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Effects of Agricultural Drainage Water Irrigation and Various Natural Extract Foliar Sprays on Mango Seedlings: An Assessment of Growth, Chemical Content and Antioxidant Activity

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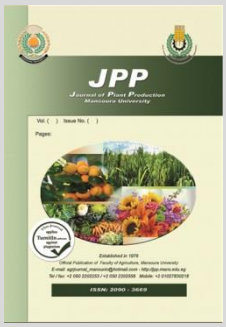

ABSTRACT

The growing scarcity of freshwater resources necessitates alternative irrigation options, such as agricultural drainage water. Mango seedlings, known for their sensitivity to water quality, face both risks and benefits from wastewater use. So, this study evaluated the response of mango seedlings to subjected to three irrigation treatments as main factor: Freshwater, agricultural drainage water and a 50:50 mix of both. Seedlings also received six foliar treatments: Garlic extract, seaweed extract, yeast extract, ginger extract, lemongrass extract and a control (tap water only). Sixty days after treatment initiation, vegetative growth parameters, photosynthetic pigments and leaf nutrient content were measured, alongside biochemical markers (POD, PPO, APX enzymes, proline and malondialdehyde MDA) to assess oxidative stress. After 120 days, antioxidant enzyme activity, proline and MDA levels were re-evaluated to monitor adaptive responses to prolonged stress. The results demonstrated that mango seedlings irrigated with agricultural drainage water and sprayed with garlic or seaweed extract showed significant improvements in growth, photosynthetic pigments and leaf nutrient content compared to other treatments. Also, irrigation with agricultural drainage water significantly increased MDA and proline, indicating oxidative stress. Foliar application of garlic extract reduced MDA and proline, suggesting reduced cellular damage. Garlic and seaweed extracts effectively enhanced antioxidant defenses, particularly under wastewater irrigation. Enzyme activities (POD, PPO, APX) were initially higher with freshwater, but after 120 days, both wastewater and mixed treatments showed increased activity, reflecting adaptation over time. In conclusion, agricultural drainage water, paired with specific natural extracts, can support mango irrigation, promoting resilience and growth.

Keywords: Water quality, Oxidative stress, Enzymatic and Non-enzymatic antioxidants

INTRODUCTION

The growing water scarcity in Egypt underscores the critical need to use agricultural drainage water for irrigation, especially as freshwater resources are dwindling under rising demand. Mango trees (*Mangifera indica* L.), among the most economically important fruit crops in Egypt, are highly valued for their productivity and contribution to the agricultural sector (Hussein and Abd EL-all, 2024). However, mango seedlings are sensitive to water quality, and the use of agricultural drainage water poses potential risks and benefits. While drainage water may contain high levels of salts and other elements, that could negatively impact plant growth,it also offers a practical solution to the water scarcity challenge if managed carefully (Helaly *et al.* 2018).

A mixed irrigation approach, combining agricultural drainage water with freshwater, can help mitigate some of the risks associated with drainage water use while maintaining a sustainable water supply. Additionally, foliar application of natural biostimulants may offer protective effects for plants irrigated with suboptimal water sources.

Garlic extract (*Allium sativum* L.) is widely recognized for its potent antimicrobial and antioxidant properties. Its bioactive compounds, particularly allicin and sulfur-containing compounds, have been shown to inhibit the growth of various pathogens and improve plant health. These antimicrobial properties can help protect plants from diseases, which is particularly valuable when plants are exposed to the additional stresses of lower-quality irrigation water. Additionally, garlic extract also boosts antioxidant enzyme activities, which play a role in scavenging reactive oxygen species (ROS), molecules that accumulate in plants under stress conditions like drought, salinity, and suboptimal water quality (Ali *et al.* 2019; Taha and Aljabary, 2024). This reduction in oxidative stress supports better growth and resilience in mango seedlings, improving their tolerance to potential adverse effects of agricultural drainage water.

Lemongrass extract (*Cymbopogon citratus*) contains a range of bioactive compounds such as citral, limonene, and other essential oils, which possess antimicrobial and antioxidant properties that support plant defenses. These compounds can help mitigate the effects of oxidative stress and bolster the plant's immune response. Lemongrass extract also contains micronutrients and secondary metabolites that contribute to overall plant vigor, enhancing growth and tolerance to adverse conditions (El-Salhy *et al.* 2023; El-Shaboury, 2024). For mango seedlings irrigated with suboptimal water quality, foliar application of

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lemongrass extract may reduce susceptibility to stress-related damage, promoting better growth and adaptation.

Ginger extract (*Zingiber officinale*) is highly valued for its potent antioxidant properties, which help alleviate oxidative stress in plants. It contains bioactive compounds such as gingerols and shogaols, which are known to boost antioxidant enzyme activities in plants. These compounds help protect cell membranes and important cellular components from oxidative damage caused by environmental stresses. In mango seedlings, ginger extract can enhance growth and stress tolerance, particularly when exposed to lower-quality water sources (Awwad *et al.* 2022; Rozhbayani and Al-Hadethi, 2023). By reducing lipid peroxidation and supporting cellular integrity, ginger extract contributes to healthier, more resilient mango seedlings under various irrigation conditions.

Yeast extract (*Saccharomyces cerevisiae*) is another effective biostimulant known for its role in enhancing stress tolerance. It is rich in vitamins, amino acids, proteins, and essential enzymes, which contribute to improved plant growth and resilience. These components boost the plant's metabolism, enhancing the synthesis of proteins and vital molecules necessary for stress adaptation. Moreover, yeast extract provides precursors for the synthesis of antioxidants, which are essential in mitigating oxidative stress (Manea *et al.* 2019; Omar *et al.* 2020). By promoting these stress-response mechanisms, yeast extract may help mango seedlings better adapt to the challenges posed by irrigation with drainage water, promoting overall plant health and growth.

Seaweed extract (*Ascophyllum nodosum*) is valued for its high content of nutrients, growth-promoting hormones, and bioactive compounds that stimulate plant growth and development. It is rich in essential nutrients like potassium, magnesium, and various trace elements, as well as natural plant hormones such as auxins, cytokinins, and gibberellins. These compounds promote root development, increase photosynthetic efficiency, and enhance nutrient uptake, all of which are beneficial to mango seedlings under stress from using mixed or drainage water (Al-Hasany *et al.* 2019; Rajendra *et al.* 2024). Seaweed extract's ability to improve plant metabolic processes makes it particularly suitable as a biostimulant to support the growth of mango seedlings under the varied conditions of alternative irrigation water sources.

The main objective of this study was to evaluate the physiological and biochemical responses of mango seedlings to different irrigation treatments using freshwater, drainage water, and a 50:50 mix of both, along with the effects of natural biostimulants as foliar sprays. The goal was to identify effective strategies to improve mango tolerance to water quality variations, supporting sustainable agriculture under Egypt's water-limited conditions.

MATERIALS AND METHODS

The experiment was conducted during the seasons of 2022 and 2023 to evaluate the effect of different irrigation water types and biostimulant treatments on antioxidant enzymes in mango seedlings. The study was carried out in a private farm, located in the northern part of Egypt (Met Antar village, Talkha district, El-Dakahlia Governorate).

Plant Material:

The experiment used Ewaise cultivar of mango seedlings, which is widely grown in Egypt.

Extracts Preparation:

Each biostimulant extract used in the study (garlic, lemongrass, and ginger) was prepared using fresh plant materials to ensure high bioactive compound content. The extraction process involved the following steps:

Garlic extract: Fresh garlic cloves were thoroughly cleaned, peeled, and then finely ground. The ground garlic was soaked in distilled water at a ratio of 1:10 (w/v) and left to steep for 24 hours at room temperature. The mixture was then filtered through muslin cloth to remove solid residues, producing a clear garlic extract rich in sulfur-containing compounds with antioxidant properties (El-Shaboury, 2024).

Lemongrass extract: Fresh lemongrass leaves were rinsed and chopped into small pieces. These were soaked in distilled water at a 1:10 (w/v) ratio for 24 hours. Afterward, the mixture was filtered to remove leaf residues, resulting in an aqueous lemongrass extract containing essential oils and phenolic compounds known for their antioxidant and antimicrobial activities (El-Shaboury, 2024).

Ginger extract: Fresh ginger rhizomes were cleaned, peeled, and finely grated. The grated ginger was soaked in distilled water at a 1:10 (w/v) ratio and allowed to stand for 24 hours. Following the soaking period, the mixture was filtered to separate the solid particles, yielding a ginger extract containing active compounds such as gingerols and shogaols, which contribute to its antioxidant potential (Awwad *et al.* 2022).

Each extract was freshly prepared and used immediately to maintain its bioactivity when applied as a foliar spray in the experiment.

Yeast extract: To prepare the yeast extract, 5 grams of dry baker's yeast were dissolved in 100 mL of warm distilled water (around 37°C) and left to activate for 15 minutes. Then, 1 gram of sucrose was added to support fermentation, and the mixture was incubated for 1–2 hours. After incubation, the solution was filtered to remove solids, producing a clear extract ready for immediate foliar application (Omar *et al.* 2020).

Seaweed extract: To prepare the seaweed extract, 10 grams of dried seaweed powder were soaked in 100 mL of distilled water. The mixture was heated to 60°C and stirred for 1 hour to ensure thorough extraction of bioactive compounds. After cooling, the solution was filtered to remove any solid residues, yielding a clear seaweed extract suitable for use in foliar applications (Rajendra *et al.* 2024).

The chemical analysis of the five extracts was conducted following the method outlined by Harborne, (1984), and the concentrations of essential nutrients were found as follows: Nitrogen (N) content was 0.7%, 0.8%, 1.5%, 1.9% and 2.0% for lemongrass extract, ginger extract, yeast extract, seaweed extract, and garlic extract, respectively. Phosphorus (P) content was 0.15%, 0.15%, 0.21%, 0.20% and 0.30% for lemongrass extract, ginger extract, yeast extract, seaweed extract, and garlic extract, respectively. Potassium (K) content was 0.7%, 1.45%, 2.0%, 1.99% and 3.0% for lemongrass extract, ginger extract, yeast extract, seaweed extract, and garlic extract, respectively. Iron (Fe) content was 22.3, 24.35, 30.15, 28.12 and 29.9 $mgkg^{-1}$ for lemongrass extract, ginger extract, yeast extract, seaweed extract, and garlic extract, respectively.

Zinc (Zn) content was 10.2, 10.9, 15.15, 19.2 and 21.3 mgkg^{-1} for lemongrass extract, ginger extract, yeast extract, seaweed extract, and garlic extract, respectively.

Experimental Design and Treatments:

The experiment was arranged in a split-plot design, with irrigation water as the main plot factor and biostimulant treatments as the subplot factor. Each treatment combination was replicated five times, with each replicate represented by a single pot. This design provided sufficient replication for accurate statistical analysis of the results. The main plot treatments included three types of irrigation water:

- Freshwater (salinity: 0.65 dSm^{-1})
- Agricultural drainage water (salinity: 4.2 dSm^{-1})
- A 50:50 mixture of freshwater and agricultural drainage water

In the subplots, five biostimulant treatments were applied as foliar sprays, along with a control treatment (distilled water):

- Control (tap water only)
- Garlic Extract at 5 mL L^{-1}
- Lemongrass Extract at 5 mL L^{-1}
- Ginger Extract at 5 mL L^{-1}
- Yeast Extract at 3 g L^{-1}
- Seaweed Extract at 3 g L^{-1}

Application of Irrigation and Foliar Spray Treatments

Irrigation treatments were applied to mango seedlings throughout the study period, using the studied different water types. Each irrigation type was consistently provided according to the main plot allocations. The irrigation was conducted regularly based on the tree seedlings' water requirements. Foliar applications of biostimulants were administered five times throughout the experiment at 10-day intervals, beginning one month after transplanting. Each foliar application was conducted in the early morning, covering the leaves thoroughly to ensure optimal absorption under varying irrigation and stress conditions.

Measurements and Sampling Schedule

Growth parameters: Measurements of plant height (cm), seedling fresh and dry weights (g) and leaf area (cm^2 plant^{-1}, according to Garnier *et al.* 2001) were taken at 60 days after initiating treatments to assess growth responses under different irrigation and foliar spray treatments.

Photosynthetic pigments: Chlorophyll content (chlorophyll a and b, mg g^{-1} FW) was analyzed in leaf samples taken at 60 days to determine the effect of treatments on the photosynthetic efficiency of mango seedlings according to Wellburn, (1994).

Leaf mineral content: Samples were taken at 60 days to assess essential nutrient levels (*e.g.*, nitrogen, potassium and phosphorus,%) in the leaves, which reflect the plant's nutritional status and uptake efficiency under different water types and foliar treatments as described by Walinga *et al.* (2013), as the digestion of leaves was done according to the method described by Peterburgski (1968).

Antioxidant Enzyme Activity: Leaf samples were collected at 60 and 120 days post-treatment to evaluate antioxidant enzyme activities, including peroxidase (POD, unit mg^{-1} protein^{-1}), polyphenol oxidase (PPO, unit mg^{-1} protein^{-1}) and ascorbate peroxidase (APX, unit mg^{-1} protein^{-1}), which were analyzed according to the methods described by Elavarthi and Martin, (2010). These enzymes serve as indicators of oxidative stress and the plant's defense response. Also, Malondialdehyde (MDA, nmol. g^{-1}) and proline (µmol g^{-1}) were measured in both studied stages as described by Valenzuela, (1991) and Ábrahám *et al.* (2010), respectively.

These measurements were carefully timed to capture the plants' responses over two critical growth stages, helping to evaluate the combined impact of irrigation salinity and biostimulant application on the growth, stress tolerance, and physiological performance of mango seedlings.

Statistical Analysis

The data obtained from this study were subjected to analysis of variance (ANOVA) using the methods described 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 5%. Statistical analysis was carried out using CoStat software (Version 6.303, CoHort, USA, 1998–2004).

RESULTS AND DISCUSSION

Growth Parameters

Tables 1 and 2 display the effects of different irrigation water types (normal water, agricultural drainage water, and a 50:50 mix of normal and drainage water) along with foliar applications of various biostimulants on the vegetative growth parameters [(plant height(cm), seedling fresh and dry weights (g plant^{-1}) and leaf area (cm^2 plant^{-1})] of mango seedlings over two seasons.

Table 1. Effect of different irrigation water types and spraying some biostimulants on vegetative growth parameters of mango seedlings during the1st season

Treatments		Plant height, cm	Seedling F.W, g	Seedling D.W, g	Leaf area, cm^2 plant^{-1}
Main factor : Irrigation water type (A)					
Normal water		87.23a	105.90a	19.71a	137.68a
Agricultural drainage water		73.70c	77.98c	17.87c	107.82c
Mix (50:50)		84.75b	98.37b	18.93b	124.77b
LSD at 5%		2.15	3.07	0.54	1.21
Sub main factor: foliar application of Biostimulants (B)					
Control (Tap water)		77.60c	84.55e	18.17b	112.84e
Garlic extract		84.20a	100.52a	19.33a	133.44a
Lemongrass extract		80.23bc	91.01d	18.60ab	120.42d
Ginger extract		82.58ab	93.65cd	18.79ab	121.78d
Yeast extract		83.13ab	96.29bc	18.93ab	124.62c
Seaweed extract		83.60ab	98.44ab	19.14a	127.43b
LSD at 5%		3.78	2.74	0.89	1.55
Interaction (A x B)					
Normal water	Control (Tap water)	83.58	92.90	18.60	120.03
	Garlic extract	88.79	110.72	20.28	155.28
	Lemongrass extract	86.85	105.86	19.55	135.46
	Ginger extract	87.35	107.48	19.87	135.93
	Yeast extract	88.47	108.83	19.93	138.56
	Seaweed extract	88.61	109.59	19.95	140.81
Agricultural drainage	Control (Tap water)	66.78	70.55	17.42	102.08
	Garlic extract	77.45	86.59	18.25	113.99
	Lemongrass extract	69.93	71.51	17.55	104.37
	Ginger extract	75.65	75.90	17.71	105.66
	Yeast extract	75.80	79.93	17.98	109.11
	Seaweed extract	76.58	83.29	18.25	111.70
Mix (50:50)	Control (Tap water)	82.45	90.26	18.50	116.43
	Garlic extract	86.73	104.25	19.44	131.06
	Lemongrass extract	83.90	95.67	18.71	121.42
	Ginger extract	84.75	97.55	18.79	123.74
	Yeast extract	85.10	100.16	18.90	126.18
	Seaweed extract	85.63	102.40	19.22	129.79
LSD at 5%		6.55	4.79	1.54	2.70

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

Table 2. Effect of different irrigation water types and spraying some biostimulants on vegetative growth parameters of mango seedlings during the 2nd season

Treatments		Plant height, cm	Seedling F.W, g	Seedling D.W, g	Leaf area, cm^2 $plant^{-1}$
Main factor : Irrigation water type (A)					
Normal water		89.69a	110.39a	20.24a	144.14a
Agricultural drainage water		75.53c	81.02c	18.29c	113.04c
Mix (50:50)		86.73b	102.43b	19.36b	131.08b
LSD at 5%		0.82	1.16	0.37	1.97
Sub main factor: foliar application of Biostimulants (B)					
Control (Tap water)		80.45e	87.95f	18.81e	118.43e
Garlic extract		87.10a	104.78a	19.98a	140.13a
Lemongrass extract		81.95d	94.79e	19.00de	126.46d
Ginger extract		84.28c	97.60d	19.18cd	127.75d
Yeast extract		84.76bc	100.23c	19.29bc	130.22c
Seaweed extract		85.36b	102.35b	19.52b	133.52b
LSD at 5%		1.05	1.18	0.23	1.74
Interaction (A x B)					
Normal water	Control (Tap water)	87.30	96.63	19.41	126.17
	Garlic extract	92.22	115.86	21.07	162.97
	Lemongrass extract	88.75	110.57	20.01	142.13
	Ginger extract	89.02	112.00	20.28	142.66
	Yeast extract	90.39	113.41	20.31	143.16
	Seaweed extract	90.47	113.89	20.35	147.75
Agricultural drainage	Control (Tap water)	68.13	73.43	17.76	106.86
	Garlic extract	80.79	90.15	19.05	119.33
	Lemongrass extract	71.50	74.30	17.92	109.50
	Ginger extract	77.45	78.90	18.12	111.15
	Yeast extract	77.17	82.90	18.32	114.38
	Seaweed extract	78.15	86.46	18.59	117.04
Mix (50:50)	Control (Tap water)	85.93	93.79	19.27	122.26
	Garlic extract	88.30	108.32	19.81	138.09
	Lemongrass extract	85.59	99.50	19.06	127.76
	Ginger extract	86.37	101.89	19.14	129.45
	Yeast extract	86.73	104.38	19.26	133.13
	Seaweed extract	87.47	106.71	19.62	135.79
LSD at 5%		1.82	2.05	0.41	3.01

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

The results indicate that irrigation with normal water achieved the best growth performance, with the highest values recorded for plant height (87.23 cm in the first season and 89.69 cm in the second season), seedling fresh and dry weights and leaf area compared to other treatments. The 50:50 water mix showed intermediate results, superior to agricultural drainage water, which recorded the lowest values. The superior performance of seedlings irrigated with normal water can be attributed to the lower salinity and reduced levels of pollutants compared to agricultural drainage water, which supports efficient nutrient uptake. The 50:50 water mix reduced the concentration of contaminants by diluting the drainage water, resulting in moderate improvement in growth parameters compared to using drainage water exclusively.

Among the foliar applications, garlic extract was the most effective, yielding the highest vegetative growth values compared to other treatments. This can be attributed to its antimicrobial and antioxidant properties, which enhance plant immunity and resilience to stress. Seaweed extract followed closely, showing strong performance thanks to its high nutrient content and growth-enhancing compounds, including natural hormones that promote plant vigor. Yeast extract ranked third, likely due to its provision of essential vitamins and amino acids that enhance stress tolerance. Ginger extract came next, contributing to growth by alleviating oxidative stress through its antioxidant properties. Lemongrass extract, although outperforming the control group, showed the lowest growth improvement among the biostimulants tested.

In terms of interaction effects, using normal water combined with garlic extract showed the highest enhancement in growth parameters compared to other treatments. Meanwhile, the combination of the 50:50 water mix with garlic or seaweed extract helped mitigate stress effects associated with drainage water, demonstrating noticeable growth improvements over drainage water alone. The same trends were observed consistently across both the first and second seasons, indicating that the positive impacts of these treatments were stable throughout the study period. The obtained findings align with previous research that highlighted the effectiveness of garlic and seaweed extracts in enhancing plant growth under non-conventional water irrigation. Both extracts contribute to plants' resilience to environmental stresses, further supporting their potential role in sustainable agriculture (Omar *et al.* 2020; Awwad *et al.* 2022; El-Shaboury, 2024; Rajendra *et al.* 2024; Taha and Aljabary, 2024).

Photosynthetic pigments and chemical constituents in leaves

Tables 3&4 show the effect of different irrigation water types and foliar applications of various biostimulants on photosynthetic pigments (chlorophyll a and b, mg g^{-1}) and chemical composition (N, P and K %) in mango seedling leaves during the first and second seasons.

Regarding irrigation treatments, the best results were observed with normal water, which significantly increased chlorophyll content and nutrient accumulation in the leaves, followed by the mixed (50:50) treatment. Agricultural drainage water produced the lowest values for all measured parameters. This trend indicates that the quality of irrigation water directly affects nutrient uptake and chlorophyll production in mango seedlings. The superior results with normal water can be attributed to its lower salinity and higher quality, which likely promotes better nutrient absorption and physiological processes within the plants. The mixed water treatment, containing a balanced proportion of normal and drainage water, moderately reduced the adverse effects of salinity. In contrast, the drainage water alone likely contains higher levels of salts and contaminants, impairing nutrient absorption and photosynthesis efficiency, which leads to lower chlorophyll and nutrient values in the leaves.

Concerning the foliar applications, the garlic extract exhibited the most significant improvement across all parameters, attributed to its antimicrobial and antioxidant properties that enhance plant immunity and stress resilience. Following garlic, seaweed extract showed strong results due to its nutrient content and natural growth-promoting compounds, including hormones that stimulate chlorophyll production and nutrient accumulation. Yeast extract ranked next, likely benefiting from its protein and vitamin content that aids plant

metabolic processes. Ginger extract was effective as well but ranked lower than the previous treatments, potentially due to its comparatively lower concentration of growth-promoting substances. Finally, lemongrass extract, while beneficial, showed the least improvement, performing slightly better than the control.

Table 3. Effect of different irrigation water types and spraying some biostimulants on photosynthetic pigments and chemical composition in leaves of mango seedlings during the 1st season

Treatments		Chlorophyll a, mg g^{-1}	Chlorophyll b, mg g^{-1}	N, %	P, %	K, %
Main factor : Irrigation water type (A)						
Normal water		0.738a	0.514a	2.80a	0.371a	2.48a
Agricultural drainage water		0.666c	0.444c	2.16c	0.304c	1.99c
Mix (50:50)		0.707b	0.485b	2.52b	0.344b	2.24b
LSD at 5%		0.002	0.005	0.05	0.001	0.05
Sub main factor: foliar application of Biostimulants (B)						
Control (Tap water)		0.676e	0.455d	2.26f	0.315f	2.05e
Garlic extract		0.729a	0.503a	2.65a	0.356a	2.37a
Lemongrass extract		0.695d	0.473c	2.44e	0.333e	2.18d
Ginger extract		0.701cd	0.479c	2.48d	0.338d	2.22cd
Yeast extract		0.708bc	0.485b	2.53c	0.345c	2.28bc
Seaweed extract		0.712b	0.491b	2.59b	0.351b	2.32ab
LSD at 5%		0.008	0.006	0.03	0.004	0.06
Interaction (A x B)						
Normal water	Control (Tap water)	0.692	0.471	2.40	0.331	2.15
	Garlic extract	0.783	0.550	2.96	0.388	2.66
	Lemongrass extract	0.729	0.507	2.81	0.367	2.43
	Ginger extract	0.735	0.513	2.85	0.375	2.49
	Yeast extract	0.741	0.519	2.88	0.379	2.55
	Seaweed extract	0.747	0.525	2.90	0.385	2.61
Agricultural drainage water	Control (Tap water)	0.651	0.429	2.05	0.290	1.89
	Garlic extract	0.680	0.458	2.28	0.319	2.09
	Lemongrass extract	0.657	0.435	2.09	0.294	1.93
	Ginger extract	0.663	0.440	2.13	0.301	1.98
	Yeast extract	0.669	0.447	2.18	0.307	2.02
	Seaweed extract	0.675	0.453	2.23	0.312	2.04
Mix (50:50)	Control (Tap water)	0.686	0.465	2.34	0.325	2.11
	Garlic extract	0.723	0.501	2.71	0.360	2.37
	Lemongrass extract	0.699	0.477	2.43	0.337	2.18
	Ginger extract	0.705	0.483	2.47	0.340	2.21
	Yeast extract	0.713	0.489	2.55	0.349	2.26
	Seaweed extract	0.716	0.494	2.63	0.355	2.32
LSD at 5%		N.S	0.010	0.05	0.006	0.11

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

The interaction between irrigation treatments and foliar sprays reveals that the highest values for all parameters were achieved with normal water combined with garlic extract. This combination seems to maximize chlorophyll content and nutrient levels, followed closely by seaweed extract under normal irrigation. Lower values were noted for all foliar sprays under drainage water irrigation, further illustrating the impact of water quality on the effectiveness of biostimulants. The same trend was found during both studied seasons. The obtained results are in harmony with those of Helaly *et al.* (2018); Ali *et al.* (2019); Al-Hasany *et al.* (2019); Manea *et al*. (2019); El-Salhy *et al.* 2023); Rozhbayani and Al-Hadethi, (2023).

Table 4. Effect of different irrigation water types and spraying some biostimulants on photosynthetic pigments and chemical composition in leaves of mango seedlings during the 2nd season

Treatments		Chlorophyll a, mg g^{-1}	Chlorophyll b, mg g^{-1}	N, %	P, %	K, %
Main factor : Irrigation water type (A)						
Normal water		0.767a	0.535a	2.92a	0.379a	2.56a
Agricultural drainage water		0.692c	0.461c	2.25c	0.312c	2.03c
Mix (50:50)		0.735b	0.504b	2.63b	0.351b	2.30b
LSD at 5%		0.009	0.009	0.05	0.006	0.05
Sub main factor: foliar application of Biostimulants (B)						
Control (Tap water)		0.703e	0.473e	2.35f	0.322d	2.11f
Garlic extract		0.757a	0.523a	2.76a	0.362a	2.45a
Lemongrass extract		0.722d	0.491d	2.54e	0.343c	2.24e
Ginger extract		0.729cd	0.498c	2.59d	0.347c	2.28d
Yeast extract		0.735bc	0.506b	2.64c	0.352b	2.33c
Seaweed extract		0.741b	0.509b	2.69b	0.356b	2.38b
LSD at 5%		0.09	0.006	0.03	0.004	0.03
Interaction (A x B)						
Normal water	Control (Tap water)	0.720	0.490	2.50	0.338	2.26
	Garlic extract	0.814	0.571	3.08	0.395	2.71
	Lemongrass extract	0.757	0.527	2.92	0.381	2.52
	Ginger extract	0.763	0.534	2.98	0.382	2.57
	Yeast extract	0.770	0.541	3.00	0.387	2.63
	Seaweed extract	0.778	0.544	3.02	0.390	2.69
Agricultural drainage	Control (Tap water)	0.677	0.446	2.13	0.296	1.93
	Garlic extract	0.707	0.475	2.38	0.325	2.14
	Lemongrass extract	0.683	0.452	2.17	0.307	1.98
	Ginger extract	0.690	0.457	2.22	0.313	2.02
	Yeast extract	0.695	0.467	2.27	0.313	2.06
	Seaweed extract	0.700	0.470	2.32	0.317	2.08
Mix (50:50)	Control (Tap water)	0.713	0.482	2.44	0.331	2.15
	Garlic extract	0.750	0.523	2.82	0.367	2.49
	Lemongrass extract	0.726	0.495	2.53	0.343	2.22
	Ginger extract	0.735	0.502	2.57	0.346	2.25
	Yeast extract	0.742	0.508	2.67	0.356	2.31
	Seaweed extract	0.744	0.514	2.74	0.360	2.36
LSD at 5%		0.015	0.010	0.05	0.007	0.05

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

Oxidative indicators (Malondialdehyde and proline)

Tables 5 and 6 illustrate the effects of different irrigation water types (normal water, agricultural drainage water, and a 50:50 mix) and foliar applications of various biostimulants (including control, lemongrass extract, ginger extract, yeast extract, seaweed extract and garlic extract) on oxidative indicators [Malondialdehyde (MDA) and proline content] in the leaves of mango seedlings. The data is presented for both the 1st season (Table 5) and 2nd season (Table 6), showing measurements taken after 60 days and 120 days from treatment initiation.

The highest values of MDA and proline were observed in mango seedlings irrigated with agricultural drainage water (21.74 nmol g^{-1} MDA and 12.79 µmol g^{-1} proline after 60 days), indicating higher oxidative stress due to water quality. This was followed by the 50:50 mix treatment, which resulted in intermediate values (18.61 nmol g^{-1} MDA and 10.39 µmol g^{-1} proline), and normal water showed the lowest oxidative stress (16.06 nmol g^{-1} MDA and 9.91 µmol g^{-1} proline). The high values in agricultural drainage water suggest that the salts and other impurities in

this type of water contribute to greater stress and oxidative damage in the plants. Similar trends were observed in the second season, with agricultural drainage water again showing the highest oxidative indicators (20.04 nmol g^{-1} MDA and 11.79 µmol g^{-1} proline after 60 days). The 50:50 mix followed with intermediate values (17.18 nmol g^{-1} MDA and 9.58 µmol g^{-1} proline), while normal water showed the least oxidative stress (14.89 nmol g^{-1} MDA and 9.13 µmol g^{-1} proline).

Table 5. Effect of different irrigation water types and spraying some biostimulants on oxidative indicators (Malondialdehyde and proline) in leaves of mango seedlings during the 1st season

Treatments		After 60 days from treatment initiation		After 120 days from treatment initiation	
		MDA, nmol g^{-1}	Proline, µmol g^{-1}	MDA, nmol g^{-1}	Proline, µmol g^{-1}
Main factor : Irrigation water type (A)					
Normal water		16.06c	9.91c	16.11c	8.63c
Agricultural drainage water		21.74a	12.79a	19.01a	11.26a
Mix (50:50)		18.61b	10.39b	17.24b	9.55b
LSD at 5%		0.21	0.15	0.18	0.07
Sub main factor: foliar application of Biostimulants (B)					
Control (Tap water)		20.91a	12.09a	18.54a	10.80a
Garlic extract		17.33f	10.44f	16.71f	9.22e
Lemongrass extract		19.40b	11.29b	17.77b	10.04b
Ginger extract		18.91c	11.01c	17.49c	9.80bc
Yeast extract		18.41d	10.74d	17.23d	9.60cd
Seaweed extract		17.85e	10.60e	16.99e	9.41de
LSD at 5%		0.23	0.13	0.22	0.28
Interaction (A x B)					
Normal water	Control (Tap water)	19.80	11.19	17.86	10.13
	Garlic extract	14.08	9.51	15.25	8.14
	Lemongrass extract	16.58	9.80	16.27	8.62
	Ginger extract	15.96	9.70	16.02	8.39
	Yeast extract	15.33	9.65	15.78	8.30
	Seaweed extract	14.63	9.59	15.50	8.21
Agricultural drainage water	Control (Tap water)	22.66	13.50	19.65	11.88
	Garlic extract	20.75	11.97	18.35	10.63
	Lemongrass extract	22.29	13.28	19.43	11.63
	Ginger extract	21.95	12.98	19.13	11.39
	Yeast extract	21.59	12.67	18.87	11.12
	Seaweed extract	21.16	12.32	18.64	10.88
Mix (50:50)	Control (Tap water)	20.28	11.58	18.09	10.39
	Garlic extract	17.17	9.84	16.54	8.88
	Lemongrass extract	19.34	10.79	17.59	9.87
	Ginger extract	18.82	10.36	17.31	9.63
	Yeast extract	18.30	9.90	17.05	9.37
	Seaweed extract	17.75	9.89	16.82	9.14
LSD at 5%		0.40	0.22	0.39	0.49

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

A similar trend was found at period 120 days from treatment initiation. These results demonstrate the negative impact of agricultural drainage water on oxidative stress in mango seedlings, which is likely due to the high concentrations of salts and other potential contaminants that stress the plants. The high oxidative indicators in plants irrigated with agricultural drainage water can be attributed to the increased salinity and potential toxicity of ions in the water, leading to the production of reactive oxygen species (ROS). These ROS cause membrane lipid peroxidation, measured by MDA, and also lead to increased proline accumulation, which acts as an osmoprotectant in response to stress. On the other hand, normal water provides a cleaner source, resulting in less oxidative stress, while the mixed water treatment has intermediate effects, possibly due to dilution of the contaminants.

Table 6. Effect of different irrigation water types and spraying some biostimulants on oxidative indicators (Malondialdehyde and proline) in leaves of mango seedlings during the 2nd season

Treatments		After 60 days from treatment initiation		After 120 days from treatment initiation	
		MDA, nmol g^{-1}	Proline, µmol g^{-1}	MDA, nmol g^{-1}	Proline, µmol g^{-1}
Main factor : Irrigation water type (A)					
Normal water		14.89c	9.13c	14.86c	7.97c
Agricultural drainage water		20.04a	11.79a	17.55a	10.38a
Mix (50:50)		17.18b	9.58b	15.89b	8.80b
LSD at 5%		0.19	0.30	0.04	0.11
Sub main factor: foliar application of Biostimulants (B)					
Control (Tap water)		19.38a	11.13a	17.05a	9.96a
Garlic extract		16.01f	9.62e	15.42f	8.52f
Lemongrass extract		18.02b	10.39b	16.41b	9.25b
Ginger extract		17.42c	10.16bc	16.16c	9.04c
Yeast extract		16.96d	9.93cd	15.90d	8.83d
Seaweed extract		16.42e	9.77de	15.66e	8.68e
LSD at 5%		0.21	0.28	0.19	0.11
Interaction (A x B)					
Normal water	Control (Tap water)	18.43	10.28	16.43	9.33
	Garlic extract	13.04	8.78	14.04	7.55
	Lemongrass extract	15.62	9.01	15.07	7.96
	Ginger extract	14.69	8.97	14.78	7.72
	Yeast extract	14.11	8.91	14.54	7.64
	Seaweed extract	13.44	8.83	14.32	7.58
Agricultural drainage water	Control (Tap water)	20.93	12.43	18.08	10.99
	Garlic extract	19.15	11.01	16.94	9.81
	Lemongrass extract	20.53	12.21	17.91	10.70
	Ginger extract	20.26	11.97	17.72	10.51
	Yeast extract	19.88	11.75	17.47	10.23
	Seaweed extract	19.45	11.39	17.15	10.03
Mix (50:50)	Control (Tap water)	18.78	10.67	16.65	9.56
	Garlic extract	15.84	9.08	15.27	8.19
	Lemongrass extract	17.91	9.94	16.24	9.10
	Ginger extract	17.32	9.54	15.96	8.89
	Yeast extract	16.89	9.13	15.69	8.62
	Seaweed extract	16.35	9.09	15.49	8.42
LSD at 5%		0.37	0.47	0.34	0.18

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

The control treatment (tap water) showed the highest levels of malondialdehyde (MDA) and proline (20.91 nmol g^{-1} MDA and 12.09 µmol g^{-1} proline in 1st season at 60 days), indicating higher oxidative stress, likely due to the absence of biostimulants. Lemongrass extract was the least effective in reducing oxidative stress, showing the highest values of MDA and proline, followed by ginger extract and yeast extract, which exhibited intermediate values. Seaweed extract and garlic extract were more effective in reducing oxidative stress, showing the lowest values. This same trend was observed during both stages across both seasons. This suggests that garlic extract was the most effective in minimizing oxidative damage, leading to a reduced need for the plant to produce proline.

The combination of normal water and garlic extract resulted in the lowest oxidative stress, while agricultural

drainage water combined with the control treatment (tap water) led to the highest oxidative stress. These findings suggest that both water quality and foliar treatments significantly impact oxidative stress. The optimal results were achieved when normal water was used alongside effective biostimulants such as garlic extract. Furthermore, the foliar application of all the studied biostimulants, especially garlic extract, helped to reduce oxidative stress under irrigation with agricultural drainage water and the mixed treatment, compared to the normal water without any biostimulant. This trend was consistently observed across both seasons during both studied stages. The obtained results are in agreement with those of Ali *et al.* (2019); Awwad *et al.* (2022); Taha and Aljabary, 2024).

Enzymatic antioxidants (POD, PPO, APX)

Tables 7 and 8 summarize the impact of irrigation water types and biostimulant treatments on antioxidant enzymes (POD, PPO, APX) in mango seedlings' leaves at 60 and 120 days after treatment application across two seasons.

At 60 days, normal water resulted in the highest levels of antioxidant enzymes, with a marked decline at 120 days. Agricultural drainage water exhibited the lowest enzyme levels at 60 days, but enzyme activity increased significantly at 120 days, indicating that polluted water enhanced oxidative stress over time. The 50:50 mixture of normal water and agricultural drainage water showed intermediate results, with enzyme activity rising at 120 days.

Garlic extract was the most effective biostimulant in reducing antioxidant enzyme levels after 120 days, demonstrating a strong antioxidant effect. Lemongrass and ginger extracts also boosted enzyme activity, though less effectively than garlic. The control treatment (tap water) had the least impact on oxidative stress reduction.

At 60 days, plants were likely experiencing oxidative stress and heavily relied on their internal production of antioxidant enzymes. The treatments, particularly the biostimulants, enhanced this defensive response. By 120 days, the biostimulants, especially garlic extract, appeared to reduce oxidative stress, leading to a decrease in the need for high enzyme production. This suggests that external interventions helped alleviate oxidative damage, allowing the plants to rely less on their endogenous antioxidant systems.

Overall, the results highlight the beneficial role of biostimulants, particularly garlic extract, in reducing oxidative stress and enhancing plant resilience over time. This shift in antioxidant enzyme activity reflects the plants' adaptive response to both water quality and foliar treatments. The results are in accordance with the findings of Omar *et al.* (2020); Awwad *et al.* (2022); El-Shaboury, (2024); Rajendra *et al.* (2024); Taha and Aljabary, (2024).

Table 7. Effect of different irrigation water types and spraying some biostimulants on enzymatic antioxidants (POD, PPO, APX) in leaves of mango seedlings during the 1st season

Treatments		After 60 days from treatment initiation			After 120 days from treatment initiation		
		POD	PPO	APX	POD	PPO	APX
		(unit mg^{-1} protein^{-1})					
Main factor : Irrigation water type (A)							
Normal water		0.519a	2.41a	4.59a	0.400c	1.86c	3.60c
Agricultural drainage water		0.354c	1.66c	3.16c	0.581a	2.69a	5.16a
Mix (50:50)		0.474b	2.25b	4.26b	0.491b	2.37b	4.47b
LSD at 5%		0.002	0.01	0.04	0.006	0.02	0.10
Sub main factor: foliar application of Biostimulants (B)							
Control (Tap water)		0.396f	1.85f	3.50f	0.557a	2.61a	5.04a
Garlic extract		0.489a	2.30a	4.34a	0.450f	2.07f	3.97f
Lemongrass extract		0.433e	2.01e	3.87e	0.511b	2.40b	4.60b
Ginger extract		0.445d	2.09d	3.99d	0.491c	2.33c	4.42c
Yeast extract		0.457c	2.16c	4.10c	0.470d	2.25d	4.27d
Seaweed extract		0.472b	2.23b	4.23b	0.463e	2.17e	4.15e
LSD at 5%		0.006	0.06	0.05	0.007	0.03	0.11
Interaction (A x B)							
Normal water	Control (Tap water)	0.435	2.13	3.99	0.528	2.50	4.82
	Garlic extract	0.555	2.55	4.88	0.353	1.44	2.98
	Lemongrass extract	0.511	2.39	4.57	0.414	2.04	3.79
	Ginger extract	0.523	2.44	4.63	0.375	1.87	3.47
	Yeast extract	0.539	2.47	4.69	0.368	1.75	3.35
	Seaweed extract	0.548	2.50	4.80	0.361	1.59	3.18
Agricultural drainage water	Control (Tap water)	0.323	1.32	2.70	0.608	2.80	5.42
	Garlic extract	0.408	1.98	3.64	0.553	2.59	4.93
	Lemongrass extract	0.330	1.45	2.89	0.598	2.73	5.28
	Ginger extract	0.335	1.60	3.04	0.595	2.72	5.21
	Yeast extract	0.348	1.74	3.25	0.569	2.67	5.07
	Seaweed extract	0.379	1.87	3.45	0.560	2.62	5.07
Mix (50:50)	Control (Tap water)	0.429	2.10	3.82	0.536	2.54	4.88
	Garlic extract	0.504	2.37	4.49	0.445	2.17	4.01
	Lemongrass extract	0.459	2.20	4.15	0.521	2.45	4.73
	Ginger extract	0.477	2.24	4.30	0.503	2.41	4.58
	Yeast extract	0.483	2.29	4.38	0.474	2.33	4.40
	Seaweed extract	0.490	2.32	4.44	0.466	2.30	4.20
LSD at 5%		0.009	0.11	0.09	0.012	0.05	0.19

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

Table 8. Effect of different irrigation water types and spraying some biostimulants on enzymatic antioxidants (POD, PPO, APX) in leaves of mango seedlings during the 2nd season

Treatments		After 60 days from treatment initiation			After 120 days from treatment initiation		
		POD	PPO	APX	POD	PPO	APX
		(unit mg^{-1} $protein^{-1}$)					
Main factor : Irrigation water type (A)							
Normal water		0.531a	2.47a	4.73a	0.411c	1.95c	3.75c
Agricultural drainage water		0.375c	1.70c	3.26c	0.593a	2.82a	5.37a
Mix (50:50)		0.494b	2.30b	4.42b	0.506b	2.49b	4.65b
LSD at 5%		0.006	0.03	0.01	0.007	0.03	0.10
Sub main factor: foliar application of Biostimulants (B)							
Control (Tap water)		0.412f	1.90f	3.61f	0.575a	2.74a	5.24a
Garlic extract		0.514a	2.35a	4.50a	0.461f	2.17f	4.13f
Lemongrass extract		0.453e	2.06e	4.00e	0.526b	2.53b	4.78b
Ginger extract		0.466d	2.14d	4.12d	0.504c	2.45c	4.60c
Yeast extract		0.478c	2.21c	4.24c	0.483d	2.35d	4.45d
Seaweed extract		0.490b	2.28b	4.36b	0.474e	2.28e	4.32e
LSD at 5%		0.005	0.03	0.05	0.006	0.03	0.05
Interaction (A x B)							
Normal water	Control (Tap water)	0.451	2.18	4.12	0.541	2.63	5.02
	Garlic extract	0.576	2.60	5.05	0.363	1.51	3.09
	Lemongrass extract	0.522	2.44	4.71	0.428	2.14	3.94
	Ginger extract	0.548	2.50	4.77	0.387	1.96	3.63
	Yeast extract	0.567	2.52	4.83	0.379	1.81	3.48
	Seaweed extract	0.569	2.56	4.93	0.376	1.67	3.31
Agricultural drainage water	Control (Tap water)	0.334	1.36	2.79	0.624	2.93	5.62
	Garlic extract	0.424	2.03	3.77	0.575	2.71	5.14
	Lemongrass extract	0.345	1.49	2.97	0.610	2.87	5.48
	Ginger extract	0.353	1.64	3.13	0.607	2.86	5.42
	Yeast extract	0.362	1.78	3.35	0.588	2.80	5.26
	Seaweed extract	0.395	1.91	3.57	0.572	2.75	5.28
Mix (50:50)	Control (Tap water)	0.448	2.15	3.93	0.551	2.67	5.08
	Garlic extract	0.527	2.42	4.67	0.461	2.29	4.16
	Lemongrass extract	0.479	2.25	4.31	0.544	2.58	4.92
	Ginger extract	0.501	2.29	4.46	0.516	2.52	4.75
	Yeast extract	0.500	2.34	4.54	0.493	2.46	4.60
	Seaweed extract	0.514	2.37	4.58	0.477	2.41	4.38
LSD at 5%		0.008	0.04	0.09	0.016	0.05	0.09

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

CONCLUSION

Finally, this study demonstrates that using agricultural drainage water, when combined with specific foliar biostimulants like garlic and seaweed extracts, can serve as a viable irrigation strategy for mango seedlings, enhancing their resilience and growth under suboptimal water conditions. The application of garlic extract, in particular, effectively mitigated oxidative stress by reducing MDA and proline levels, highlighting its potential as a protective agent against cellular damage. Based on these findings, it is recommending further long-term research to refine the use of drainage water with natural biostimulants to ensure crop safety, productivity, and sustainability. Future studies could explore optimal irrigation intervals, nutrient supplementation, and their effects on fruit quality, which would provide a broader understanding of how such sustainable irrigation practices can be scaled in water-limited agricultural systems.

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تأثير الري بمياه الصرف الزراعي والرش بمستخلصات طبيعية على شتلات المانجو: تقييم النمو، المحتوى الكيميائي، ونشاط مضادات الأكسدة

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[3]قسم الفاكهة ، كلية الزراعة ، جامعة المنصورة

الملخص

تستدعي ندرة المياه العذبة المتزايدة البحث عن خيارات بديلة للري، مثل مياه الصرف الزراعي. تُعد شتلات المانجو حساسة لجودة المياه، وقد تواجه مخاطر وفوائد عند الري بمياه الصرف الزراعي. لذلك، قيّمت هذه الدراسة استجابة شتلات المانجو لريّها بثلاثة معاملات رئيسية: المياه العذبة، مياه الصرف الزراعي، ومزيج بنسبة 50:50 من كليهما. ستة معاملات رش ورقي تشمل مستخلصات الثوم، والطحالب البحرية، والخميرة، والزنجبيل، وحشيشة الليمون، و الكنترول تم تقيمهم. بعد 60 يومًا من بدء المعاملات، تم قياس مؤشرات النمو الخضري، وصبغات البناء الضوئي، ومحتوى العناصر الغذائية في الأوراق، إلى جانب مؤشرات الإجهاد التأكسدي، مثل انزيمات البيروكسيداز (POD) والبوليفينول (PPO) و الأسكوربات (APX)، بالإضافة إلى البرولين والمالونديألدهيد (MDA). وبعد 120 يومًا، أعيد تقييم نشاط الإنزيمات المضادة للأكسدة ومستويات البرولين وMDA لمراقبة الاستجابات التكيفية للإجهاد المطول. أظهرت النتائج أن الشتلات المروية بمياه الصرف الزراعي والتي تم رشها بمستخلص الثوم أو الطحالب البحرية حققت تحسنًا ملحوظًا في النمو وصبغات البناء الضوئي ومحتوى العناصر الغذائية مقارنة بالمعاملات الأخرى. كما زاد الري بمياه الصرف من مستويات MDA والبرولين، مما يشير إلى حدوث إجهاد تأكسدي. وقد ساهم استخدام مستخلص الثوم في تقليل مستويات MDA والبرولين، مما يشير إلى تقليل الضرر التاكسدي. وبرزت مستخلصات الثوم والطحالب البحرية كالأكثر فعالية في تعزيز الدفاعات المضادة للأكسدة، خاصةً في ظل الري بمياه الصرف. كانت أنشطة الإنزيمات (POD، PPO، APX) أعلى في البداية مع المياه العذبة، ولكن بعد 120 يومًا زادت الأنشطة مع معاملات مياه الصرف والخليط، مما يعكس استجابة تكيفية على المدى الطويل. في الختام، يمكن لمياه الصرف الزراعي عند إقرانها ببعض المستخلصات الطبيعية أن تدعم ري المانجو وتعزز من مرونتها ونموها.