



International Journal of
**Agricultural
Research**

ISSN 1816-4897



Academic
Journals Inc.

www.academicjournals.com

Research Article

Effect of Glutathione and Some Mineral Nutrients on Fruit Cracking and Quality in Washington Navel Orange

¹Gehan Abd El-Malek El-Hadidy, ¹Ashraf Mahfouz Mshrakyand and ²Thanaa Shaban Mohamed Mahmoud

¹Department of Fruit Handling Research, Horticultural Research Institute Agricultural Research Centre, Giza, Egypt

²Department of Horticultural Crops Technology, Agricultural and Biological Research Institute, National Research Centre, 33 El-Buhouth St., Dokki, Cairo, Egypt

Abstract

Background and Objective: Cracking observed on navel orange fruits in the pre-harvest stage is one of the main physiological disorders that negatively affect the amount of the crop, as it may lead to a decrease in the annual yield up to 60%, which causes huge economic losses for farmers. Therefore, this study was conducted to test the physiological effects of spraying navel orange trees with glutathione, potassium and calcium on the occurrence of this phenomenon, yield and fruit quality. **Materials and Methods:** A field trial was conducted to determine the physiological effects of foliar application with glutathione (25, 50 and 75 mg L⁻¹), calcium EDTA (40, 80 and 120 mg L⁻¹) and soil potassium sulphate application (250, 500 and 750 g/tree) on fruit cracking, yield and fruit quality of Washington navel orange. **Results:** All treatments significantly reduced fruit creaking percentage with significantly enhanced yield, fruit weight, peel (weight and thickness), pulp weight, TSS/acid ratio and ascorbic acid, total sugars percentage, pectin content and protopectin as compared with control. **Conclusion:** As a result, it can be recommended foliar application of glutathione 50 mg L⁻¹, Ca-EDAT 80 mg L⁻¹ and soil potassium sulphate application at 500 g/tree divided to twice, the first after fruit set stage and the second after four weeks later to reduce the fruit creaking as well as enhancing yield and fruit quality of Washington navel orange.

Key words: Physiological disorder, fruit cracking, glutathione, potassium, calcium, yield, fruit quality

Citation: El-Hadidy, G.A.E.M., A.M. Mshrakyand and T.S.M. Mahmoud, 2022. Effect of glutathione and some mineral nutrients on fruit cracking and quality in Washington navel orange. Int. J. Agric. Res., 17: 5-13.

Corresponding Author: Thanaa Shaban Mohamed Mahmoud, Department of Horticultural Crops Technology, Agricultural and Biological Research Institute, National Research Centre, 33 El-Buhouth St., Dokki, Cairo, Egypt

Copyright: © 2022 Gehan Abd El-Malek El-Hadidy *et al.* This is an open access article distributed under the terms of the creative commons attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Fruit cracking or splitting is one of the major pre-harvest physiological disorders which almost occur on various citrus species, sweet orange (*Citrus sinensis*) cultivars such as Navel and Valencia, as well as thin-rinded mandarin and mandarin hybrids¹. This disorder is recognized to create by pressure resulting from the expanding and enlargement pulp of a unique fruit on the rind, finally creating a rupture at the astylar or navel-end and resulting in the fruit cracking². Fruit cracking not only negatively influence fruit yield, but it also attracts insects and pathogens which leads to decay and finally causes a decrease of annual yield up to 60% thus causing severe economic losses^{1,3}. Several factors impede citrus fruit development and result in the rind being more susceptible to cracks like K and Ca deficiency, warm and humid climatic conditions during early fruit development, heavy crop load, cultivar characteristics, rootstock, growth regulators and cultural practices such as pruning, thinning and irrigation^{1,2}. In recent years, control strategies of fruit cracking have focused on the use of plant growth regulators and nutrients as foliar treatments.

Glutathione (GSH) (molecular formula $C_{10}H_{17}N_3O_6S$) is a tripeptide γ -L glutamyl-L-cysteinyl-glycine. GSH is a small intracellular thiol molecule that was first identified in yeasts in 1888 but its structure was not described until 1935. The intensive study began in the 1960s due to the discovery of its functions in human body fluids. The GSH metabolism was credited to Dr Alton Meister, due to his indisputable contribution. Glutathione is important in sulfur metabolism and defence against all stresses. Glutathione is a strong antioxidant that has a critical role in preserving a normal balance between oxidation and antioxidation. It regulates the number of cell vital functions such as synthesis and repair of DNA, synthesis of proteins and activation and regulation of enzymes in plants. Besides, its effects on defence gens expression maintain the integrity of cell structures and the proper functions of different metabolic pathways, for example, it protects membranes by maintaining the reduced state of both α -tocopherol and zeaxanthin. As well, it prevents the oxidative denaturation of proteins under stress conditions by protecting their thiol groups. Also, it serves as a substrate for glutathione peroxidases, glutathione S-transferase and glutaredoxin which is involved in flower development and plant defence signalling^{4,5}. Subjecting most fruit crops with glutathione at different concentrations and frequencies of application had positive effects on yield and fruit quality⁶⁻¹⁰.

Calcium (Ca) is the most important mineral in ensuring cell structure stability and mechanical strength¹¹. The application of calcium to fruits protects against physiological deterioration, retardation of maturity and improvement of fruit quality¹²⁻¹⁴. Calcium plays an important role in regulating the absorption of water by plant roots and stabilization of membrane system and the formation of C-pectates which increase the rigidity of the middle portion and cell wall of the fruit. It also regulates the mechanism of photosynthesis and protein synthesis. Calcium treatments have been reported to reduce the cracking and increased yield of healthy fruits in pomegranate¹⁵⁻¹⁷.

The potassium (K) is identified as a vital nutrient element for all steps of protein products that are related to all plant growth processes. K manages numerous enzymes activities in plant cells by the compilation of photosynthesis level as well as an increment in the translocation amount from leaves within the phloem to storage tissue, leading to enhance the yield and fruit quality attributes¹⁸. Furthermore, K can cause higher osmotic and turgor pressure, which can give power for cell division, cell wall extension and cell expansion to stimulate cell growth rate. A high K content could enhance the cell and fruit size and make peel smooth, in contrast, when the peel K amount is low, fruit splitting and dropping will happen quickly, following in less and smaller fruit, thinner peel and the decline of SSC, organic acids and vitamin C¹⁹. K can stimulate cell division in citrus and diminish fruit splitting. Using K in the spring season or during the early fruit development stages can raise fruit peel development, enhance peel thickness, increase the fruit cracking resistance capacity and diminish pre-harvest fruit splitting²⁰. However, the extra utilization of K during the late fruit development stages has a slight impact on the decline of fruit splitting¹. Application of K was found to be effective in enhancing yield and fruit quality and reducing fruit cracking²¹⁻²³.

Thus, this study aimed to examine the physiological effects of glutathione, calcium and potassium application on fruit cracking percentage, yield and fruit quality of Washington navel orange.

MATERIALS AND METHODS

Plant materials: This study was carried out in two successive seasons 2019 and 2020 on 21-year-old Washington navel orange (*Citrus sinensis* L. Osbeck) trees budded on sour orange (*Citrus aurantium*) rootstock planted at 5×5 m in loamy soil under a surface irrigation system at a private orchard in Shebein El Qanater region, Kaloubia Governorate, Egypt.

Treatments:

- T₁ : Glutathione 25 mg L⁻¹
- T₂ : Glutathione 50 mg L⁻¹
- T₃ : Glutathione 75 mg L⁻¹
- T₄ : Ca-EDTA 40 mg L⁻¹
- T₅ : Ca-EDTA 80 mg L⁻¹
- T₆ : Ca-EDTA 120 mg L⁻¹
- T₇ : Potassium sulphate 250 g/tree
- T₈ : Potassium sulphate 500 g/tree
- T₉ : Potassium sulphate 700 g/tree
- T₁₀ : Control (untreated)

The amount of each treatment was divided into two doses and applied at two different application times, the first after the fruit set stage and the second after 4 weeks later. Glutathione and Ca-EDTA were applied as a foliar application using litres solution volume per tree which was sufficient for thorough coverage of the canopy. Salient-film at 0.3% was used as a wetting agent. Potassium sulphate was applied as soil application. Each treatment of this experiment was arranged in a Randomized Complete Block Design (RCBD) and replicated three times with three trees per replicate. All the experimental trees were selected at random as uniform as possible in their growth. They were treated alike as far as a culture was concerned except for this study.

Measurements

Total yield: At commercial harvesting time (colour break) in early December of both seasons fruits per tree were picked and weighed to estimate the total yield (kg/tree).

Fruit cracking percentage: Cracked fruits were sorted after harvesting for each tree and weighed to estimate the weight of cracking fruit (kg/tree) then the percentage of fruit cracking relative to the total yield per tree was calculated. As well, the weight of sound fruit per tree was then calculated.

Fruit quality: Twenty fruits were randomly taken per tree to determine fruit characteristics as follow:

- **Fruit physical properties:** Fruit weight (g), pulp weight (g), peel weight (g), peel thickness (mm) and fruit firmness (Lb inch⁻²) was determined by using Magness Taylor Pressure Tester

- **Fruit chemical properties:** Total Soluble Solids (TSS (%)) was determined by using the hand refractometer Abbe., titratable acidity percentage was determined by titrating the juice against 0.1 N sodium hydroxide using phenolphthalein as an indicator and expressed as a gram of citric acid 100 mL⁻¹ juice according to AOAC²⁴ and then the TSS: TA ratio was calculated

Ascorbic acid content (vitamin C) was determined by titration against 2,6 dichlorophenolendophenol and using 2% oxalic acid solution as substrate described by AOAC²⁴. Vitamin C content was calculated as mg 100 mL⁻¹ juice.

Total sugars (%), non-reducing sugars (%) and reducing sugars (%) in fruit juice were determined according to AOAC²⁴.

Pectin (total and soluble) and protopectin were determined in albedo layer and pulp according to Ywassaki and Canniatti-Brazaca²⁵ and the results were expressed in mg of polygalacturonic acid per 100 g of fresh fruit.

Statistical analysis: The obtained data of both seasons were subjected to Analysis of Variance (ANOVA) according to Snedecor and Cochran²⁶ using the MSTAT Computer Software program. The least significant difference (LSD) was used to compare between means of treatments at the probability of 5%.

RESULTS

Total yield: Table 1 showed that all treatments applied improved the total yield of Washington navel orange trees compared to untreated trees in the two experimental seasons. Regarding glutathione treatment, 50 mg L⁻¹ gave the highest value (66.8 and 69.9 kg/tree) in the 2019 and 2020 seasons respectively. Concerning calcium treatment, 80 mg L⁻¹ gave the highest total yield (86.7 and 89.9 kg/tree) in both seasons respectively. Concerning potassium sulphate treatment, 500 g/tree recorded the highest total yield (72.8 and 76.2 kg/tree) in the first and second seasons, respectively. On the other hand, untreated trees gave the lowest total yield (48.4 and 46.2 kg/tree) during the two studied seasons, respectively.

Weight of sound fruits (kg/tree): Table1 demonstrated that during the 1st and 2nd seasons of study the application with glutathione at 50 mg L⁻¹, calcium at 80 mg L⁻¹ and potassium at 500 g/ tree produced the highest weight of sound fruits. Meanwhile, the lowest value was obtained in control trees (35.7 and 33.6 kg/tree) during the 2019 and 2020 seasons, respectively.

Table 1: Effect of glutathione, calcium and potassium on yield components and fruit cracking of Washington navel orange

Treatments	Total yield (kg/tree)		Weight of sound fruits (kg/tree)		Weight of cracking fruits (kg/tree)		Fruit cracking (%)	
	2019	2020	2019	2020	2019	2020	2019	2020
T ₁ Glutathione (25 mg L ⁻¹)	55.2	66.8	44.8	55.3	10.4	11.5	18.84	17.22
T ₂ Glutathione (50 mg L ⁻¹)	66.8	69.9	58.7	62.1	8.1	7.8	12.13	11.16
T ₃ Glutathione (75 mg L ⁻¹)	59.8	63.8	51.2	55.7	8.6	8.1	14.38	12.70
T ₄ Ca-EDTA (40 mg L ⁻¹)	75.6	78.4	68.7	72.1	6.9	6.3	9.13	8.04
T ₅ Ca-EDTA (80 mg L ⁻¹)	86.7	89.9	83.2	87.8	3.5	2.1	4.04	2.34
T ₆ Ca-EDTA (120 mg L ⁻¹)	79.4	81.9	73.3	77.5	6.1	4.4	7.68	5.37
T ₇ Potassium sulphate 250 g/tree	63.7	66.5	56.4	58.8	7.3	7.7	11.46	11.58
T ₈ Potassium sulphate 500 g/tree	72.8	76.2	69.5	73.2	3.3	3	4.53	3.94
T ₉ Potassium sulphate 750 g/tree	66.5	70.7	60.7	65.8	5.8	4.9	8.72	6.93
T ₁₀ Control	48.4	46.2	35.7	33.6	12.7	12.6	26.24	27.27
LSD at 5 %	1.601	1.808	3.714	1.573	2.40	1.75	3.567	3.983

Table 2: Effect of glutathione, calcium and potassium on fruit physical properties of Washington navel orange

Treatments	Fruit weight (g)		Pulp weight (g)		Peel weight (g)		Peel thickness (mm)		Fruit firmness (Lb inch ⁻²)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
T ₁ Glutathione (25 mg L ⁻¹)	230	248	200.9	219.8	29.1	28.2	4.1	4.1	4.3	4.6
T ₂ Glutathione (50 mg L ⁻¹)	252	259	223.2	231	28.8	28	4.3	4.2	4.6	4.9
T ₃ Glutathione (75 mg L ⁻¹)	239	250	210.3	222.2	28.7	27.8	4.2	4	4.9	5.2
T ₄ Ca-EDTA (40 mg L ⁻¹)	270	275	242.2	248.2	27.8	26.8	4.3	4.3	6	6.1
T ₅ Ca-EDTA (80 mg L ⁻¹)	299	305	270.4	277.3	28.6	27.7	4.5	4.6	4.96	5.23
T ₆ Ca-EDTA (120 mg L ⁻¹)	294	296	264.5	267.6	29.5	28.4	4.4	4.5	4.1	4.2
T ₇ Potassium sulphate 250 g/tree	245	248	216.1	220.1	28.6	27.9	4.3	4.4	4.5	4.7
T ₈ Potassium sulphate 500 g/tree	265	273	236.5	245.3	28.5	27.7	4.2	4.3	4.9	5.1
T ₉ Potassium sulphate 750 g/tree	261	269	232.8	241.5	28.2	27.5	4.1	4.2	5.3	5.5
T ₁₀ Control	215	210	191.8	185.7	23.2	24.3	3.9	3.8	3.6	3.8
LSD at 5 %	7.786	7.635	7.901	8.63	0.64	0.544	1.11	1.212	1.566	1.714

Fruit cracking percentage: Table 1 show that all treatments significantly decreased fruit cracking percentage compared to the control which record the highest percent during the two seasons. Regarding glutathione treatment, 50 mg L⁻¹ gave the lowest fruit creaking percentage (12.13 and 11.16%) in the first and second seasons respectively. Concerning calcium treatment, 80 mg L⁻¹ gave the lowest percent (4.04 and 2.34%) in both seasons, respectively. Potassium sulphate treatment, 500 g/tree recorded the lowest fruit creaking percentage (4.53 and 3.94%) in 2019 and 2020 seasons, respectively. Whereas, the fruit creaking percentage in untreated trees was (26.24 and 27.27%) during the first and second seasons, respectively.

Fruit quality

Fruit physical properties: Table 2 showed the effect of glutathione, calcium and potassium on fruit physical properties of Washington navel orange. Data illustrated that all properties were significantly affected by different treatments under study.

Concerning glutathione treatment, 50 mg L⁻¹ gave the highest values of fruit weight (252 and 259 g), pulp weight (223.2 and 231 g) and peel thickness (4.3 and 4.2 mm)

during the 2019 and 2020 seasons, respectively. Glutathione at 25 mg L⁻¹ achieved the highest peel weight (29.1 and 28.2 g). Glutathione at 75 ppm attained the highest fruit firmness (4.9 and 5.2 Lb inch⁻²).

Regarding calcium treatment, 80 mg L⁻¹ gave the highest values of fruit weight (299 and 305 g), pulp weight (270.4 and 277.3 g) and peel thickness (4.5 and 4.6 mm) in both seasons, respectively. Calcium at 120 mg L⁻¹ recorded the highest peel weight (29.5 and 28.4 g). Calcium at 40 mg L⁻¹ recorded the highest fruit firmness (6 and 6.1 Lb inch⁻²).

Respecting potassium sulphate treatment, 500 g/tree recorded the highest fruit weight (265 and 273 g) and pulp weight (236.5 and 245.3 g) in the first and second seasons, respectively. Potassium sulphate at 250 g/tree achieved the highest peel weight (28.6 and 27.9 g) and peel thickness (4.3 and 4.4 mm) during the 2019 and 2020 seasons, respectively. Potassium sulphate at 750 g/tree exhibited the highest fruit firmness (5.3 and 5.5 Lb inch⁻²) in the two seasons of study, respectively. Meanwhile, the lowest values of fruit weight (215 and 210 g), pulp weight (191.8 and 185.7 g), peel weight (23.2 and 24.3 g), peel thickness (3.9 and 3.8 mm) and fruit firmness (3.6 and 3.8 Lb inch⁻²) during 2019 and 2020 season, respectively.

Table 3: Effect of glutathione, calcium and potassium on TSS (%), acidity (%), TSS/acidity ratio and ascorbic acid content of Washington navel orange

Treatments	TSS (%)		Acidity (%)		TSS/acidity ratio		Ascorbic acid content (mg/100 mL juice)	
	2019	2020	2019	2020	2019	2020	2019	2020
T ₁ Glutathione (25 mg L ⁻¹)	11.7	11.8	1.23	1.2	9.51	9.83	42.6	42.7
T ₂ Glutathione (50 mg L ⁻¹)	11.8	11.8	1.23	1.18	9.59	10	42.8	42.9
T ₃ Glutathione (75 mg L ⁻¹)	11.9	11.9	1.19	1.17	10	10.17	43.5	43.6
T ₄ Ca-EDTA (40 mg L ⁻¹)	12.3	12.6	1.19	1.13	10.34	11.15	45.5	45.6
T ₅ Ca-EDTA (80 mg L ⁻¹)	11.9	12	1.17	1.17	10.17	10.25	43.7	43.8
T ₆ Ca-EDTA (120 mg L ⁻¹)	11.6	11.7	1.23	1.21	9.43	9.67	42.3	42.4
T ₇ Potassium sulphate 250 g/tree	11.8	11.9	1.23	1.18	9.59	10.08	42.9	43.4
T ₈ Potassium sulphate 500 g/tree	11.9	11.9	1.2	1.16	9.92	10.25	43.2	43.9
T ₉ Potassium sulphate 750 g/tree	12.1	12.1	1.19	1.14	10.17	10.61	43.6	44.3
T ₁₀ Control	11.5	11.6	1.25	1.21	9.28	9.59	41.3	41.7
LSD at 5 %	1.062	NS	1.065	1.062	1.325	1.325	1.664	1.78

Table 4: Effect of glutathione, calcium and potassium on sugars content of Washington navel orange

Treatments	Total sugars (%)		Non-reducing sugars (%)		Reducing sugars (%)	
	2019	2020	2019	2020	2019	2020
T ₁ Glutathione (25 mg L ⁻¹)	7.44	7.75	4.3	4.6	3.14	3.15
T ₂ Glutathione (50 mg L ⁻¹)	7.7	7.91	4.6	4.9	3.1	3.01
T ₃ Glutathione (75 mg L ⁻¹)	7.9	8.12	4.9	5.2	3	2.92
T ₄ Ca-EDTA (40 mg L ⁻¹)	8.7	8.9	6	6.1	2.7	2.8
T ₅ Ca-EDTA (80 mg L ⁻¹)	7.94	8.14	4.96	5.23	2.98	2.91
T ₆ Ca-EDTA (120 mg L ⁻¹)	7.5	7.7	3.6	3.8	3.9	3.9
T ₇ Potassium sulphate 250 g/tree	8.02	8.2	4.5	4.7	3.52	3.5
T ₈ Potassium sulphate 500 g/tree	8.33	8.45	4.9	5.1	3.43	3.35
T ₉ Potassium sulphate 750 g/tree	8.65	8.79	5.3	5.5	3.35	3.29
T ₁₀ Control	7.3	7.56	4.1	4.4	3.2	3.16
LSD at 5 %	1.566	1.714	1.601	1.808	3.569	3.714

Fruit chemical properties

Total soluble solid percentage (TSS %): Table 3 showed that, the TSS % of Washington navel orange was greatly affected by using all applied treatments during the first season. Referring to the effect of glutathione treatment, 75 mg L⁻¹ gave the highest percentage of TSS (11.9%). As for the calcium treatments, 40 mg L⁻¹ gave the highest values of TSS (12.3%). Regarding potassium sulphate treatment, 750 g/tree recorded the highest values of TSS (12.1%). On contrary, the lowest TSS (11.5%) was registered in untreated trees. During the second season of the study, there were no significant differences between the treatments.

Acidity percentage: Table 3 cleared that, all studied treatments succeeded in decreasing the acidity percentage of Washington navel orange fruits as compared with untreated fruits in both seasons. Regarding glutathione treatment, 75 mg L⁻¹ gave the lowest acidity percentage (1.21 and 1.17%) in the first and second seasons, respectively. Concerning calcium treatment, 80 mg L⁻¹ gave the lowest percent (1.17%) in the first season and at 40 mg L⁻¹ (1.13%) in the second season.

Potassium sulphate treatment, 750 g/tree recorded the lowest percentage of acidity (1.19 and 1.16%) in the 2019 and 2020 seasons, respectively. Meanwhile, the untreated trees scored the highest percentage of acidity (1.25 and 1.21%) during the first and second seasons, respectively.

TSS/acidity ratio and ascorbic acid content: Concerning the impact of glutathione treatment, 75 mg L⁻¹ gave the highest values of TSS/acidity ratio and ascorbic acid content (10, 10.17 and 43.5, 43.6 mg/100 mL juice) during 2019 and 2020 seasons, respectively. As for the calcium treatments, 40 mg L⁻¹ gave the highest values of TSS/ acidity ratio and Ascorbic acid content (10.34, 11.15, 45.5 and 45.6 mg /100 mL juice) in both seasons, respectively. Concerning potassium sulphate treatment, 750 g/tree recorded the highest values of TSS/acidity ratio and Ascorbic acid content (10.17, 10.61, 43.6 and 44.3 mg/100 mL juice) during the two seasons, respectively. On the other hand, the untreated trees recorded the lowest values of TSS/acidity ratio and ascorbic acid content (9.28, 9.59, 41.3 and 41.7 mg/100 mL juice) in both seasons, respectively.

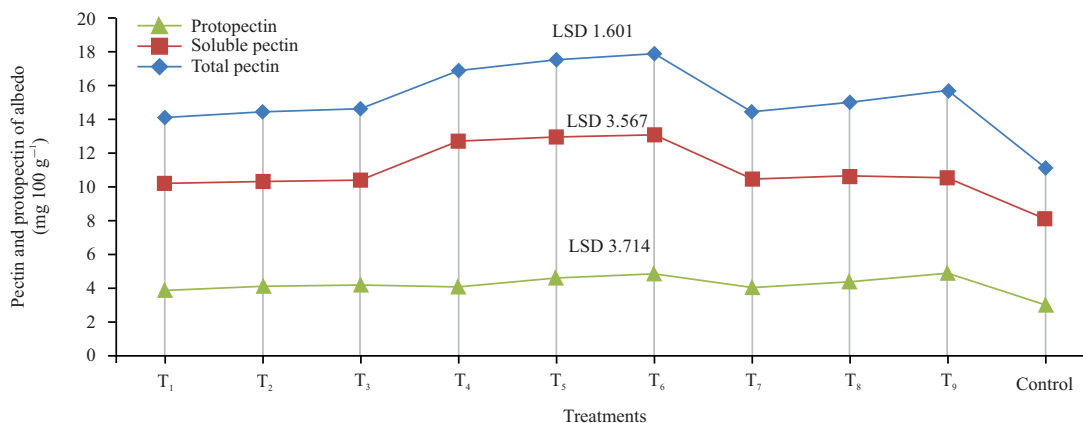


Fig. 1: Effect of glutathione, calcium and potassium on pectin and protopectin albedo of Washington navel orange

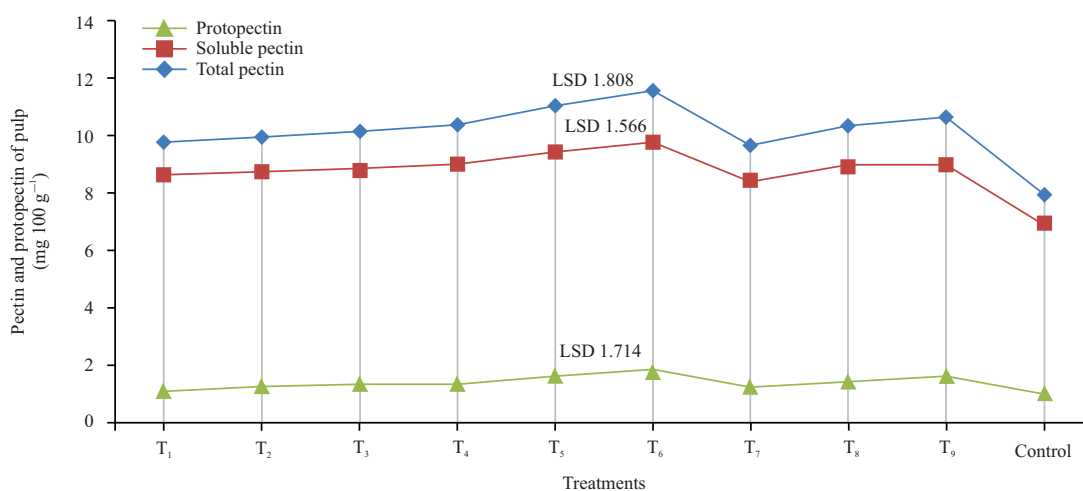


Fig. 2: Effect of glutathione, calcium and potassium on pectin and protopectin pulp of Washington navel orange

Sugars content: Table 4 show the effect of various treatments on sugars content, total sugars, non-reducing and reducing sugars of Washington navel orange. The highest percentage of total sugars was found in the fruits treated with glutathione at 75 mg L⁻¹ (7.9 and 8.12%), calcium at 40 mg L⁻¹ (8.7 and 8.9%) and potassium sulphate at 750 g/tree (8.65 and 8.79%) during first and second seasons, respectively. Non-reducing sugars percentage took the same trend of the total sugars, could be observed where the same previous treatments recorded the highest percentage and the differences between treatments were significant. Concerning reducing sugars (%), glutathione at 25 mg L⁻¹ achieved the highest value (3.14 and 3.15%), calcium at 120 mg L⁻¹ (3.9%) and potassium sulphate at 750 g/tree (3.52 and 3.5%) during both seasons, respectively. However, the control recorded the lowest percentages of total sugars, non-reducing sugars and

reducing sugars (7.3, 7.56, 4.1, 4.4, 3.2 and 3.16%) during the 1st season and 2nd season, respectively.

Pectin and protopectin content: Considering the albedo and pulp parts of the fruit Washington navel orange shown in Fig. 1 and 2, the highest values for pectin (total and soluble) and protopectin were found in the albedo layer. It is obvious from the obtained results that the application of glutathione, calcium and potassium treatments significantly improved the pectin and protopectin contents. Regarding glutathione treatment, 75 mg L⁻¹ gave the highest values of total pectin, soluble pectin and protopectin of albedo (14.6, 10.4 and 4.2 mg 100 g⁻¹) respectively.

Concerning calcium treatment, 120 mg L⁻¹ recorded the highest values of total pectin, soluble pectin and protopectin of albedo (17.9, 13.1 and 4.8 mg/100 g) respectively. As for

the potassium sulphate treatment, 750 g/tree recorded the highest values of total pectin and protopectin of albedo (15.7 and 4.9 mg 100 g⁻¹), whereas the 500 g/tree recorded the highest value of soluble pectin. On the other hand, the untreated trees scored the lowest values of total pectin, soluble pectin and protopectin of albedo (11.1, 8.1 and 3 mg/100 g) respectively in Fig. 1.

Total pectin, soluble pectin and protopectin content in the pulp of treated fruits took the same trend of albedo Fig. 2. Glutathione at 75 mg L⁻¹ achieved the highest values (10.1, 8.8 and 1.3 mg/100 g), calcium at 120 mg L⁻¹ (11.5, 9.7 and 1.8 mg/100 g) and potassium sulphate at 750 g/tree (10.6, 9 and 1.6 mg/100 g) respectively. However, the control recorded the lowest values of total pectin, soluble pectin and protopectin content in pulp (10.6, 9 and 1.6 mg/100 g), respectively.

DISCUSSION

The phenomenon of cracking or splitting Washington navel orange fruits that are observed on peel and pulp in the pre-harvest stage is one of the main physiological disorders that greatly limit the quantity of yield and fruit quality. Also, it leads to decrease marketing value of these fruits due to their poor quality. The present study suggested that foliar application of glutathione, calcium EDTA and soil application of potassium sulphate effectiveness in reducing the fruit cracking, improving yield and fruit quality of Washington navel orange.

The good effect of glutathione may be attributed to its physiological role in plant cells as an antioxidant acting to regulate other antioxidant components both enzymatic and non-enzymatic²⁷ that enhance physiological activities such as chlorophyll biosynthesis or reduce their degradation and incorporation into metabolism²⁸, nutrient uptake²⁹, increase the amount of assimilates and increasing their translocations from leaves to fruits, thus returns in increasing total yield and improving fruit quality. These results are in agreement with those obtained by Haikal and Gomaa⁸ on mango.

The effectiveness of calcium treatments in decreasing fruit cracking may be attributed to the stabilization of membranes systems and increasing Ca bound to the cell wall, formation of calcium pectates in the cell wall which increases the rigidity of the middle portion of the cell wall and delays degradation of protopectin by regulating enzymes associated with cell wall disassembly, enhanced the skin break force and ultimately significantly reduced the frequency and degree of fruit cracking³⁰. Moreover, the foliar spray of calcium stimulated calcium absorption and enhanced fruit growth

through the maintenance of water balance and improved the nutrition uptake, consequently increasing the food synthesized that translocated to fruit and enhanced their maturation and improved its contents of chemical constituents. These results are in the same line as Sharma and Belsare³¹⁻³⁴.

Potassium may reduce fruit cracking and enhance yield by can maintain high osmotic pressure and turgor pressure, which can provide power for cell division, cell wall extension and cell expansion to accelerate cell growth and finally, reduce fruit splitting^{19,35}. Similarly, Sallato *et al.*²⁰ indicated that the use of K in spring or during the early fruit development stage can raise fruit peel development, enhance peel thickness, increase the fruit cracking resistance capacity and diminish pre-harvest fruit splitting. Previous studies demonstrated that foliar spray of the nutrient perhaps reduced fruit split via rising peel elasticity and flexibility, as the increment of compounds and solutes such as K in the vacuole is needed for the osmotic potential required for cell expansion, enhancing cell wall elasticity^{36,37}. The present study demonstrated that most potassium treatments could be control cracking besides increasing the total yield and fruit quality. These results are in the same trend as those obtained by Ashraf *et al.*²¹ on Kinnaw, Stander *et al.*³, on mandarin, Hardiyanto and Friyanti²² on Washington navel orange.

CONCLUSION

It can be recommended foliar application of glutathione 50 mg L⁻¹, Ca-EDAT 80 mg L⁻¹ and soil potassium sulphate application at 500 g/tree divided to twice, the first after fruit set stage and the second after four weeks later to reduce the fruit creaking, enhancing yield and fruit quality of Washington navel orange.

SIGNIFICANCE STATEMENT

This study reveals that plant nutrition is one of the reliable methods to control fruit creaking and also improve fruit quality. Therefore, in the current study, we applied different concentrations of glutathione (25, 50 and 75 mg L⁻¹), calcium EDTA (40, 80 and 120 mg L⁻¹) and potassium sulphate soil application (250, 500 and 750 g/tree) at two stages on Washington navel orange during two growing seasons (2019 and 2020). It was found that all treatments were effective to reduced fruit creaking percentage as well as enhancing yield and fruit quality. Furthermore, fruit creaking % significantly decreased in response to 50 mg L⁻¹ GSH, 80 mg L⁻¹ Ca and 500 g/tree K. The same treatments

were produced the biggest yield (kg/tree), the highest fruit weight, peel (weight and thickness) and pulp weight. While, treatments of GSH at 75 mg L⁻¹, Ca at 40 mg L⁻¹ and K at 750 g/tree increased the most of fruit chemical parameters such as TSS/ acid ratio, ascorbic acid, total sugars percentage, total pectin and protopectin. Thus, it can have practical application in Washington navel orange orchards to reduce the fruit creaking as well as enhance yield and fruit quality.

REFERENCES

- Juan, L. and C. Jiezhong, 2017. Citrus fruit-cracking: Causes and occurrence. *Hortic. Plant J.*, 3: 255-260.
- Cronje, P.J.R., O.P.J. Stander and K.I. Theron, 2013. *Fruit Splitting in Citrus*. 1st Edn., John Wiley & Sons, Inc. United States, PP: 177-200.
- Standar, O.P.J., K.I. Theron and P.J.R. Cronje, 2014. Foliar 2, 4-D application after physiological fruit drop reduces fruit splitting of mandarin. *HortTechnology*, 24: 717-723.
- Rouhier, N., D.L. Stephane and J.P. Jacquot, 2008. The role of glutathione in photosynthetic organisms: Emerging functions for glutaredoxins and glutathionylation. *Ann. Rev. Plant Biol.*, 59: 143-166.
- Hasanuzzaman, M., K. Nahar, T.I. Anee and M. Fujita, 2017. Glutathione in plants: Biosynthesis and physiological role in environmental stress tolerance. *Physiol. Mol. Biol. Plants*, 23: 249-268.
- Ahmed, F., A. Abdelaal, S.E. El-Masry and M. Metwally, 2019. Trials for improving the productivity and reducing shot berries in superior grapevines by using silicon and glutathione. *J. Product. Dev.*, 23: 23-38.
- Ahmed, F.F., M.R.G. El-Kareem and M.M.M. Oraby, 2013. Response of Zaghloul date palms to spraying boron, silicon and glutathione. *Stem Cell*, 4: 29-34.
- Haikal, A. and A. Gomaa, 2017. Fruiting of "Keitte" mango trees in relation to application of glutathione and boron. *Hortsci. J. Suez Canal Univ.*, 6: 73-80.
- Saied, H., 2019. Effect of spraying fish oil and glutathione on fruiting of ewaise mango trees grown under sandy soil. *Hortsci. J. Suez Canal Uni.*, 8: 95-108.
- Dawood, M.G., M.S. Sadak, B.A. Bakry and H.H. Kheder, 2020. Effect of glutathione and/or selenium levels on growth, yield and some biochemical constituents of some wheat cultivars grown under sandy soil conditions. *Bull. Nat. Res. Cent.*, Vol. 44. 10.1186/s42269-020-00410-z.
- Elmer, P.A.G., T.M. Spiers and P.N. Wood, 2007. Effects of pre-harvest foliar calcium sprays on fruit calcium levels and brown rot of peaches. *Crop Prot.*, 26: 11-18.
- Bonomelli, C. and R. Ruiz, 2010. Effects of foliar and soil calcium application on yield and quality of table grape cv. 'thompson seedless'. *J. Plant Nutr.*, 33: 299-314.
- Chen, F., H. Liu, H. Yang, S. Lai and X. Cheng *et al.*, 2011. Quality attributes and cell wall properties of strawberries (*Fragaria annanassa* duch.) under calcium chloride treatment. *Food Chem.*, 126: 450-459.
- Irfan, P.K., V. Vanjakshi, M.N.K. Prakash, R. Ravi and V.B. Kudachikar, 2013. Calcium chloride extends the keeping quality of fig fruit (*Ficus carica* L.) during storage and shelf-life. *Postharvest Biol. Technol.*, 82: 70-75.
- Davarpanah, S., A. Tehranifar, J. Abadía, J. Val, G. Davarynejad, M. Aran and R. Khorassani, 2018. Foliar calcium fertilization reduces fruit cracking in pomegranate (*Punica granatum* cv. ardestani). *Sci. Horti.*, 230: 86-91.
- Masoud, A.A.B., F.E. Ibraheem and O.A. Khodair, 2019. Effect of gibberellic acid, naphthalenacetic acid, calcium and zinc spraying on fruiting of manfalouty pomegranate trees. *Assiut J. Agric. Sci.*, 50: 219-228.
- Mohamed, A.K.A., H.A. Abdel-Galil and N. Galal, 2020. Effect of some nutrients and amino acids spraying on yield and fruit quality of manfalouty pomegranate. *SVU-Int. J. Agric. Sci.*, 2: 18-29.
- Gaaliche, B., A. Ladhari, A. Zarrelli and M.B. Mimoun, 2019. Impact of foliar potassium fertilization on biochemical composition and antioxidant activity of fig (*Ficus carica* L.). *Sci. Horti.*, 253: 111-119.
- Alva, A.K., D. Mattos, S. Paramasivam, B. Patil, H. Dou and K.S. Sajwan, 2006. Potassium management for optimizing citrus production and quality. *Int. J. Fruit Sci.*, 6: 3-43.
- Sallato, B., C. Bonomelli and J. Martiz, 2017. Differences in quality parameters and nutrient composition in Fukumoto oranges with and without creasing symptoms. *J. Plant Nutr.*, 40: 954-963.
- Ashraf, M.Y., A. Gul, M. Ashraf, F. Hussain and G. Ebert, 2010. Improvement in yield and quality of kinnow (*Citrus deliciosa* × *Citrus nobilis*) by potassium fertilization. *J. Plant Nutr.*, 33: 1625-1637.
- Hardiyanto and F.D. Nirmala, 2019. Application of K, Ca and Mg on peel thickness and fruit cracking incidence of citrus. *RJOAS*, 87: 45-56.
- Wen, A., J. Zhang, Y. Zheng and S. Yi, 2021. Effects of combined potassium and organic fertilizer application on newhall navel orange nutrient uptake, yield and quality. *Agronomy*, Vol. 11. 10.3390/agronomy11101990.
- AOAC., 1984. *Official Methods of Analysis*. 13th Edn., Association of Official Analytical Chemists, Washington, DC., USA., pp: 768-800.
- Ywassaki, L.A. and S.G. Canniatti-Brazaca, 2011. Ascorbic acid and pectin in different sizes and parts of citric fruits. *Cienc. Tecnol. Aliment.*, 31: 319-326.
- Jones, D.H., 1994. *Statistical Methods*. 8th Edn., Iowa State University Press, USA, pp: 304-307.

27. Ogawa, K., 2005. Glutathione-associated regulation of plant growth and stress responses. *Antioxid. Redox Signaling*, 7: 973-981.
28. Foyer, C.H. and B. Halliwell, 1976. The presence of glutathione and glutathione reductase in chloroplasts: A proposed role in ascorbic acid metabolism. *Planta*, 133: 21-25.
29. Qiu, B., F. Zeng, S. Cai, X. Wu, S.I. Haider, F. Wu and G. Zhang, 2013. Alleviation of chromium toxicity in rice seedlings by applying exogenous glutathione. *J. Plant Physiol.*, 170: 772-779.
30. Yu, J., M. Zhu, M. Bai, Y. Xu, S. Fan and G. Yang, 2020. Effect of calcium on relieving berry cracking in grape (*Vitis vinifera* L.) 'Xiangfei'. *PeerJ*, Vol. 8. 10.7717/peerj.9896.
31. Sharma, N. and C. Belsare, 2011. Effect of plant bio-regulators and nutrients on fruit cracking and quality in pomegranate (*Punica granatum* L.) 'G-137' in Himachal Pradesh. *Acta Horti.*, 890: 347-352.
32. Shiri, M.A., M. Ghasemnezhad, J.F. Moghaddam and R. Ebrahimi, 2016. Efficiency of CaCl₂ spray at different fruit development stages on the fruit mineral nutrient accumulation in cv. Hayward kiwifruit. *J. Elem.* 21: 195-209.
33. Masoud, A.A.B., E.M.A. Radwan and E.A.A. Abou-Zaid, 2018. Effect of some micronutrients, silicon and GA₃ spraying on yield and fruit quality of pomegranate. *Assuit. J. Agric. Sci.*, 49: 97-106.
34. Dichala, O., I. Therios, M. Koukourikou-Petridou and A. Papadopoulos, 2018. Nickel effect on pomegranate cracking, nutrient concentrations and biochemical parameters of pomegranate peel. *HortScience*, 53: 1677-1682.
35. Lu, P.L. and C.H. Lin, 2011. Physiology of fruit cracking in wax apple (*Syzygium samarangense*). *Botanica Orientalis: J. Plant Sci.*, 8: 70-76.
36. Chater, J.M. and L.C. Garner, 2018. Foliar nutrient applications to 'wonderful' pomegranate (*Punica granatum* L.). II. Effects on leaf nutrient status and fruit split, yield and size. *Sci. Horti.*, 242: 207-213.
37. Ramezani, A., R. Dadgar and F. Habibi, 2018. Postharvest attributes of "Washington navel" orange as affected by preharvest foliar application of calcium chloride, potassium chloride, and salicylic acid. *Int. J. Fruit Sci.*, 18: 68-84.