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INTERACTIVE EFFECTS OF SALINITY AND WATER DEFICIT STRESSES ON THE GROWTH PARAMETERS AND CHEMICAL COMPOSITION OF *LAGERSTROEMIA INDICA* PLANTS

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ABSTRACT: A pots experiment was conducted to assess the stress effects of salinity and water deficit on *Lagerstroemia indica* L. Salinity stress was imposed by irrigating with saline water at concentrations of 500, 1000, 2000, or 3000 ppm, in addition to the control (tap water of 280 ppm). Whereas water deficit was applied by using tap water for irrigation at intervals of 4, 6, 8, or 10 days. The treatments were arranged in a split-plot design, with the salinity treatments assigned to the main plots and the water deficit treatments assigned to the subplots. The results indicated that vegetative growth and flowering parameters (plant height, number of leaves/plant, number of branches/plant, stem diameter, root length, dry weight of shoots, number of flowers/plant and flower diameter), as well as total chlorophylls, total carbohydrates, N, P, K^+ and Ca^{2+} % were reduced in response to both salinity and water deficit stresses. In contrast, both stresses resulted in an increase in the concentrations of Na^+, Cl^-, proline, total phenolics and antioxidant enzymes activities (CAT, SOD and APX) in leaves. The interaction effects showed that in plants irrigated every 6 or 8 days with tap water or every 4 days using a salt concentration of 1000 or 2000 ppm, the reduction in growth and flowering parameters, total chlorophylls, total carbohydrates, N, P, K^+, and Ca^{2+} % was insignificant. Compared to unstressed plants, the accumulation of harmful Na^+ and Cl^- ions was insignificant in plants that were irrigated every 6 or 8 days with tap water or every 4 days with salinity levels up to 2000 ppm. Based on the findings of this study, it can be concluded that *L. indica* can be irrigated every eight days with tap water or every four days with saline water with concentrations up to 2000 ppm without any significant reduction in most of its vegetative growth and flowering characteristics.

Keywords: *Lagerstroemia indica*, crape myrtle, salinity, drought, antioxidant enzymes.

INTRODUCTION

Lagerstroemia indica L. is a deciduous shrub or small tree belonging to the family of Lythraceae. It is a tropical and subtropical ornamental plant native to China that is also referred to as crape myrtle and crepe flower. In landscape projects, crape myrtle is utilized as a multipurpose, attractive shrub (Odenwald and Turner, 2006). The plant also has a long history of traditional medical uses, such as treating urinary dysfunctions, analgesia, diabetes, diarrhoea, controlling blood pressure and cholesterol levels, narcotics, purgatives, antioxidants, diuretics, gargles, anti-cancer, anti-microbial, anti-inflammatory, and anti-Alzheimer's (Al-Snafi, 2019).

Salinity and drought are prevalent abiotic stresses that inhibit plants' growth and productivity. Both kinds of stress can result in various metabolic, morphological, physiological, and biochemical changes via different mechanisms, lately affecting plant development, growth, and productivity. Plants' reactions to these stressors are rather complicated and rely on different factors, like age, size, genotype and species of plant and time of the stresses. Both stresses cause a reduction in photosynthesis due to the reduction of CO_2 diffusion, may change the production, accumulation, and distribution of a number of phytohormones, encourage the formation of reactive oxygen species (ROS) such as hydroxyl radicals, hydrogen peroxide, singlet oxygen and superoxide in the cells of plants, as well as their accumulation causes harm to plant membrane lipids, proteins, DNA, and nucleic acids due to oxidation. Salt and drought tolerance differs considerably with species and even cultivars inside a species. Plants utilize different techniques to control the harmful impacts of stress like the accumulation of sugars, proline and other osmotic adjusting substances. Salt-adapt plants exclude Na^+ and Cl^- or decrease their accumulation in plant tissues. Under salinity and drought, two systems are mainly involved in removing excessive amounts of ROS; these are the effective non-enzymatic antioxidant defense system, which includes ascorbate, flavonoids, glutathione, tocopherols, and phenolics, as well as the enzymatic antioxidant defense system, which includes catalase (CAT), superoxide dismutase (SOD), and ascorbate peroxidase (APX). Despite the fact that the reactions of plants to salinity are similar to drought, some xerophytes can withstand drought but not salt stress or vice versa (Ma *et al*., 2020). Therefore, assessing the drought and salt tolerance of plants utilized in landscape activities is essential for helpful advice on plant selection.

The interaction effects between salinity and drought stress may provide the correct information on the plant's efficiency in the case of many locations where salinity and drought occur (Saqib *et al*., 2013). Several prior investigations have been undertaken on the interactive results between drought and salinity and its impact on the morphological and physiological parameters of various ornamental plants. The outcomes of these studies elucidated morphological alteration in growth and flowering traits (El-Juhany *et al*., 2014; Ashour and El-Attar 2017; El-Nashar and Hassan, 2020; Sarvandi *et al*., 2020), reduction in the amount of chlorophyll, total carbohydrates, accumulation of nutrients, increase in proline, total phenolic compounds (Ashour and El-Attar 2017; Kumar *et al*., 2017), increase in accumulation of Na^+ or Cl^- (El-Nashar and Hassan, 2020), and activation of antioxidant enzymes (Kumar *et al*., 2017; Plesa *et al*. 2018).

Despite the high interest in *L. indica* in landscape activities in recent years, the information about its responses to salinity and drought stress is limited. Therefore, the study aimed to investigate the effects of salinity and water deficit stresses and their interactions on the growth, flowering and chemical composition of *Lagerstroemia indica* plants to determine the physiological and morphological processes underlying their resistance to salinity and drought.

MATERIALS AND METHODS

The current experiment was conducted at the experimental nursery (under open field conditions, 30-32 °C temperature, 14 h light conditions and 40-61% relative humidity) of the Ornamental Horticulture Department, Faculty of Agriculture, Cairo University, Giza, during the two consecutive seasons of 2021 and 2022. The study aimed to investigate the effects of salinity and water deficit stresses and their interactions on the growth, flowering and chemical composition of *Lagerstroemia indica* plants.

Plant material:

In both seasons, on February 1st, one-year old uniform seedlings of *Lagerstroemia indica* (Dark purple flower color) were purchased from a commercial nursery (Menoufia Governorate) with a plant height of 15-20 cm and two branches per plant. Each seedling was then individually potted in a 30 cm plastic pot with 9 kg of a clay + sand (2:1: v/v) mixture. The physical and chemical characteristics of the utilized soil mix were examined according to (Jackson, 1973) and the results are shown in Table (1).

Experimental procedures:

Treatments were initiated on 1st March in both seasons. To impose salt stress the plants were watered with saline water at concentrations of 500, 1000, 2000 or 3000 ppm, in addition to the control (tap water of 280 ppm). Salinity concentrations were prepared using a mixture of NaCl and $CaCl_2$ (1:1 w/w). Different irrigation intervals of 4, 6, 8 or 10 days with tap water were used to impose water stress. Each time, the amount of water utilized was equal to the field capacity (pot capacity), which was ascertained empirically by filling three pots (30 cm) with around 2 kg of soil mixture, fully watering them to saturation, and then weighing them. Aluminum foil was used to cover the pots to stop evaporation before they were placed in a cool, shaded area for 4 hours to allow water to drain freely. To determine how much water the soil combination could hold, they were once more weighed. The average weight of the three pots used to represent the field capacity was determined to be 1540 g, or 1540 cm^3 or 1.54 l of water (Abd-Elmoneim *et al*., 2018). In accordance with the watering schedule, 1.54 l of water was thus promptly applied to each pot. In other words, at the end of the experiment (after 8 months), plants that received irrigation at intervals of 4, 6, 8, and 10 days received 92.4, 61.6, 46.2, and 37.0 litres of water, respectively. Common agricultural practices were also performed on all the plants including hand weeding, pest and disease management, as well as fertilization with Kristalon (NPK 19:19:19) at 2.5 g/pot every month applied as a soil drench.

Experimental layout:

The experiment was designed as a split-plot design with 20 treatments [5 salt concentrations (including the control, tap water of 280 ppm) × 4 irrigation intervals], and each treatment include 9 pots organized in 3 replicates. Salinity treatments were assigned to the main plots, whereas irrigation intervals were assigned at random under each salinity level to the sub-plots.

The data recorded:

Growth and flowering characteristics:

On November 1st of both seasons, (after 8 months from the beginning of the experiment) the experiment was ended and the vegetative growth attributes were recorded; these included plant height (cm), number of leaves per plant, number of branches per plant, diameter of the stem (mm, at 5 cm above soil surface), length of root (cm) and shoots dry weight (at 70°C till consistent weight). Besides flowering characteristics were collected on flowers number per plant and flower diameter (cm).

Chemical constituents:

Total chlorophylls were evaluated in fresh leaf samples utilizing a chlorophyll meter (SPAD-502, Minolta, Japan). The concentration of total carbohydrates (% D.W) was determined in samples of dried leaves as described by Dubois *et al*. (1956). Samples of dried shoot were digested to extract nutrients and the extract was examined to find out concentrations of nitrogen, phosphorus

Table 1. Some physical and chemical characteristics of the soil mixture used for growing of *Lagerstroemia indica* during 2021 and 2022 seasons.

Physical properties					
Field capacity (% V)	Clay (%)	Coarse sand (%)	Fine sand (%)	Silt (%)	Soil texture
29.58	44	5.2	19	31.8	Clay loam

Chemical properties								
Macro-nutrients (ppm)				PH	Organic matter (%)	EC (dS/m)	CEC (meq/100 g)	$CaCO_3$ (%)
N	P	K	Mg					
67.55	30.95	72.33	35.66	7.24	1.57	1.45	33.94	1.34

EC: Electrical conductivity, CEC: cation exchange capacity: $CaCO_3$: calcium carbonate

potassium, calcium, sodium and chloride contents (as a percentage of D.W) which were evaluated according to Estefan *et al*. (2013). The content of proline was estimated in fresh leaves (µ moles/g fresh matter of leaves) using the method of Bates *et al*. (1973). The content of total phenolics was estimated spectrophotometrically on the basis of the Folin Ciocalteau's reagent colorimetric method and represented as milligram gallic acid equivalent per gram of leaves dry weight extract (mg GAE/g DW) (John *et al*., 2014).

Enzyme activity and total protein content:

To prepare the enzyme extract, fresh leaves (0.05 g) were weighed and thoroughly ground with liquid nitrogen. The mixture was homogenized entirely before the addition of 1 ml of phosphate-buffered saline (PBS) (50 mM, pH = 7.8) and 0.1 mM of ethylene diamine tetra acetic acid (EDTA). The product underwent a 15-minute centrifugation at 12000 g and 4 °C. The supernatant was collected and kept in a freezer at 80 °C to assess enzyme activity and total protein content. To determine the amount of protein in the extract, 2.5 ml of Bradford solution was added to 50 µl of the separated supernatant, and the absorbance was read at 595 nm after 5 min. Specific concentrations of standard bovine serum albumin (BSA) were prepared in the extraction buffer to create a protein calibration curve (Bradford, 1976). Antioxidant enzymes i.e., catalase (CAT), superoxide dismutase (SOD), and ascorbate peroxidase (APX) were assayed as described by Haida and Hakiman (2019). Units/min/mg protein was used to express the enzyme activity.

Statistical analysis:

The means of all collected data were submitted to statistical analysis of variance (ANOVA) in split plot design. The Least Significant Difference (LSD) test at the level of 0.05 was used to compare means (Steel and Torrie, 1997).

RESULTS AND DISCUSSION

Growth and flowering parameters:

Effect of salinity stress:

Evidently, data in Tables (2 and 3) emphasize that salinity stress had unfavorable effects on the various growth and flowering parameters of *Lagerstroemia indica* plants. In both seasons, plant height, leaf number per plant, branch number per plant, stem diameter, root length, shoots dry weight, number of flower/plant and flower diameter were significantly decreased as the salinity concentration was increased from 500 to 3000 ppm compared to the control. Such findings are in line with those obtained by previous workers such as Ibrahem (2016) on *Conocarpus erectus*, Ahmed (2017) on *Hibiscus rosa-sinensis*, Soliman and Shanan (2017) on *Lagerstroemia indica*, El-Sayed *et al*. (2018) on *Thuja orientalis*, Abd-El-Hady *et al*. (2019) on *Acalypha wilkesiana*, Saadawy *et al*. (2019) on *Taxodium distichum*, El-Ashwah (2020) on *Cortaderia selloana*, Ashour *et al*. (2021) on *Vitex trifolia* 'Purpurea', Soliman *et al*. (2022) and Farooq *et al*. (2022) on *Moringa oleifera* who revealed decreases in growth and flowering characteristics due to adverse effects of salinity stress.

Effect of water stress:

Results in Tables (2 and 3) clearly show that the growth and flowering attributes of *L. indica* plants were negatively affected by the extended irrigation intervals. In both seasons, prolonging irrigation intervals from 6 to 8 or 10 days caused significant decreases in all growth and flowering attributes compared to the shortest interval (4 days). Such reductions in growth or flowering traits due to water deficiency stress were reported by previous reports such as Abd-Elmoneim *et al*. (2018) on *Euphorbia milii* var. *longifolia*, Toscano *et al*. (2018) on *Lantana camara* and *Ligustrum lucidum*, Yousaf *et al*. (2018) on *Eucalyptus* sp., El-Shanhorey and Sorour (2019) on *Beaucarnea recurvata*, Tribulato *et al*. (2019) on *Polygala myrtifolia* and *Viburnum tinus,*

Table 2. Plant height, number of leaves/plant, number of branches/plant and stem diameter of *Lagerstroemia indica* as affected by water salinity, irrigation intervals and their interactions during the 2021(1st) and 2022 (2nd) seasons.

Treatments		Plant height (cm)		No. of leaves/ plant		No. of branches/plant		Stem diameter (mm)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Mean of salinity (S), ppm									
Control		77.06	72.19	26.44	23.61	4.86	5.08	1.46	1.16
500		72.35	67.01	24.54	21.74	4.55	4.44	1.41	1.08
1000		70.52	65.06	24.39	20.92	4.44	4.56	1.39	1.09
2000		64.76	60.45	22.67	19.07	4.39	4.36	1.36	1.04
3000		47.50	40.70	21.22	17.46	4.19	4.17	1.28	1.01
Mean of irrigation intervals(I), days									
4		74.82	68.82	26.32	23.00	4.82	5.36	1.45	1.15
6		68.50	62.90	23.75	20.44	4.52	4.56	1.38	1.06
8		64.39	57.12	23.13	19.88	4.41	4.27	1.37	1.06
10		58.04	55.48	22.20	18.92	4.20	3.91	1.31	1.03
Mean of the interaction (S ppm x I days)									
Control	**4**	82.97	76.82	28.08	24.29	5.09	6.00	1.50	1.21
	6	80.70	74.52	26.95	24.19	5.05	5.22	1.49	1.18
	8	79.12	73.25	26.92	23.80	5.04	5.00	1.48	1.17
	10	65.46	64.17	23.81	22.17	4.25	4.11	1.37	1.07
500	**4**	80.00	75.00	26.86	24.13	5.00	5.34	1.48	1.19
	6	75.42	71.83	25.54	22.56	4.44	4.44	1.42	1.06
	8	70.21	63.25	23.34	20.50	4.33	4.11	1.41	1.05
	10	63.76	57.96	22.41	19.75	4.44	3.89	1.34	1.04
1000	**4**	79.06	73.59	27.70	24.19	4.78	5.33	1.49	1.17
	6	73.94	63.19	23.87	20.44	4.44	4.56	1.37	1.06
	8	67.15	63.95	22.93	19.67	4.33	4.22	1.35	1.06
	10	61.91	59.52	23.04	19.38	4.22	4.11	1.33	1.05
2000	**4**	78.73	74.98	27.17	24.03	4.78	5.22	1.49	1.14
	6	62.51	57.88	21.54	17.59	4.33	4.45	1.34	1.02
	8	60.21	48.95	20.97	17.38	4.11	3.89	1.32	1.02
	10	57.58	59.97	21.01	17.28	4.33	3.89	1.30	1.00
3000	**4**	53.33	43.72	21.78	18.35	4.44	4.89	1.31	1.03
	6	49.91	47.08	20.84	17.40	4.34	4.11	1.28	0.99
	8	45.24	36.19	21.49	18.04	4.22	4.11	1.29	1.03
	10	41.52	35.79	20.76	16.04	3.78	3.55	1.22	0.97
L.S.D. (0.05)									
S		2.20	2.00	0.68	0.46	0.30	0.53	0.07	0.06
I		1.97	1.79	0.61	0.41	0.27	0.47	0.06	0.05
S X I		4.41	4.00	1.36	0.92	0.61	1.06	0.13	0.12

Table 3. Root length, dry weight of shoots, number of flower /plant and flower diameter of *Lagerstroemia indica* as influenced by salinity, irrigation intervals and their interactions during the 2021(1st) and 2022 (2nd) seasons.

Treatments		Root length		dry weight of shoots (g)		No. of flowers/plant		flower diameter (cm)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Mean of salinity (S), ppm									
Control		28.18	30.02	51.05	47.41	4.00	3.80	3.27	3.86
500		26.85	27.90	45.97	42.97	3.42	3.14	2.67	3.44
1000		26.17	27.45	43.48	40.48	3.17	2.86	2.66	3.16
2000		25.55	26.85	38.93	35.22	2.98	2.64	2.55	2.65
3000		19.14	20.40	36.56	32.91	2.42	2.17	2.50	2.41
Mean of irrigation intervals (I), days									
4		28.22	29.55	50.64	46.80	4.04	3.78	3.28	3.72
6		25.81	27.24	42.39	39.01	3.13	2.89	2.66	3.09
8		24.63	25.98	41.83	38.47	3.00	2.73	2.62	2.98
10		22.05	23.33	37.92	34.91	2.61	2.29	2.35	2.62
Mean of the interaction (S ppm x I days)									
Control	**4**	30.62	32.19	54.20	50.28	4.44	4.22	3.77	4.33
	6	29.45	31.38	53.19	49.37	4.11	4.00	3.44	3.89
	8	29.00	30.60	52.62	48.74	4.00	3.78	3.22	3.78
	10	23.63	25.90	44.21	41.23	3.44	3.22	2.66	3.44
500	**4**	29.96	31.20	52.82	49.07	4.11	3.78	3.33	3.97
	6	27.63	28.97	46.33	43.47	3.45	3.22	2.33	3.44
	8	26.10	27.44	44.57	41.82	3.22	3.11	2.67	3.33
	10	23.70	24.00	40.14	37.52	2.89	2.44	2.33	3.00
1000	**4**	29.28	30.55	52.86	48.87	4.00	3.78	3.22	3.77
	6	26.89	28.18	42.10	39.04	3.11	2.78	2.55	3.33
	8	25.06	26.33	41.15	38.55	3.00	2.78	2.55	3.11
	10	23.45	24.72	37.79	35.46	2.56	2.11	2.33	2.44
2000	**4**	29.55	30.86	52.73	48.73	4.22	3.89	3.11	3.66
	6	24.71	26.02	33.87	30.26	2.56	2.22	2.55	2.44
	8	25.09	26.39	34.57	30.77	2.56	2.22	2.33	2.37
	10	22.85	24.15	34.54	31.11	2.59	2.22	2.22	2.11
3000 ppm	**4**	21.68	22.95	40.58	37.07	3.44	3.22	2.99	2.88
	6	20.37	21.66	36.47	32.88	2.44	2.22	2.44	2.33
	8	17.88	19.13	36.26	32.47	2.22	1.78	2.33	2.33
	10	16.61	17.87	32.93	29.21	1.56	1.45	2.22	2.11
L.S.D. (0.05)									
S		0.87	0.86	0.88	0.82	0.24	0.38	0.52	0.42
I		0.78	0.77	0.79	0.74	0.21	0.34	0.46	0.37
S X I		1.74	1.72	1.74	1.65	0.47	0.76	1.03	0.83

Alidust and Sedaghathoor (2020) on *Cordyline terminalis*, Singh and Singh (2020) on *Albizia lebbeck*, Papú *et al*. (2021) on *Araucaria araucana* and Shaltout *et al.* (2022) on *Swietenia mahagoni*.

The reductions in the tested attributes due to salinity and/or water deficit may be related to the harmful impact of the two factors on osmotic stress and water availability to the roots. Low soil osmotic potentials and low soil moisture lead to a decrease in water nutrient uptake by the roots, ionic toxicity, nutritional imbalance and oxidative damage in cellular compounds (Ma *et al*., 2020), resulting in decreases in vegetative biomass which followed by a reduction in flowering parameters.

Interaction effects between salinity and water deficiency stresses:

Data concerning the interaction effect of salinity and irrigation intervals were presented in Tables (2 and 3). The obtained results showed that the tested traits of *L. indica* were reduced response to increasing salinity levels and/or extending irrigation intervals compared to the control (plants irrigated with tap water every four days) which scored the highest values. Meanwhile, the lowest values in this respect were produced by plants watered with the most extended period (10 days) and exposed to salinity at the highest level (3000 ppm). The data also declared that when the plants were watered every 6 or 8 days with tap water or every 4 days with salinity levels up to 2000 ppm, the reduction in tested attributes was insignificant compared to unstressed plants. These results are in agreement with the previous reports of Ashour and El-Attar (2017) on *Leucophyllum frutescens*, Kumar *et al*. (2017) on *Nerium oleander*, Plesa *et al.* (2018) on *Larix decidua*, Sedaghathoor and Abbasnia, (2019) on three hedge shrubs, El-Nashar and Hassan (2020) on *Zinnia elegans*, Sarvandi *et al*. (2020) on *Iris* spp and Toscano *et al*. (2021) on *Callistemon citrinus* who reported a decrease in growth or flowering parameters due to salinity and water deficit stresses.

Chemical composition:

Chlorophyll and total carbohydrates content:

It is evident from data in Fig. (1) that, the total contents of chlorophyll and carbohydrates were significantly reduced by salinity stress. In both seasons increasing salinity level from 500 to 3000 ppm led to a significant reduction in the tested parameters compared to the control. Such reduction was also reported by El-Sayed *et al*. (2018) on *Thuja orientalis*, Abd-El-Hady *et al*. (2019) on *Acalypha wilkesiana*, Saadawy *et al*. (2019) on *Taxodium distichum***,** El-Ashwah (2020) on *Cortaderia selloana***,** Hamayl *et al*. (2020) on *Azadirachta indica*, Ashour *et al*. (2021) on *Vitex trifolia* 'Purpurea' and Soliman *et al*. (2022) on *Moringa oleifera*.

It is also clear from data in Fig (1) that chlorophyll and carbohydrate contents were markedly decreased due to prolonging the intervals between irrigations from 4 to 6, 8 or 10 days. Such results are in accordance with the results obtained by Abd-Elmoneim *et al*. (2018) on *Euphorbia milii* var. *longifolia***,** Sarker and Oba (2018) on *Amaranthus tricolor*, El-Shanhorey and Sorour (2019) on *Beaucarnea recurvate***,** Zafar *et al*. (2019) on *Ficus benjamina* and *Conocarpus erectus*, Singh and Singh (2020) on *Albizia lebbeck*, El-Gamal and Khamis (2021) on *Jatropha curcas* and *Moringa oleifera***,** Sorour (2021) on *Cycas revoluta*, Shaltout *et al*. (2022) on *Swietenia mahagoni* who reported a similar reduction in total chlorophylls and total carbohydrates under water shortage stress.

The unfavorable impact of both salt and water deficit stresses on reducing total chlorophyll content may be related to the generation of ROS (Sharma *et al*., 2022) that causes oxidative stress and harm to chloroplasts structure and chlorophyll losses along with toxic impacts of ions. Reducing chlorophyll content and photosynthetic activity could consequently cause a decrease in carbohydrate percentage. Moreover, salt and drought stress conditions assist in abscisic acid translocation from root to shoot through

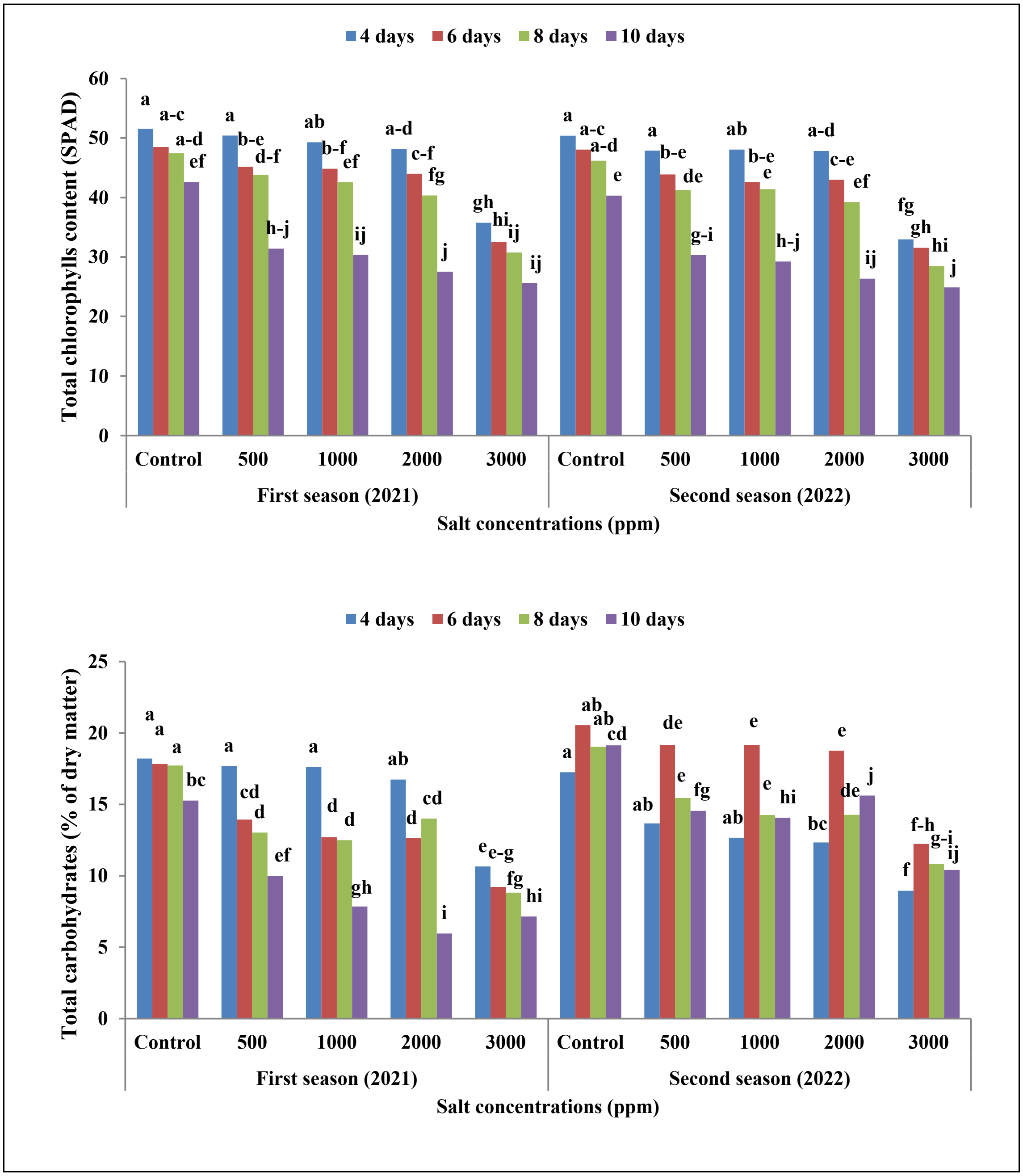

Fig. 1. Total chlorophylls, total carbohydrates of *Lagerstroemia indica* as affected by the interaction between water salinity and irrigation intervals during the 2021 and 2022 seasons. Column with different letters indicate a significant difference at 5% level.

xylem vessels for stomatal closure (Marusig and Tombesi, 2020); this may be related to reducing net photosynthesis and carbohydrate accumulation.

Data illustrated in Fig (1) show that, under each salinity level, prolonging irrigation intervals caused a gradual decrease in the chlorophyll content and total carbohydrates. Additionally, at each irrigation interval, increasing salinity levels caused progressive decline in chlorophyll and carbohydrate contents compared to the control. Compared to unstressed control plants, the recorded mean values decreased insignificantly in plants irrigated every 6 or 8 days with tap water or every 4 days with salinity levels up to 2000 ppm. These results are in accordance with the reports of Ashour and El-Attar (2017) on *Leucophyllum frutescens* who found a reduction in total chlorophyll and total carbohydrates due to salt and/or water deficit stresses. Other studies such as Kumar *et al*. (2017) on *Nerium oleander*, Plesa *et al*. (2018) on *Larix decidua*, El-Nashar and Hassan (2020) on *Zinnia elegans* and Toscano *et al*. (2021) on *Callistemon citrinus* reported similar trend which supports the current findings.

Contents of N, P, K^+ and Ca^{2+}:

During both of the experimental seasons, increasing salinity level from 500 to 3000 ppm considerably decreased N, P, K^+ and Ca^{2+} % compared to the control (Table, 4). Similar reduction in nutrient elements due to salt stress has been observed by Ibrahem (2016) on *Conocarpus erectus*, Ahmed (2017) on *Hibiscus rosa-sinensis*, Soliman and Shanan (2017) on *Lagerstroemia indica*, Abd-El-Hady *et al*. (2019) on *Acalypha wilkesiana*, Hamayl *et al*. (2020) on *Azadirachta indica*, Ashour *et al*. (2021) on *Vitex trifolia* 'Purpurea' and Soliman *et al*. (2022) on *Moringa oleifera*.

The results in Table (4) also reveal that the percentages of the studied nutrients were decreased significantly with prolonging the intervals between irrigation from 4 to 6, 8 or 10 days. Our findings are consistent with those observed by earlier researchers of Abd-Elmoneim *et al*. (2018) on *Euphorbia milii* var. *longifolia*, El-Shanhorey and Sorour (2019) on *Beaucarnea recurvata*, Singh and Singh (2020) on *Albizia lebbeck*, El-Gamal and Khamis (2021) on *Jatropha curcas* and *Moringa oleifera* who reported a decrease in N, P and K^+ % due to water shortage stress.

The adverse impact of salinity and drought stresses on the absorption and accumulation of such nutrients may be due to the reduction in nutrient absorption by the roots owing to the reduction of transpiration rates and impaired active transport and membrane permeability. Moreover, salt stress leads to nutritional imbalance, since higher levels of Na^+ and Cl^- control the absorption of other nutrients by rivaling them or modifying the ion permeability of the membrane. Na^+ obstructs K^+ absorption by vying Na^+ with K^+ ions and NO^{3-} absorption is reduced due to the contesting with Cl^- (Angon *et al*., 2022). Additionally, both stresses impact soil osmotic stress; they decrease soil moisture content which decreases the solubility of the nutrients in the soil and their uptake efficiency by root surface thus causing a decrease in their accumulation in plant tissues (Alam, 1999).

As for the interaction between salinity concentrations and irrigation intervals, the results presented in Table (4) elucidated that the tested nutrients were reduced due to increasing salinity levels and/or prolonging irrigation intervals against control plants (plants that received tap water every four days), which registered the highest values. Meanwhile, in most cases, the lowest values were recorded by plants irrigated with saline water at 3000 ppm for the most extended period (10 days). The data also showed that the reduction in the concentration of the tested nutrients was insignificant in plants irrigated every 6 or 8 days with tap water or every 4 days with salinity levels up to 2000 ppm in comparison to control plants. These results are in harmony with the finding of Ashour and El-Attar (2017) on *Leucophyllum frutescens*.

Table 4. N, P, K^+ and Ca^{2+}% of *Lagerstroemia indica* as influenced by salinity, irrigation intervals and their interactions during the 2021(1st) and 2022 (2nd) seasons.

Treatments		N%		P%		K^+%		Ca^{2+} %	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Mean of salinity (S), ppm									
Control		1.78	2.15	0.21	0.28	1.91	1.61	0.94	1.10
500		1.57	1.94	0.18	0.23	1.66	1.45	0.81	0.99
1000		1.46	1.84	0.16	0.22	1.57	1.43	0.76	0.96
2000		1.39	1.77	0.16	0.21	1.55	1.41	0.74	0.95
3000		1.17	1.57	0.12	0.17	1.17	1.27	0.59	0.83
Mean of irrigation intervals (I), days									
4		1.70	2.07	0.20	0.27	1.84	1.59	0.89	1.07
6		1.54	1.91	0.17	0.22	1.65	1.43	0.80	0.98
8		1.49	1.86	0.17	0.21	1.55	1.39	0.76	0.95
10		1.18	1.57	0.13	0.18	1.25	1.34	0.61	0.87
Mean of the interaction (S ppm x I days)									
Control	**4**	1.88	2.26	0.22	0.31	2.03	1.73	1.02	1.17
	6	1.85	2.21	0.21	0.29	1.97	1.67	0.99	1.14
	8	1.83	2.19	0.21	0.29	1.85	1.60	0.92	1.08
	10	1.57	1.93	0.18	0.24	1.80	1.45	0.84	1.02
500	**4**	1.76	2.12	0.21	0.29	1.99	1.64	0.93	1.10
	6	1.71	2.08	0.18	0.23	1.80	1.42	0.88	1.02
	8	1.63	2.00	0.18	0.22	1.71	1.38	0.83	0.99
	10	1.17	1.55	0.13	0.18	1.16	1.37	0.58	0.85
1000	**4**	1.74	2.10	0.21	0.30	1.95	1.63	0.92	1.09
	6	1.53	1.90	0.18	0.22	1.69	1.41	0.80	0.98
	8	1.49	1.86	0.16	0.19	1.51	1.35	0.75	0.94
	10	1.10	1.50	0.11	0.15	1.12	1.33	0.55	0.83
2000	**4**	1.73	2.10	0.21	0.29	1.86	1.61	0.91	1.08
	6	1.40	1.78	0.16	0.20	1.62	1.40	0.75	0.95
	8	1.36	1.73	0.15	0.20	1.59	1.33	0.73	0.94
	10	1.06	1.48	0.11	0.16	1.12	1.28	0.54	0.82
3000	**4**	1.37	1.75	0.14	0.18	1.37	1.31	0.69	0.89
	6	1.20	1.59	0.13	0.17	1.16	1.26	0.59	0.82
	8	1.13	1.52	0.12	0.17	1.07	1.27	0.55	0.81
	10	0.99	1.40	0.10	0.15	1.08	1.24	0.52	0.80
L.S.D. (0.05)									
S		0.08	0.09	0.01	0.02	0.10	0.13	0.06	0.05
I		0.07	0.08	0.01	0.01	0.09	0.11	0.05	0.04
S X I		0.16	0.17	0.02	0.03	0.21	0.26	0.12	0.10

Na^+, Cl^- %, proline and total phenolic:

The results in Table (5) showed that Na^+, Cl^- %, proline and total phenolic content were gradually augmented as salinity concentration was increased compared to the control. The current results are in agreement with the previous reports that proved an increase in Na^+ and Cl^- % (Abd-El-Hady *et al*., 2019; Soliman *et al*., 2022), proline content (Ibrahem, 2016; Ahmed, 2017; El-Sayed *et al*., 2018; El-Ashwah, 2020) and total phenols (Soliman and Shanan, 2017; Ashour *et al*., 2021) under salt stress conditions.

The results in Table (5) also pointed out that extending the intervals between irrigation from 4 to 6, 8 or 10 days resulted in a significant augmentation in the same investigated features in comparison to irrigation every 4 days. Similar results were reported by previous workers who reported an increase due to water deficit stress in Na^+ or Cl^- % (Ashour and El-Attar, 2017), proline or phenols content (Hodaei *et al*., 2018; Kashefi and Bahri, 2019; El-Gamal and Khamis, 2021; Papú *et al*., 2021 and Shaltout *et al*., 2022).

Increasing the proline content in plants exposed to stress may be since this is one of the protection mechanisms used by plants to control the unfavorable impacts of osmotic and ionic stresses, thus elevating stress tolerance. Moreover, the proline acts as a perfect osmolyte for intracellular osmotic adjustments to maintain cell turgor and osmotic balance. Proline is regarded as a free radical scavenger and an antioxidant defense molecule, stabilizing membranes and subcellular structure by stopping electrolyte leakage (Hosseinifard *et al*., 2022). Additionally, plants under stress release phenolic compounds which may work as antioxidants to defend them against oxidative damage (Sharma *et al*., 2012).

Regarding the influence of the interaction, the data presented in Table (5) emphasize that the recorded mean values were increased with increasing salinity and/or water stress compared to control plants. Accordingly, the plants that received irrigation every 10 days using saline water at the highest concentration (3000 ppm) produced the highest values in this respect, while the lowest values were obtained from plants irrigated every four days with tap water (control). Additionally, plants watered every 6 or 8 days with tap water or those watered every four days with salinity levels up to 2000 ppm were recorded slightly higher values than those of the control. In this regard, Plesa *et al*. (2018) on *Larix decidua* and El-Nashar and Hassan (2020) on *Zinnia elegans* found an increase in proline due to salt and/or water deficit stresses. Also, Ashour and El-Attar (2017) on *Leucophyllum frutescens* found an increase in Na, Cl % and proline due to salt and/or water deficiency stresses, while Kumar *et al*. (2017) on *Nerium oleander* reported an increase in proline, total phenolic compounds due to salt and/or water deficit stresses.

Enzyme activity:

It is clear from the data in Fig. (2) that within each salinity level, prolonging irrigation intervals resulted in a gradual augmentation in the activity of CAT, SOD and APX. Within each irrigation interval, increasing salinity levels caused a gradual increase in the activity of all enzymes compared to unstressed plants which registered the lowest activities. The highest CAT, SOD and APX activities were recorded by plants watered every 10 days using saline water at the highest concentration (3000 ppm). These findings confirmed the reports of Soliman and Shanan (2017) on *Lagerstroemia indica* who found an increase in antioxidant enzyme activity (CAT, SOD, APX) due to salinity stress. Similarly, increasing the antioxidant enzymes activity (CAT, SOD and APX) due to water deficit stress has been previously reported (Cheng *et al.*, 2018; Kashefi and Bahri, 2019).

Moreover, Kumar *et al*. (2017) on *Nerium oleander* and Plesa *et al*. (2018) on *Larix decidua* found an increase in antioxidant

Table 5. Na^+, Cl^- %, proline and total phenolic content of *Lagerstroemia indica* as affected by salinity, irrigation intervals and the interactions between them during the 2021(1st) and 2022 (2nd) seasons.

Treatments		Na^+%		Cl^-%		Proline (µ moles/g f.w.)		Total phenolic (mg GAE/g DW)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Mean of salinity (S), ppm									
Control		0.39	0.55	0.46	0.43	7.56	7.49	1.32	1.24
500		0.48	0.62	0.56	0.52	9.42	10.18	1.63	1.68
1000		0.49	0.63	0.57	0.54	10.69	11.89	1.85	1.96
2000		0.55	0.67	0.58	0.52	11.31	12.48	1.94	2.03
3000		0.75	0.81	0.68	0.74	12.95	15.10	2.18	2.40
Mean of irrigation intervals (I), days									
4		0.44	0.59	0.46	0.47	8.11	8.24	1.41	1.34
6		0.53	0.66	0.58	0.56	10.28	11.30	1.77	1.84
8		0.55	0.66	0.58	0.56	11.53	12.94	1.97	2.10
10		0.61	0.70	0.66	0.62	11.63	13.22	1.98	2.16
Mean of the interaction (S ppm x I days)									
Control	**4**	0.32	0.49	0.34	0.35	5.95	5.11	1.06	0.83
	6	0.35	0.51	0.45	0.40	6.97	6.71	1.23	1.12
	8	0.36	0.55	0.47	0.42	8.30	8.47	1.46	1.42
	10	0.52	0.65	0.58	0.56	9.00	9.68	1.55	1.59
500	**4**	0.33	0.50	0.41	0.41	6.45	6.16	1.14	1.03
	6	0.52	0.66	0.58	0.51	10.38	11.26	1.80	1.85
	8	0.53	0.67	0.59	0.56	10.48	11.57	1.80	1.90
	10	0.53	0.64	0.66	0.61	10.36	11.71	1.78	1.95
1000	**4**	0.36	0.53	0.44	0.42	8.27	8.49	1.46	1.41
	6	0.51	0.66	0.58	0.53	10.91	12.02	1.89	1.98
	8	0.54	0.66	0.60	0.53	11.93	13.40	2.05	2.20
	10	0.55	0.67	0.64	0.70	11.67	13.64	2.01	2.25
2000	**4**	0.48	0.62	0.48	0.45	8.83	8.99	1.53	1.45
	6	0.55	0.65	0.59	0.59	11.47	13.07	1.96	2.13
	8	0.57	0.67	0.59	0.52	12.07	13.51	2.07	2.19
	10	0.60	0.73	0.67	0.53	12.87	14.37	2.21	2.36
3000	**4**	0.69	0.82	0.62	0.73	11.03	12.47	1.88	1.97
	6	0.75	0.83	0.68	0.78	11.69	13.46	1.98	2.14
	8	0.75	0.77	0.68	0.75	14.85	17.76	2.49	2.82
	10	0.82	0.81	0.76	0.71	14.24	16.70	2.37	2.66
L.S.D. (0.05)									
S		0.09	0.07	0.10	0.05	1.50	2.00	0.26	0.32
I		0.08	0.06	0.09	0.06	1.34	1.79	0.23	0.29
S X I		0.19	0.14	0.20	0.12	3.00	4.00	0.52	0.65

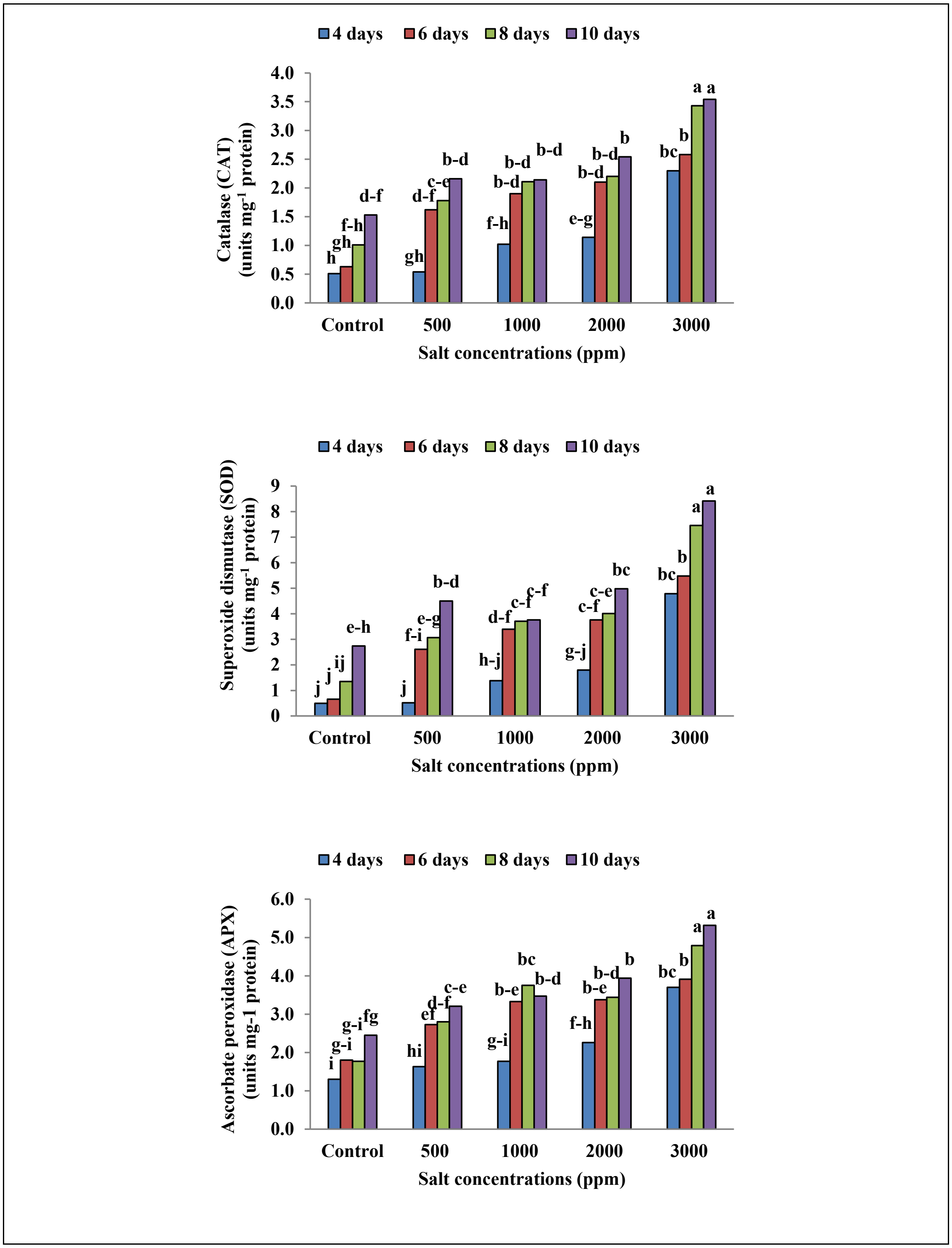

Fig. 2. Catalase (CAT), superoxide dismutase (SOD), and ascorbate peroxidase (APX) of *Lagerstroemia indica* as affected by the interaction between water salinity and irrigation intervals during the 2022 season. Column with different letters indicate a significant difference at 5% level.

enzymes activity (CAT, SOD, APX) due to salt and/or water deficit stresses.

Activating antioxidant enzymes (CAT, SOD and, APX) may be occurred to overcome the oxidative stress damage which resulted by increased levels of ROS such as hydrogen peroxide under stress conditions (Sharma *et al*., 2012). It is well known that CAT is highly effective in removing H_2O_2 with a unique capacity to convert two H_2O_2 molecules into water and molecular oxygen without the need for reduction equivalent. SOD plays an important role in reducing oxidative stress by accelerating the dismutation of O_2^- and decreasing the danger of OH production through metal-catalyzed processes. Furthermore, APX is considered as one of the most vital enzymes to decrease such reactive molecules (Dumanović *et al*., 2021).

Based on the findings of the study it can be concluded that *Lagerstroemia indica* can be irrigated every eight days with tap water or every four days with saline water with concentrations up to 2000 ppm without any significant reduction in most of its vegetative growth and flowering characteristics.

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التأثيرات التفاعلية لاجهادات الملوحة ونقص الماء على خصائص النمو والتركيب الكيميائي لنبات تمر حنة الافرنجى

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أجريت تجربة أصص لتقييم تأثير إجهاد الملوحة ونقص المياه على نبات تمر حنة الأفرنجي. إجهاد الملوحة تم عن طريق الري بالمياه المالحة بتركيز ٥٠٠ ، ١٠٠٠ ، ٢٠٠٠ أو ٣٠٠٠ جزء في المليون. بالإضافة إلى الكنترول (ماء الصنبور، ٢٨٠ جزء في المليون). إجهاد نقص المياه تم عن طريق إستخدام ماء الصنبور على فترات ري كل ٤ ، ٦ ، ٨ أو ١٠ أيام. صممت التجربة بالنظام العاملى باستخدام القطع المنشقة. معاملات الملوحة استخدمت كقطع رئيسية ومعاملات نقص الماء استخدمت كقطع تحت رئيسية. أشارت النتائج إلى أن خصائص النمو الخضري والزهرى (إرتفاع النبات، عدد

الأوراق/نبات ، عدد الأفرع/نبات، قطر الساق، طول الجذر، الوزن الجاف للمجموع الخضري، عدد الازهار/نبات وقطر الزهرة) كذلك الكلوروفيل الكلي، الكربوهيدرات الكلية ونسبة النيتروجين، الفسفور، البوتاسيوم والكالسيوم قلت نتيجة إجهاد الملوحة و نقص المياه. في المقابل، كلا الإجهادين أدى إلى زيادة تركيز الصويوم، الكلور، البرولين، إجمالي الفينولات و إنزيمات مضادات الأكسدة (CAT ، SOD ،APX) في الأوراق. أوضحت تأثيرات التفاعل أن الإنخفاض في خصائص النمو الخضري والزهرى بالإضافة إلى الكلوروفيل الكلي، الكربوهيدرات الكلية، ونسبة النيتروجين، الفسفور، البوتاسيوم والكالسيوم كان غير معنوي في النباتات التي تم ريها كل ٦ أو ٨ أيام بإستخدام ماء الصنبور أو في النباتات التي تم ريها كل ٤ أيام بتركيز ملح ١٠٠٠ أو ٢٠٠٠ جزء في المليون. مقارنة بالنباتات التي لم تتعرض للإجهاد، تراكم أيونات الصوديوم والكلور الضارة كان غير معنوي في النباتات التي تم ريها كل ٦ أو ٨ أيام باستخدام ماء الصنبور أو في النباتات التي تم ريها كل ٤ أيام بإستخدام مستوى ملوحة يصل إلى ٢٠٠٠ جزء في المليون. بناءاً على نتائج البحث، يمكن إستنتاج أنه يمكن ري نبات تمر حنة الافرنجى كل ٨ أيام باستخدام ماء الصنبور، أو كل ٤ أيام باستخدام المياه المالحة بتركيزات تصل إلى ٢٠٠٠ جزء في المليون دون إنخفاض معنوى في معظم خصائص النمو الخضري والزهري.