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Effects of Water Deficit and Different some Substances Foliar Sprays on Growth, Antioxidants and Biochemical Components in Loquat (*Eriobotrya japonica*) Seedlings

Doaa M. Hamza[1]; M. A. El-Sherpiny[2*] and Doaa S. Mahmoud[3]

[1]Pomology Department, Faculty of Agriculture, Mansoura University, Egypt
[2] Soil & Water and Environment Research Institute, Agriculture Research Center, El-Gama St., Giza, 12619 Egypt
[3]Horticulture Department, Faculty of Agriculture, Zagazig University, Egypt

ABSTRACT

Water scarcity poses a major environmental challenge affecting plant growth and productivity, especially in arid and semi-arid regions like Egypt. This study evaluates the response of loquat (*Eriobotrya japonica*) seedlings to water deficit stress under three irrigation regimes [100%, 66% and 33% of full irrigation requirements (FIR)] and six foliar treatments, including tap water (control), ascorbic acid, salicylic acid, glutathione, potassium silicate and kaolin aiming to enhance the plant's stress tolerance. Growth parameters (*i.e.*, plant height and leaf area), photosynthetic pigments (chlorophyll a and b) and leaf nutrient content (N, P, K) were measured 60 days after treatment initiation. Also, biochemical analyses were conducted to assess antioxidant activity, including enzymatic antioxidants [Superoxide Dismutase, (SOD), catalase (CAT) and Ascorbate Peroxidase (APX)], non-enzymatic antioxidants (total phenol) and malondialdehyde (MDA) levels as a marker of lipid peroxidation and cellular damage. Antioxidant enzyme activities and malondialdehyde (MDA) levels were re-evaluated after two months to monitor adaptive responses to prolonged stress conditions. Preliminary results indicate that reducing irrigation levels to 66% and 33% of FIR notably decreased vegetative growth, while specific foliar treatments mitigated oxidative stress damage by enhancing antioxidant activity, with glutathione being the most effective followed by potassium silicate, ascorbic acid, salicylic acid and letely kaolin. Overall, the findings demonstrate the potential of targeted foliar treatments to improve drought tolerance in loquat seedlings, offering valuable insights for sustainable crop management in water-limited environment conditions.

Keywords: Drought, Malondialdehyde, Oxidative stress, Sustainable agriculture

INTRODUCTION

Loquat trees (*Eriobotrya japonica*) are valuable fruit trees with notable nutritional and economic importance, particularly in Egypt. Their fruits are rich in essential nutrients such as vitamins, minerals and fiber, making them highly sought after in local markets due to their nutritional benefits (Ali *et al.* 2021). Loquat cultivation plays an important role in boosting food security and agricultural diversity in the country, thereby enhancing the value of fruit production (Sagar *et al.* 2020).

However, loquat trees are significantly challenged by drought, a growing concern for agriculture in Egypt, especially in arid and semi-arid regions. Water scarcity severely impacts tree productivity and fruit quality, often triggering an increase in the production of free radicals and reactive oxygen species (ROS) within plant tissues, such as hydrogen peroxide and superoxide radicals. This oxidative stress can cause lipid peroxidation, protein denaturation, and damage to nucleic acids, ultimately compromising the health and productivity of the plant (Wang *et al.* 2021&2023).

To mitigate the adverse effects of water stress, foliar applications of various substances have shown potential for enhancing plant tolerance. Ascorbic acid (vitamin C) is a natural antioxidant that can effectively reduce free radical levels and improve stress resilience (Penella *et al.* 2017). Salicylic acid plays an important role in stimulating plant defense mechanisms and enhancing drought tolerance (Farhan and Rehman, 2023). Glutathione, another vital compound, aids in reducing oxidative stress, thereby enhancing plant resilience (Doklega *et al.* 2024). Potassium silicate strengthens cell walls and enhances water retention capacity (Mosa *et al.* 2022), while kaolin forms a protective layer on the leaf surface, reducing water loss and alleviating stress (Mahmoudian *et al.* 2021).

Therefore, this study aims to evaluate the impact of water deficit on growth and leaf composition in loquat trees and to investigate the effectiveness of foliar treatments in alleviating drought-induced damage, improving drought tolerance and recommending the best foliar application.

MATERIALS AND METHODS

Plant Material and Experimental Location: One-year-old loquat seedlings (*Eriobotrya japonica.* Cv. Gold Nugget), grafted on quince rootstock, were obtained from a private nursery. The seedlings were selected for uniformity in size and health to ensure consistent experimental conditions. The trial was executed at a private farm located in Met Antar village, Talkha district, El-Dakahlia Governorate, Egypt during two successive seasons (2022 and 2023).

Experimental Design and Treatments: The experimental design was a split plot with 5 replicates. The seedlings were subjected to three irrigation regimes, representing different levels of water deficit as the main factor: 100% (control), 66%

* **Corresponding author.**
E-mail address: M_elsherpiny2010@yahoo.com
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and 33% of the Full Irrigation Requirement (FIR). In addition, six foliar treatments were applied as a sub-main factor: tap water (control), ascorbic acid (100 mgL^{-1}), salicylic acid(100 mgL^{-1}, glutathione (50 mgL^{-1}), potassium silicate (0.5%) and kaolin (2%). All foliar treatment solutions were prepared according to concentrations recommended in previous literature, ensuring optimal effectiveness, and the required chemicals were sourced from the Egyptian commercial market.

Irrigation Treatments: Three irrigation treatments were applied to the loquat seedlings to simulate different levels of water deficit stress. The treatments included:

- 100% Full Irrigation Requirement (FIR): This served as the control and provided the full water requirement for optimal growth conditions.
- 66% FIR: This moderate water deficit level provided two-thirds of the full irrigation requirement to simulate moderate drought conditions.
- 33% FIR: This severe water deficit treatment provided only one-third of the full irrigation requirement to create high-stress conditions.

Irrigation amounts were calculated based on the loquat seedlings' estimated water requirements, with each treatment adjusted to match the specified percentage of FIR. The irrigation schedule was consistently maintained to ensure accurate and uniform stress levels across all replicates.

Each irrigation regime was designed to replicate real-world scenarios with varying water availability, allowing for an assessment of the loquat seedlings' tolerance to water stress at different hydration levels. This approach provided insights into the plant's response mechanisms under reduced water availability, as well as the effectiveness of the foliar treatments in enhancing drought resilience.

Foliar Applications: Foliar applications were performed five times throughout the experiment, with a 10 days interval. The spray treatments were carefully applied to ensure complete coverage of the foliage, avoiding runoff. Applications were conducted in the early morning to maximize absorption and minimize evaporation. The first foliar time was after seedlings transportation immediately (one year old for seedlings)**.**

Sampling Schedule: Samples for measuring vegetative growth parameters, photosynthitic pigments and leaf nutrient content were collected 60 days after initiating the treatments. At the same time, biochemical analyses were conducted to assess enzymatic antioxidants, non-enzymatic antioxidants, and malondialdehyde levels, which serve as an indicator of lipid peroxidation and cellular damage.To monitor changes over time, enzymatic antioxidant activity and MDA levels were re-evaluated two months later to observe any adaptive responses to prolonged water deficit stress (Table 1).

Table1. Measurements during the studied stages

Parameters	Methods	References
At 60 days after treatment initiation		
Plant height (cm), seedling fresh and dry weights (g)	Manually	-------------
Leaf area (LA,cm^2 $plant^{-1}$)	LA=Length × Width× Correction factor	[1]
Chlorophyll a & b (mg g^{-1} FW)	Spectrophotometrically, using acetone	[2]
Digestion of leaves	Using a mixture of $HClO_4$ + H_2SO_4	[3]
Loquat leaf chemical NPK (%DW)	Micro-Kjeldahl (for N), spectrophotometric (for P) and flame photometer (for K)	[4]
At 60 and 120 days after treatment initiation		
Malondialdehyde (MDA, nmol.g^{-1})	Spectrophotometrically	[5]
Phenol, mg GAE/g		[6]
Superoxide Dismutase (SOD), catalase (CAT) and Ascorbate Peroxidase (APX), unit mg^{-1}		[7]

List of refs: [1] Garnier *et al.* (2001), [2] Wellburn (1994),[3] Peterburgski (1968),[4] Walinga *et al.* (2013), [5] Valenzuela (1991), [6] Robards, (2003), [7] Elavarthi and Martin, (2010)

Statistical Analysis: Data collected in this study were analyzed using analysis of variance (ANOVA), following procedures outlined by Gomez and Gomez (1984). The least significant difference (L.S.D) method was used to determine the differences between treatment means at the probability of < 0.05. The analysis was performed using the CoStat software package (CoHort Version 6.303, CoHort, USA, 1998–2004).

RESULTS AND DISCUSSION

Growth Parameters

Tables 2 and 3 present the effects of different irrigation regimes, with varying levels of full irrigation requirements (FIR) and foliar spray treatments on the vegetative growth parameters of loquat seedlings. The parameters measured include plant height (cm), seedling fresh weight (F.W, g), seedling dry weight (D.W, g), and leaf area (cm^2 $plant^{-1}$).

Effect of irrigation regimes: The data reveal a clear trend of reduced growth with decreasing irrigation levels. Seedlings irrigated with 100% of FIR exhibited the highest growth parameters across all measured traits, with significant differences compared to the 66% and 33% FIR treatments. For instance, the average plant height under 100% FIR was 84.10 cm, which was significantly greater than the 77.98 cm recorded under 66% FIR, and 66.35 cm observed under 33% FIR. Similarly, seedling fresh weight, dry weight, and leaf area showed the same pattern, with the 33% FIR treatment consistently displaying the lowest values for all parameters. This decline in growth with reduced irrigation aligns with previous studies indicating that water stress limits plant growth by reducing cellular processes and nutrient uptake (Wang *et al.* 2021&2023). The same trend was found during both studied seasons.

Effect of foliar treatments: In terms of foliar treatments, glutathione showed the most positive impact on growth parameters, leading to the highest values for plant height (81.23 cm), fresh weight (104.53 g), dry weight (23.64 g), and leaf area (115.10 cm^2). This suggests that glutathione's role as a powerful antioxidant may play a crucial role in mitigating the oxidative damage caused by water deficit stress (Doklega *et al.* 2024). Following glutathione, potassium silicate and ascorbic acid also had significant positive effects on growth, likely due to their roles in improving cellular integrity and enhancing stress tolerance through antioxidant mechanisms (Mosa *et al.* 2022). The salicylic acid treatment came in the fourth order due to its role as antioxidant (Farhan and Rehman, 2023). The kaolin treatment, while beneficial, was less effective compared to these antioxidants, reflecting its primary role in reducing water loss through its physical properties rather than directly enhancing cellular protection (Mahmoudian *et al.* 2021). The control (tap water) treatment exhibited the lowest growth across all parameters, supporting the notion that water stress without any additional treatments negatively affects the plant's ability to grow and develop. The same trend was found during both studied seasons.

Table 2. Effect of different irrigation regimes [various levels of full irrigation requirements (FIR)] and spraying different stimulants on vegetative growth parameters of loquat seedlings during the first season

Treatments		Plant height, cm	Seedling F.W, g	Seedling D.W, g	Leaf area, cm^2 plant^{-1}
Main factor					
100% of FIR		84.10a	108.83a	24.93a	118.40a
66% of FIR		77.98b	101.75b	23.18b	114.30b
33% of FIR		66.35c	81.26c	16.88c	99.78c
LSD at 5%		3.53	3.25	0.05	1.12
Sub main factor					
Control (Tap water)		68.99e	84.83e	18.75f	104.27d
Kaolin (2%)		73.83d	94.77d	20.76e	109.24c
Salicylic acid (100 mgL^{-1})		75.64cd	97.74c	21.42d	110.54c
Ascorbic acid (100 mgL^{-1})		77.41bc	99.84bc	22.42c	112.05b
Potassium silicate (0.5%)		79.76ab	101.96ab	22.99b	113.74a
Glutathione (50 mgL^{-1})		81.23a	104.53a	23.64a	115.10a
LSD at 5%		3.23	2.90	0.27	1.36
Interaction					
100% of FIR	Control (Tap water)	72.78	90.69	21.29	110.51
	Kaolin	82.29	110.94	24.71	119.20
	Salicylic acid	84.60	111.17	24.82	119.36
	Ascorbic acid	86.59	111.56	25.64	119.70
	Potassium silicate	87.90	112.65	26.16	120.24
	Glutathione	90.43	115.96	26.96	121.37
66% of FIR	Control (Tap water)	72.53	90.19	20.33	107.28
	Kaolin	76.43	97.49	22.24	111.74
	Salicylic acid	77.13	101.69	23.21	113.99
	Ascorbic acid	79.03	104.24	24.19	116.33
	Potassium silicate	81.06	107.50	24.47	117.43
	Glutathione	81.72	109.37	24.65	119.03
33% of FIR	Control (Tap water)	61.66	73.60	14.63	95.03
	Kaolin	62.78	75.89	15.32	96.77
	Salicylic acid	65.18	80.36	16.23	98.27
	Ascorbic acid	66.60	83.73	17.44	100.13
	Potassium silicate	70.33	85.72	18.34	103.56
	Glutathione	71.54	88.27	19.32	104.91
LSD at 5%		5.59	5.02	0.47	2.37

Means within the same column followed by a different letter (s) are statistically different at the probability of 0.05 level

Interaction effect: When analyzing the interaction between irrigation levels and foliar treatments, interesting trends emerge. In the case of the 66% FIR treatment, seedlings that received the studied substances exhibited significantly higher growth than those receiving the control (tap water), even surpassing the 100% FIR treatment with water alone. This suggests that foliar applications, particularly those enhancing antioxidant systems, can partially alleviate the growth limitations imposed by reduced irrigation. These findings align with research by Mahmoudian *et al.* (2021), Mosa *et al.* (2022), Farhan and Rehman, (2023) and Doklega *et al.* (2024), which highlighted the role of antioxidants in enhancing water stress tolerance by reducing oxidative damage. These results indicate that foliar sprays not only support growth under reduced irrigation conditions but can also be more effective than full irrigation alone when coupled with appropriate treatments. The same trend was found during both studied seasons.

Table 3. Effect of different irrigation regimes [various levels of full irrigation requirements (FIR)] and spraying different stimulants on vegetative growth parameters of loquat seedlings during the second season

Treatments		Plant height, cm	Seedling F.W, g	Seedling D.W, g	Leaf area, cm^2 plant^{-1}
Main factor					
100% of FIR		87.13a	112.15a	25.99a	123.95a
66% of FIR		79.64b	104.29b	24.09b	119.93b
33% of FIR		67.65c	83.14c	17.58c	104.84c
LSD at 5%		0.54	0.21	0.16	1.17
Sub main factor					
Control (Tap water)		71.01f	87.82f	19.51f	109.49e
Kaolin (2%)		76.18e	97.52e	21.62e	114.73d
Salicylic acid (100 mgL^{-1})		77.92d	99.80d	22.29d	115.93cd
Ascorbic acid (100 mgL^{-1})		79.39c	101.77c	23.33c	117.26c
Potassium silicate (0.5%)		81.36b	104.08b	23.91b	119.20b
Glutathione (50 mgL^{-1})		82.97a	108.17a	24.64a	120.85a
LSD at 5%		0.71	1.24	0.30	1.43
Interaction					
100% of FIR	Control (Tap water)	76.12	94.68	22.17	116.22
	Kaolin	86.24	115.63	25.77	125.09
	Salicylic acid	88.76	113.34	25.87	125.16
	Ascorbic acid	89.61	113.73	26.73	123.95
	Potassium silicate	89.68	115.15	27.19	126.11
	Glutathione	92.34	120.37	28.20	127.21
66% of FIR	Control (Tap water)	74.06	92.09	21.16	112.48
	Kaolin	78.31	99.53	23.14	117.31
	Salicylic acid	78.56	104.18	24.09	119.82
	Ascorbic acid	80.61	106.24	25.09	122.17
	Potassium silicate	82.78	109.55	25.43	123.07
	Glutathione	83.53	114.16	25.64	124.75
33% of FIR	Control (Tap water)	62.85	76.69	15.21	99.78
	Kaolin	63.98	77.40	15.95	101.79
	Salicylic acid	66.43	81.89	16.93	102.81
	Ascorbic acid	67.94	85.33	18.18	105.65
	Potassium silicate	71.62	87.54	19.12	108.43
	Glutathione	73.05	89.98	20.07	110.60
LSD at 5%		1.23	2.16	0.52	2.48

Means within the same column followed by a different letter (s) are statistically different at the probability of 0.05 level

Photosynthetic pigments and chemical constituents in leaves

Tables 4 and 5 illustrate the effects of various irrigation regimes (different levels of Full irrigation requirements, FIR) and foliar stimulant treatments on the photosynthetic pigments (chlorophyll a & b, mg g^{-1}) and chemical constituents in the leaves (N, P, K, %) of loquat seedlings.

Effect of irrigation regimes: Data from Tables 4 and 5 clearly show a trend of declining photosynthetic pigment and chemical constituent content as the irrigation levels decrease. In the first season, seedlings receiving 100% of FIR exhibited the highest values for chlorophyll a (0.617 mg g^{-1}), chlorophyll b (0.444 mg g^{-1}), nitrogen (2.67%), phosphorus (0.376%) and potassium (2.33%), significantly outperforming the 66% and 33% FIR treatments. This suggests that full irrigation ensures optimal plant water status, which is critical for maintaining high levels of photosynthetic pigments and nutrients essential for plant growth and metabolism. As water availability decreases, photosynthetic efficiency and nutrient uptake are likely restricted, leading to reduced chlorophyll content and nutrient levels, as seen in the 33% FIR treatment where chlorophyll a and b levels were significantly lower (0.537 mg g^{-1} and 0.369 mg g^{-1}, respectively). Similar results were also found in the second season.

Effect of foliar treatments: Among the foliar treatments, glutathione consistently promoted the highest levels of chlorophyll a, chlorophyll b, nitrogen, phosphorus, and potassium. This treatment, known for its antioxidant properties, appears to effectively mitigate oxidative stress induced by water scarcity, thereby enhancing photosynthetic capacity and nutrient assimilation. Following glutathione, potassium silicate also showed considerable benefits, particularly in improving potassium content (2.15% in 1st season) and chlorophyll levels (0.597 mg g^{-1} for chlorophyll a and 0.420 mg g^{-1} for chlorophyll b in 1st season). This is in line with research suggesting that potassium silicate strengthens plant cell walls, increases water use efficiency, and may enhance photosynthetic efficiency under stress conditions. On the other hand, kaolin, a reflective agent used to reduce water loss, improved the chlorophyll content and nutrients moderately but was less effective than glutathione and potassium silicate. Ascorbic acid and salicylic acid treatments showed intermediate improvements in pigment and nutrient levels, with both treatments contributing to enhanced chlorophyll content. Similar results were also observed in the second season.

Table 4. Effect of different irrigation regimes [various levels of full irrigation requirements (FIR)] and spraying different stimulants on photosynthetic pigments and chemical constituents in leaves of loquat seedlings in the first season

Treatments		Chlorophyll a, mg g^{-1}	Chlorophyll b, mg g^{-1}	N, %	P, %	K, %
Main factor						
100% of FIR		0.617a	0.444a	2.67a	0.376a	2.33a
66% of FIR		0.593b	0.401b	2.38b	0.340b	2.09b
33% of FIR		0.537c	0.369c	1.97c	0.287c	1.72c
LSD at 5%		0.007	0.008	0.04	0.001	0.05
Sub main factor						
Control (Tap water)		0.551d	0.374f	2.02f	0.299f	1.82d
Kaolin (2%)		0.574c	0.396e	2.28e	0.328e	2.00c
Salicylic acid (100 mgL^{-1})		0.580c	0.403d	2.35d	0.336d	2.03bc
Ascorbic acid (100 mgL^{-1})		0.589b	0.410c	2.42c	0.341c	2.08b
Potassium silicate (0.5%)		0.597a	0.420b	2.46b	0.347b	2.15a
Glutathione (50 mgL^{-1})		0.604a	0.425a	2.52a	0.354a	2.20a
LSD at 5%		0.008	0.004	0.03	0.003	0.06
Interaction						
100% of FIR	Control (Tap water)	0.572	0.381	2.10	0.313	1.95
	Kaolin	0.617	0.440	2.70	0.380	2.33
	Salicylic acid	0.620	0.455	2.74	0.386	2.36
	Ascorbic acid	0.624	0.460	2.80	0.389	2.40
	Potassium silicate	0.632	0.462	2.82	0.392	2.47
	Glutathione	0.641	0.468	2.88	0.395	2.50
66% of FIR	Control (Tap water)	0.563	0.379	2.05	0.304	1.92
	Kaolin	0.581	0.383	2.20	0.320	2.02
	Salicylic acid	0.589	0.386	2.35	0.338	2.04
	Ascorbic acid	0.603	0.400	2.49	0.347	2.10
	Potassium silicate	0.610	0.425	2.57	0.360	2.19
	Glutathione	0.615	0.432	2.65	0.373	2.25
33% of FIR	Control (Tap water)	0.520	0.363	1.92	0.280	1.60
	Kaolin	0.524	0.365	1.94	0.283	1.64
	Salicylic acid	0.532	0.368	1.97	0.284	1.71
	Ascorbic acid	0.541	0.369	1.98	0.288	1.74
	Potassium silicate	0.550	0.373	2.00	0.290	1.80
	Glutathione	0.555	0.375	2.03	0.295	1.86
LSD at 5%		0.012	0.008	0.05	0.006	0.10

Means within the same column followed by a different letter (s) are statistically different at the probability of 0.05 level

Table 5. Effect of different irrigation regimes [various levels of full irrigation requirements (FIR)] and spraying different stimulants on photosynthetic pigments and chemical constituents in leaves of loquat seedlings in the second season

Treatments		Chlorophyll a, mg g^{-1}	Chlorophyll b, mg g^{-1}	N, %	P, %	K, %
Main factor						
100% of FIR		0.642a	0.455a	2.77a	0.382a	2.42a
66% of FIR		0.606b	0.409b	2.47b	0.345b	2.16b
33% of FIR		0.554c	0.379c	2.05c	0.295c	1.79c
LSD at 5%		0.007	0.008	0.06	0.006	0.10
Sub main factor						
Control (Tap water)		0.566e	0.384f	2.10e	0.305f	1.89d
Kaolin (2%)		0.589d	0.407e	2.37d	0.331e	2.07c
Salicylic acid (100 mgL^{-1})		0.602c	0.412d	2.45c	0.342d	2.13c
Ascorbic acid (100 mgL^{-1})		0.608bc	0.419c	2.52bc	0.349c	2.16bc
Potassium silicate (0.5%)		0.615ab	0.429b	2.55ab	0.356b	2.23ab
Glutathione (50 mgL^{-1})		0.622a	0.434a	2.59a	0.361a	2.27a
LSD at 5%		0.007	0.004	0.07	0.004	0.05
Interaction						
100% of FIR	Control (Tap water)	0.595	0.395	2.21	0.325	2.04
	Kaolin	0.641	0.457	2.83	0.376	2.43
	Salicylic acid	0.643	0.464	2.86	0.388	2.48
	Ascorbic acid	0.648	0.468	2.90	0.397	2.49
	Potassium silicate	0.658	0.471	2.88	0.400	2.52
	Glutathione	0.667	0.478	2.94	0.404	2.55
66% of FIR	Control (Tap water)	0.573	0.388	2.10	0.309	1.97
	Kaolin	0.594	0.391	2.26	0.326	2.08
	Salicylic acid	0.603	0.394	2.45	0.344	2.12
	Ascorbic acid	0.615	0.408	2.59	0.354	2.18
	Potassium silicate	0.622	0.434	2.68	0.366	2.29
	Glutathione	0.627	0.440	2.76	0.372	2.34
33% of FIR	Control (Tap water)	0.531	0.370	2.00	0.281	1.65
	Kaolin	0.533	0.373	2.02	0.291	1.70
	Salicylic acid	0.559	0.379	2.04	0.293	1.78
	Ascorbic acid	0.563	0.381	2.06	0.298	1.80
	Potassium silicate	0.567	0.382	2.08	0.301	1.87
	Glutathione	0.573	0.386	2.09	0.307	1.93
LSD at 5%		0.012	0.008	0.12	0.008	0.15

Means within the same column followed by a different letter (s) are statistically different at the probability of 0.05 level

Interaction effect: The interaction between irrigation levels and foliar treatments revealed that foliar sprays, particularly glutathione and potassium silicate, had a more pronounced effect under moderate (66% FIR) and low (33% FIR) irrigation conditions. For instance, in the 66% FIR treatment during the 1st season, glutathione significantly increased chlorophyll a (0.615 mg g^{-1}), chlorophyll b (0.432 mg g^{-1}), nitrogen (2.65%) and potassium (2.25%) levels compared to the control, even surpassing the 100% FIR treatment with tap water. This suggests that foliar treatments can alleviate some of the negative effects of reduced irrigation on photosynthetic efficiency and nutrient content. In contrast, the 33% FIR treatment exhibited the lowest values for all parameters, with chlorophyll a (0.520 mg g^{-1}), chlorophyll b (0.363 mg g^{-1}) and the nutrients nitrogen (1.92%), phosphorus (0.280%), and potassium (1.60%) showing significant reductions. However, foliar treatments such as glutathione still led to improvements in these parameters, underscoring the importance of antioxidant and nutrient-supporting compounds in mitigating the effects of water stress. The obtained results are in harmony with those of Mahmoudian *et al.* (2021), Mosa *et al.* (2022), Farhan and Rehman, (2023) and Doklega *et al.* (2024). Similar trends were also found during the second season.

Oxidative indicators (Malondialdehyde and phenol)

Tables 6 and 7 display the effects of different irrigation regimes and foliar stimulant treatments on oxidative indicators, specifically Malondialdehyde (MDA) and phenol content in the leaves of loquat seedlings. MDA is a product of lipid peroxidation, indicating oxidative stress, while phenols are compounds associated with plant defense and antioxidative capacity.

Table 6. Effect of different irrigation regimes [various levels of full irrigation requirements (FIR)] and spraying different stimulants on oxidative indicators (Malondialdehyde and phenol) in leaves of loquat seedlings during the first season

Treatments		At 60 days after treatment initiation		At 120 days after treatment initiation	
		MDA, nmol g^{-1}	Phenol, mg GAE/g	MDA, nmol g^{-1}	Phenol, mg GAE/g
Main factor					
100% of FIR		13.94c	45.93b	10.60c	42.81b
66% of FIR		15.10b	47.04b	12.51b	43.76b
33% of FIR		17.76a	50.81a	15.54a	45.96a
LSD at 5%		0.14	2.35	0.17	0.97
Sub main factor					
Control (Tap water)		17.14a	49.48a	14.65a	45.36a
Kaolin (2%)		15.94b	48.46ab	13.45b	44.46b
Salicylic acid (100 mgL^{-1})		15.59c	47.97ab	12.80c	44.21bc
Ascorbic acid (100 mgL^{-1})		15.30d	47.54ab	12.43d	43.92cd
Potassium silicate (0.5%)		14.98e	47.21b	12.18e	43.67d
Glutathione (50 mgL^{-1})		14.65f	46.89b	11.80f	43.43d
LSD at 5%		0.20	2.18	0.18	0.50
Interaction					
100% of FIR	Control (Tap water)	16.20	47.53	13.55	44.49
	Kaolin	13.65	45.74	10.92	42.90
	Salicylic acid	13.53	45.90	9.94	42.72
	Ascorbic acid	13.54	45.76	9.83	42.45
	Potassium silicate	13.43	45.46	9.76	42.09
	Glutathione	13.31	45.17	9.61	42.18
66% of FIR	Control (Tap water)	16.58	48.71	13.89	44.76
	Kaolin	15.81	47.80	13.22	44.05
	Salicylic acid	15.35	46.65	12.58	43.79
	Ascorbic acid	14.80	46.54	12.23	43.48
	Potassium silicate	14.26	46.34	11.91	43.43
	Glutathione	13.79	46.22	11.25	43.04
33% of FIR	Control (Tap water)	18.65	52.19	16.53	46.83
	Kaolin	18.35	51.83	16.21	46.44
	Salicylic acid	17.89	51.37	15.87	46.12
	Ascorbic acid	17.55	50.33	15.22	45.83
	Potassium silicate	17.26	49.83	14.88	45.49
	Glutathione	16.84	49.30	14.54	45.07
LSD at 5%		0.34	3.76	0.31	0.87

Means within the same column followed by a different letter (s) are statistically different at the probability of 0.05 level

Effect of irrigation regimes: The data indicate a significant increase in both MDA and phenol content as irrigation levels decrease. In the first season, seedlings irrigated with 100% of FIR had the lowest MDA (13.94 nmol g^{-1}) and phenol (45.93 mg GAE/g) content at 60 days after treatment, and similar trends were observed at 120 days (10.60 nmol g^{-1} MDA, 42.81 mg GAE/g phenol). This suggests that full irrigation helps maintain cellular integrity and reduces oxidative stress in loquat seedlings. On the other hand, plants subjected to 66% FIR showed increased oxidative stress, as evidenced by higher MDA (15.10 nmol g^{-1} in 1st season) and phenol (47.04 mg GAE/g in 1st season) content compared to the full irrigation treatment. The 33% FIR treatment resulted in the highest MDA (17.76 nmol g^{-1} in 1st season) and phenol (50.81 mg GAE/g in 1st season) levels, both at 60 and 120 days, which indicates a higher degree of oxidative stress due to water deficit. These findings suggest that reduced irrigation negatively impacts the plant's antioxidant defense mechanisms, leading to increased lipid peroxidation and phenolic accumulation. The same trend was achieved during the second season.

Table 7. Effect of different irrigation regimes [various levels of full irrigation requirements (FIR)] and spraying different stimulants on oxidative indicators (Malondialdehyde and phenol) in leaves of loquat seedlings during the second season

Treatments		At 60 days after treatment initiation		At 120 days after treatment initiation	
		MDA, nmol g^{-1}	Phenol, mg GAE/g	MDA, nmol g^{-1}	Phenol, mg GAE/g
Main factor					
100% of FIR		12.94c	46.91c	9.82c	44.10c
66% of FIR		13.92b	48.20b	11.54b	45.10b
33% of FIR		16.38a	51.89a	14.36a	47.57a
LSD at 5%		0.17	0.12	0.15	0.86
Sub main factor					
Control (Tap water)		15.80a	50.69a	13.62a	46.77a
Kaolin (2%)		14.69b	49.52b	12.40b	45.90b
Salicylic acid (100 mgL^{-1})		14.39c	49.11bc	11.79c	45.62bc
Ascorbic acid (100 mgL^{-1})		14.18d	48.56cd	11.42d	45.28cd
Potassium silicate (0.5%)		13.93e	48.22de	11.25e	44.99d
Glutathione (50 mgL^{-1})		13.50f	47.91e	10.94f	44.98d
LSD at 5%		0.18	0.60	0.16	0.60
Interaction					
100% of FIR	Control (Tap water)	15.00	48.62	12.76	45.88
	Kaolin	12.64	46.62	10.05	44.19
	Salicylic acid	12.48	46.98	9.14	43.94
	Ascorbic acid	12.63	46.66	9.02	43.69
	Potassium silicate	12.65	46.56	9.04	43.22
	Glutathione	12.26	46.03	8.87	43.68
66% of FIR	Control (Tap water)	15.24	50.07	12.80	46.25
	Kaolin	14.56	48.99	12.20	45.30
	Salicylic acid	14.21	47.88	11.59	44.99
	Ascorbic acid	13.65	47.60	11.23	44.74
	Potassium silicate	13.16	47.27	10.98	44.85
	Glutathione	12.73	47.39	10.42	44.48
33% of FIR	Control (Tap water)	17.16	53.38	15.30	48.19
	Kaolin	16.88	52.96	14.93	48.21
	Salicylic acid	16.49	52.47	14.64	47.92
	Ascorbic acid	16.26	51.41	14.02	47.40
	Potassium silicate	15.99	50.84	13.72	46.90
	Glutathione	15.50	50.30	13.53	46.79
LSD at 5%		0.31	1.02	0.28	1.04

Means within the same column followed by a different letter (s) are statistically different at the probability of 0.05 level

Effect of foliar treatments: Among the foliar treatments, tap water (control) resulted in the highest MDA (17.14 nmol g^{-1} at 60 days in 1st season) and phenol (49.48 mg GAE/g in 1st season) content at 60 days after treatment. This could be due to the inherent stress of water application alone without additional stimulants. Kaolin, a reflective foliar spray, reduced oxidative stress, as it showed significantly lower MDA levels compared to the control at both 60 and 120 days. Similarly, salicylic acid and ascorbic acid, both known for their role in enhancing plant defense systems, helped reduce MDA and phenol levels relative to the control. Specifically, salicylic acid showed moderate improvements in oxidative stress markers, particularly at 60 days (MDA: 15.59 nmol g^{-1}, phenol: 47.97 mg GAE/g in 1st season). Ascorbic acid also performed well, lowering MDA and phenol content at both sampling times. Potassium silicate and glutathione treatments were more effective in reducing MDA and phenol content at 60 days but showed less pronounced effects at 120 days, suggesting a temporary boost in oxidative stress protection. At 60 days, glutathione was particularly effective in reducing MDA (14.65 nmol g^{-1} in 1st season) and phenol (46.89 mg

GAE/g in 1st season) compared to other treatments. Similar findings were achieved during the second season.

Interaction effect: The interaction between irrigation regimes and foliar treatments showed that at 100% FIR, foliar treatments like kaolin and glutathione were particularly effective in reducing oxidative indicators. At 66% FIR, although the levels of MDA and phenol increased, foliar treatments such as kaolin and salicylic acid still helped mitigate some oxidative stress. In the most severe water deficit condition (33% FIR), salicylic acid and glutathione helped reduce MDA and phenol levels relative to the untreated control, but oxidative stress remained high. For example, in the 33% FIR treatment, kaolin reduced phenol content (51.83 mg GAE/g in 1st season) compared to the control (52.19 mg GAE/g in 1st season), while glutathione also exhibited protective effects. However, these treatments did not fully prevent the increase in MDA and phenol content, which indicates the overriding influence of water stress in inducing oxidative damage. The obtained results are in agreement with those of Wang *et al.* (2021&2023). Similar findings were achieved during the second season.

Enzymatic antioxidants (SOD, CAT, APX)

Tables 8 and 9 reflect the effects of varying irrigation regimes and foliar treatments on enzymatic antioxidants (SOD, CAT, and APX) in loquat seedlings. At both 60 and 120 days after treatment initiation, the results demonstrate that reduced irrigation levels (66% and 33% FIR) as well as foliar applications led to significant changes in antioxidant enzyme activities.

Table 8. Effect of different irrigation regimes [various levels of full irrigation requirements (FIR)] and spraying different stimulants on enzymatic antioxidants (SOD, CAT, APX) in leaves of loquat seedlings during the first season

Treatments		At 60 days after treatment initiation			At 120 days after treatment initiation		
		SOD	CAT	APX	SOD	CAT	APX
		(unit mg^{-1} protein^{-1})					
Main factor							
100% of FIR		59.77a	6.31a	10.66a	61.18c	7.64c	10.17c
66% of FIR		56.31b	5.18b	9.76b	66.26b	8.47b	12.02b
33% of FIR		48.24c	4.04c	8.53c	7٥.12a	9.22a	14.98a
LSD at 5%		0.46	0.05	0.45	0.20	0.24	0.44
Sub main factor							
Control (Tap water)		50.46f	4.36f	8.74d	73.05a	9.02a	14.20a
Kaolin (2%)		53.66e	4.94e	9.45c	68.62b	8.67ab	12.76b
Salicylic acid (100 mgL^{-1})		54.61d	5.10d	9.68bc	٦7.41c	8.53bc	12.43bc
Ascorbic acid (100 mgL^{-1})		55.71c	5.33c	9.84abc	66.94d	8.32bcd	12.01cd
Potassium silicate (0.5%)		56.68b	5.56b	10.00ab	65.26e	8.16cd	11.65de
Glutathione (50 mgL^{-1})		57.52a	5.77a	10.18a	63.84f	7.96d	11.32e
LSD at 5%		0.71	0.06	0.41	0.81	0.39	0.59
Interaction							
100% of FIR	Control (Tap water)	54.05	4.68	9.08	69.82	8.71	13.25
	Kaolin	59.54	6.09	10.64	60.19	8.07	10.04
	Salicylic acid	60.28	6.38	10.81	60.05	7.78	9.82
	Ascorbic acid	61.02	6.65	11.01	59.70	7.43	9.49
	Potassium silicate	61.56	6.91	11.14	59.06	7.08	9.31
	Glutathione	62.14	7.13	11.25	58.27	6.75	9.13
66% of FIR	Control (Tap water)	52.85	4.58	9.10	70.49	8.89	13.65
	Kaolin	55.14	4.84	9.40	68.42	8.59	12.75
	Salicylic acid	56.07	5.00	9.60	67.03	8.58	12.24
	Ascorbic acid	57.03	5.28	9.88	66.22	8.35	11.68
	Potassium silicate	58.02	5.55	10.16	64.20	8.29	11.17
	Glutathione	58.78	5.82	10.42	61.19	8.11	10.65
33% of FIR	Control (Tap water)	44.48	3.81	8.05	78.83	9.44	15.71
	Kaolin	46.29	3.88	8.32	77.26	9.34	15.48
	Salicylic acid	47.49	3.91	8.62	٧٥.14	9.23	15.22
	Ascorbic acid	49.07	4.05	8.62	74.89	9.19	14.84
	Potassium silicate	50.45	4.21	8.70	72.52	9.10	14.46
	Glutathione	51.64	4.37	8.88	72.07	9.02	14.16
LSD at 5%		1.23	0.11	0.72	1.39	69.82	1.02

Means within the same column followed by a different letter (s) are statistically different at the probability of 0.05 level

Effect of irrigation regimes: At the first stage (60 days after treatment initiation), it was noticed that the highest values for the enzymatic antioxidants SOD, CAT and APX were observed in plants receiving 100% of the Full irrigation requirements. This suggests that this irrigation regime provides optimal conditions for enhancing antioxidant enzyme activity, helping the plant combat reactive oxygen species (ROS) damage. Under the 66% FIR, the values of SOD, CAT and APX were lower compared to the 100% FIR treatment but higher than those under the 33% FIR treatment. This indicates that reducing irrigation may still stimulate the plant to improve its antioxidant capacity, as it responds to environmental stress. On the other hand, the lowest enzymatic antioxidant values were recorded under the treatment of 33% FIR.

On the contrary, at the second stage (120 days after treatment initiation), the 33% of FIR treatment consistently exhibited the highest levels of antioxidant activity, particularly in SOD and APX, suggesting an adaptive response to drought stress. This highlights the loquat seedlings' ability to activate defense mechanisms under water deficit conditions. The same trend was found during both studied seasons.

Effect of foliar treatments: In terms of foliar treatments, glutathione and potassium silicate emerged as the most effective in enhancing antioxidant activity, followed by ascorbic acid then salicylic acid then kaolin and lately the control (tap water). In the

1st stage, glutathione treatment showed consistently high levels of enzymatic antioxidants, particularly SOD, suggesting its potential to boost the plant's resistance to oxidative stress under challenging conditions. While, in 2nd stage, the control treatment (tap water) had the highest values for antioxidant enzymes among all treatments, indicating that the plants were needed to produce more antioxidant defense to face the environmental stress in this stage.

Table 9. Effect of different irrigation regimes [various levels of full irrigation requirements (FIR)] and spraying different stimulants on enzymatic antioxidants (SOD, CAT, APX) in leaves of loquat seedlings during the second season

Treatments		At 60 days after treatment initiation			At 120 days after treatment initiation		
		SOD	CAT	APX	SOD	CAT	APX
		(unit mg^{-1} $protein^{-1}$)					
Main factor							
100% of FIR		60.58a	6.53a	10.95a	63.49c	7.85c	10.34c
66% of FIR		57.05b	5.29b	9.95b	68.60b	8.65b	12.23b
33% of FIR		48.97c	4.14c	8.82c	77.86a	9.42a	15.30a
LSD at 5%		0.87	0.09	0.17	0.81	0.43	0.06
Sub main factor							
Control (Tap water)		51.17f	4.49f	8.99f	75.75a	9.27a	14.44a
Kaolin (2%)		54.40e	5.10e	9.69e	71.17b	8.87b	12.94b
Salicylic acid (100 mgL^{-1})		55.32d	5.26d	9.87d	69.83c	8.71bc	12.68c
Ascorbic acid (100 mgL^{-1})		56.51c	5.46c	10.13c	69.46c	8.49bcd	12.26d
Potassium silicate (0.5%)		57.49b	5.67b	10.28b	67.65d	8.35cd	11.88e
Glutathione (50 mgL^{-1})		58.29a	5.93a	10.49a	66.03e	8.15d	11.55f
LSD at 5%		0.73	0.07	0.13	0.88	0.40	0.15
Interaction							
100 % of FIR	Control (Tap water)	54.82	4.91	9.52	73.34	9.10	13.44
	Kaolin	60.34	6.38	11.02	63.07	8.29	10.20
	Salicylic acid	61.02	6.68	11.05	62.94	7.94	9.98
	Ascorbic acid	61.96	6.87	11.23	61.82	7.61	9.66
	Potassium silicate	62.45	7.05	11.37	60.25	7.24	9.48
	Glutathione	62.88	7.27	11.53	59.49	6.92	9.30
66 % of FIR	Control (Tap water)	53.50	4.67	9.25	71.99	9.11	13.90
	Kaolin	55.91	4.96	9.58	70.16	8.79	12.97
	Salicylic acid	56.70	5.10	9.79	69.77	8.74	12.44
	Ascorbic acid	57.76	5.39	10.11	68.81	8.53	11.86
	Potassium silicate	58.88	5.66	10.34	67.18	8.46	11.36
	Glutathione	59.55	5.94	10.63	63.70	8.27	10.85
33 % of FIR	Control (Tap water)	45.20	3.89	8.20	81.91	9.60	15.99
	Kaolin	46.94	3.96	8.48	80.28	9.53	15.65
	Salicylic acid	48.25	3.99	8.77	76.79	9.44	15.60
	Ascorbic acid	49.82	4.13	9.04	77.74	9.32	15.25
	Potassium silicate	51.14	4.28	9.13	75.52	9.35	14.81
	Glutathione	52.44	4.59	9.31	74.89	9.26	14.51
LSD at 5%		1.27	0.13	0.22	1.52	0.68	0.26

Means within the same column followed by a different letter (s) are statistically different at the probability of 0.05 level

The direction of the enzymatic antioxidant activity changed between the two sampling times (60 and 120 days) due to the dynamic adaptation of loquat seedlings to prolonged water deficit stress. In the first 60 days, glutathione and potassium silicate were the most effective treatments, showing a significant increase in enzymatic antioxidants, particularly SOD. This suggests that these treatments effectively enhanced the seedlings' immediate defense against oxidative stress caused by water deficit. However, after 120 days, a shift in the pattern was observed. While glutathione continued to promote antioxidant activity, its effect was slightly reduced compared to the initial stage. This decrease could reflect the plant's acclimatization to the stress, with a more balanced antioxidant defense mechanism developed over time. Other treatments, such as salicylic acid and ascorbic acid, began to show more prominent effects as the plants adapted, indicating that these treatments might contribute to long-term stress tolerance. Thus, while glutathione was highly effective early on, other foliar treatments displayed a more balanced impact over time, highlighting the complexity of the plant's response to prolonged water stress. These findings are in accordance with those of Wang *et al.* (2021&2023). The same trend was found during both studied seasons.

Interaction effect: The interaction between irrigation regimes and foliar treatments further emphasizes the significance of combining these strategies. Under full irrigation (100% FIR), the foliar treatments enhanced antioxidant activity, but at reduced irrigation levels (66% and 33% FIR), the beneficial effects of these treatments became more pronounced. This suggests that foliar applications can be particularly useful in mitigating the adverse effects of water scarcity, enhancing the plant's stress tolerance.

CONCLUSION

In conclusion, this study emphasizes the detrimental effects of reduced irrigation on loquat seedling growth, with 66% and 33% FIR leading to significant decreases in vegetative growth. However, foliar treatments, particularly glutathione and potassium silicate, proved effective in enhancing antioxidant activity, mitigating oxidative stress and improving drought tolerance. These findings underscore the potential of using specific foliar treatments to enhance plant resilience in water-scarce environments. It is recommended to implement moderate irrigation regimes (66% FIR) combined with foliar applications of glutathione or potassium silicate as a sustainable strategy for improving loquat growth and productivity under drought conditions.

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تأثير نقص المياه و معاملات الرش الورقي ببعض المواد المختلفة على النمو، ومضادات الأكسدة، وبعض المكونات الكيميائية في شتلات البشملة

دعاء مصطفي حمزه إبراهيم سيد الاهل[١]، محمد عاطف الشربيني [٢] و دعاء صبري محمود محمد[٣]

[١] قسم الفاكهة ، كلية الزراعة ، جامعة المنصورة
[٢] معهد بحوث الأراضي والمياه والبيئة، مركز البحوث الزراعية، ش الجامعة، الجيزة، ١٢٦١٩ مصر
[٣] قسم البساتين، كلية الزراعه، جامعة الزقازيق

الملخص

تعتبر ندرة المياه تحدٍ بيئي كبير يؤثر على نمو وإنتاجية النباتات، خاصة في المناطق الجافة وشبه الجافة مثل مصر. تقيم هذه الدراسة استجابة شتلات البشملة (*Eriobotrya japonica*) للإجهاد الناتج عن نقص المياه تحت ثلاثة أنظمة ري [١٠٠%، ٦٦% و٣٣% من الاحتياجات المائية الكاملة (FIR)] وستة معاملات رش، تشمل الماء العادي (كنترول)، حمض الأسكوربيك، حمض الساليسيليك، الجلوتاثيون، سليكات البوتاسيوم، والكاؤلين بهدف تعزيز تحمل النبات للإجهاد. تم قياس مؤشرات النمو (مثل طول النبات والمساحة الورقية)، صبغات البناء الضوئي (الكلوروفيل أ و ب) ومحتوى العناصر الغذائية في الأوراق (N، P، K) بعد ٦٠ يومًا من بدء رش المعاملات. كما أجريت تحليلات كيميائية حيوية لتقييم نشاط مضادات الأكسدة، مثل مضادات الأكسدة الإنزيمية [السوبرأوكسيد (SOD)، الكاتالاز (CAT)، بيروكسيداز (APX)]، ومضادات الأكسدة غير الإنزيمية (الفينولات الكلية)، ومستويات المالونداي‌الدهيد (MDA) كمؤشر على أكسدة الخلايا وتلفها . تمت إعادة تقييم نشاط إنزيمات مضادات الأكسدة ومستويات MDA بعد شهرين لرصد الاستجابات التكيفية تحت الإجهاد المطول. تشير النتائج الأولية إلى أن مستويات الري المنخفضة (٦٦% و٣٣% من FIR) قللت بشكل ملحوظ من النمو الخضري، بينما ساهمت معاملات الرش المدروسة في تقليل أضرار الإجهاد التأكسدي عن طريق تعزيز نشاط مضادات الأكسدة، حيث كان الجلوتاثيون هو الأكثر فعالية، يليه سليكات البوتاسيوم، ثم حمض الأسكوربيك، ثم حمض الساليسيليك، والكاؤلين. بشكل عام، توضح النتائج إمكانية استخدام معاملات رش محددة لتحسين تحمل الجفاف في شتلات البشملة، مما يوفر رؤى قيمة لإدارة المحاصيل بشكل مستدام في البيئات ذات الموارد المائية المحدودة.