiveness of these treatments can be attributed to their synergistic effects. Gibberellic acid (GA_3) promotes cell elongation and enhances cell flexibility (Peng *et al.,* 2001; Sekse *et al.,* 2005). Calcium improves cell wall cohesion by interacting with cell wall components (Bakeer, 2016), and boron enhances the water content of the fruit peel by promoting nutrient uptake, maintaining ionic balance in cell membranes, and regulating enzymatic activity (Shireen et al., 2018). Together, these treatments create an optimal physiological state, improving both the qualitative and quantitative attributes of Washington Navel orange and Wonderful pomegranate fruits.

Table 6. Effect of gibberellic acid, calcium and boron treatments on fruit splitting of Washington Navel orange and Wonderful pomegranate, plodded data of two seasons 2019 - 2020 and 2020 - 2021.

Treatments	Fruit splitting %	
	Washington Navel orange	Wonderful pomegranate
Control (distilled water)	36.51 a	23.66 a
GA_3 (150 mg/l)	4.31 d	3.12 d
$CaCl_2$ (2.0 %)	2.56 c	2.22 c
Boric acid (0.3%)	6.11 b	5.50 b
GA_3 (150 mg/l) + $CaCl_2.2H_2O$ (2.0 %) + Boric acid (0.3 %)	0.32 e	0.17 e

Values in the column followed by the same letter(s) are not significantly different at a 5 % level of probability.

Effect of treatments on fruit yield and quality parameters

Fruit yield, measured as weight (kg/tree), along with fruit weight, diameter, firmness, and peel thickness, were evaluated in response to different treatments during the 2019–2020 and 2020–2021 experimental seasons. The data, presented in Tables 7 and 8, clearly demonstrate that all treatments, including gibberellic acid (GA_3), calcium chloride ($CaCl_2.2H_2O$), and boric acid (H_3BO_3), significantly ($p \leq 0.05$) enhanced fruit diameter, firmness, peel thickness, fruit weight, and overall yield per tree for Washington Navel orange and Wonderful pomegranate compared to the control (water-sprayed trees).

The effectiveness of the treatments in improving these parameters varied among the substances. However, all showed a consistent trend across both experimental seasons. The combination of GA_3 (150 mg/L), $CaCl_2.2H_2O$ (2.0%), and boric acid (0.3%) proved to be the most effective treatment, resulting in the highest increases in all measured fruiting parameters compared to the control and other treatments. The remaining treatments ranked as follows, in descending order of efficacy for enhancing these parameters: GA_3 (150 mg/L) ranked second, followed by $CaCl_2.2H_2O$ (2.0%) and boric acid (0.3%), which ranked third and fourth, respectively. These findings align with those of Parthiban *et al.* (2021) and Singh *et al.* (2022), who reported that the combined application of GA_3, calcium, and boron significantly improved yield components in grapes (*Vitis vinifera*) and litchi (*L. chinensis*), respectively.

Table 7. Effect of gibberellic acid, calcium and boron treatments on yield parameters of Washington Navel orange and Wonderful pomegranate, plodded data of two seasons 2019 - 2020 and 2020 - 2021.

Treatments	Washington Navel orange		Wonderful pomegranate	
	Fruit weight (g)	Yield (kg/tree)	Fruit weight (g)	Yield (kg/tree)
Control (distilled water)	230.70 e	49.32 e	381.21 e	35.51 e
GA_3 (150 mg/l)	277.41 b	88.33 b	490.57 b	58.71 b
$CaCl_2$ (2.0 %)	260.21 c	73.11 c	478.02 c	50.24 c
Boric acid (0.3%)	255.33 d	68.82 d	465.66 d	47.11 d
GA_3 (150 mg/l) + $CaCl_2.2H_2O$ (2.0 %) + Boric acid (0.3 %)	301.11 a	98.70 a	507.91 a	62.70 a

Values in the column followed by the same letter(s) are not significantly different at a 5 % level of probability.

Table 8 . Effect of gibberellic acid, calcium and boron treatments on fruit diameter (cm), firmness (kg/cm^2) and peel thickness (mm) of Washington Navel orange and Wonderful pomegranate fruits, plodded data of two seasons 2019 - 2020 and 2020 - 2021.

Treatments	Washington Navel orange			Wonderful pomegranate		
	Fruit diameter (cm)	Firmness (kg/cm^2)	Peel thickness (mm)	Fruit diameter (cm)	Firmness (g/cm^2)	Peel thickness (mm)
Control (distilled water)	5.02 e	10.71 e	3.01 e	11.51 e	420.57 e	54.70 e
GA_3 (150 mg/l)	6.50 b	18.78 b	3.90 b	13.71 b	523.17 b	64.50 b
$CaCl_2$ (2.0 %)	5.87 c	16.45 c	3.77 c	13.57 c	509.11 c	62.56 c
Boric acid (0.3%)	5.33 d	13.67 d	3.45 d	13.12 d	487.38 d	57.33 d
GA_3 (150 mg/l) + $CaCl_2.2H_2O$ (2.0 %) + Boric acid (0.3 %)	7.76 a	21.33 a	4.21 a	14.50 a	541.40 a	68.67 a

Values in the column followed by the same letter(s) are not significantly different at a 5 % level of probability.

Effect of treatments on fruit chemical properties

The chemical properties of fruit, including total soluble solids (TSS %), titratable acidity (%), ascorbic acid (vitamin C), and reducing sugar content (%), were evaluated in response to different treatments during the 2019–2020 and 2020–2021 experimental seasons. The results, shown in Tables 9 and 10, demonstrate that all treatments significantly ($p \leq 0.05$) enhanced the four chemical parameters when compared to the control. Among the treatments, the combination of GA_3 (150 mg/L), $CaCl_2.2H_2O$ (2.0%), and boric acid (0.3%) resulted in the highest values for TSS, ascorbic acid, and reducing sugars while achieving the lowest titratable acidity. This treatment was the most effective, followed by GA_3 (150 mg/L) alone, which ranked second during both seasons. These findings align with prior studies by Verreynne and Der Merwe (2011) and Hegazi *et al.* (2014). Similarly, El-Akkad *et al.* (2016) reported that calcium chloride and GA_3 applications significantly improved the fruit quality of Manfalouty pomegranate by increasing TSS, vitamin C, and reducing sugars while lowering titratable acidity compared to untreated controls.

The observed improvements are likely due to the combined effects of calcium and GA_3 on promoting growth, enhancing nutrient uptake, and improving food synthesis. These processes contribute to better fruit maturation and enriched chemical constituents, as suggested by Ismail *et al.* (2018).

Table 9. Effect of gibberellic acid, calcium and boron treatments on fruit quality parameters (TSS, acidity, ascorbic acid content, reducing sugar %) of Washington Navel orange, plodded data of 2019-2020 and 2020-2021 seasons.

Treatment	Total soluble solid (%)	Titratable acidity (%)	Ascorbic acid content (mg /100 ml juice)	Reducing sugars (%)
Control (distilled water)	18.11 c	0.87 c	64.50 c	6.07 c
GA_3 (150 mg/l)	16.50 e	0.97 a	55.44 e	4.60 e
$CaCl_2$ (2.0 %)	19.03 b	0.71 d	68.52 b	7.10 b
Boric acid (0.3%)	17.60 d	0.91 b	60.01 d	5.30 d
GA_3 (150 mg/l) + $CaCl_2.2H_2O$ (2.0 %) + Boric acid (0.3 %)	20.01 a	0.67 e	73.11 a	8.61 a

Values in the column followed by the same letter(s) are not significantly different at a 5 % level of probability.

Table 10. Effect of gibberellic acid, calcium and boron treatments on fruit quality parameters (TSS, acidity, ascorbic acid content, reducing sugar %) of Wonderful pomegranate, plodded data of 2019-2020 and 2020-2021 seasons.

Treatment	Total soluble solid (%)	Titratable acidity (%)	Ascorbic acid content (mg /100 ml juice)	Reducing sugars (%)
Control (distilled water only)	15.34 e	1.72 a	11.26 e	10.18 e
GA_3 (150 mg/l)	19.73 c	0.90 c	20.50 c	11.70 c
$CaCl_2$ (2.0 %)	21.55 b	0.88 d	24.77 b	12.00 b
Boric acid (0.3%)	17.60 d	0.98 b	18.79b d	11.05 d
GA_3 (150 mg/l) + $CaCl_2.2H_2O$ (2.0 %) + Boric acid (0.3 %)	24.59 a	0.85 e	26.32 a	12.70 a

Values in the column followed by the same letter(s) are not significantly different at a 5 % level of probability.

Conclusions

The results indicated that high percentages of fruit splitting were observed in July, a period characterized by high air temperatures, high solar radiation, and low relative humidity. Additionally, the highest rates of fruit splitting occurred on the south side and in the lower part of the canopy. Fruits without splitting symptoms had higher concentrations of calcium (Ca) and boron (B) in their peel compared to split fruits. The combination of (150 mg/L), $CaCl_2{\cdot}2H_2O$ (2.0%), and boric acid (0.3%) was found to be the most effective treatment for reducing fruit splitting, as well as improving tree yield and fruit quality parameters for both Washington Navel orange and Wonderful pomegranate. Based on these findings, foliar application of GA_3 (150 mg/L), $CaCl_2{\cdot}2H_2O$ (2.0%), and boric acid (0.3%) is recommended to reduce fruit splitting and enhance yield and quality under the experimental conditions.

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