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RESEARCH ARTICLE

Using some anti-salinity materials for alleviating the adverse effects of soil and water salinity on fruiting of Keitte mango trees

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Abstract

The anti-salinity effects of six substances arginine, mannitol, proline, salicylic acid, seaweed extracts, or potassium silicate each at 500 ppm were assessed over the 2021 and 2022 seasons. Keitte mango trees were treated with three spray treatments of either of these substances: at the beginning of growth, after fruit setting, and one month later. The trees were grown in soil and irrigation water with salinity levels of 4.51 dsm and 3.03 dsm, respectively. The trees' growth, productivity, and fruit quality were observed, as well as their nutritional condition.
In comparison to salinity stress alone, adding any of the six materials: mannitol, proline, salicylic acid, seaweed extracts, or potassium silicate (500 ppm) to the trees improved growth characteristics, tree nutritional condition, yield, and fruit quality. The best substances for minimizing the salinity-induced negative effects were, in ascending order, arginine, mannitol, proline, salicylic acid, seaweed extract, and potassium silicate.
Exposing the Keitte mango trees to any of the six studied materials resulted in an improvement in growth aspects, the nutritional status of the trees, yield, and fruit quality when compared to trees that were grown under the stress of salinity alone. The most effective materials, ranked in ascending order in terms of their ability to alleviate the negative effects of salinity, were arginine, mannitol, proline, salicylic acid, seaweed extract, and potassium silicate.
To counteract the unfavorable impact of soil and water salinity on the growth and fruiting of Keitte mango trees, it is suggested to spray potassium silicate or seaweed extracts (500 ppm) three times: at the beginning of growth, immediately after fruit setting, and one month later.

Keywords: Anti-salinity; Fruit quality; Keitte mango trees; Seaweed extract; Yield

1. Introduction

Mango (*Manifera indica* L.), a member of the Anacardiaceae family, is considered one of the most significant fruits in tropical and subtropical countries worldwide. It can grow under varying climatic and soil conditions. In Egypt, mango is the second most important fruit after citrus, with a total orchard area of approximately 294,100 hectares, producing about 766,128 tons of fruit in 2021 (Egyptian ministry of Agriculture, 2021). However, mango growers in newly reclaimed areas, specifically those with sandy soil conditions, face the challenge of low yields and poor fruit quality. Salinity reduces fruit setting and increases fruit drop rates after setting. Besides, salinity stress causes irregular bearing, low tree productivity, and fruit malformation (Sayed *et al.*, 2009).
In many parts of the world, especially in arid and semi-arid regions, salinity is a major environmental abiotic stress characterized by water deficiency and soil deterioration (Velmurugan, *et al.*, 2020) that limits crop

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growth and production (Singh, 2009). Saline substrates adversely affect plants by inducing either a primary injury, by the toxic effect of ionic constituents, or a secondary injury by inducing nutritional deficiencies and hyperosmotic stress related effects. Salinity affects approximately 950 million hectares, or 8% of the land surface (Singh, 2009), while others estimate salinity-affected areas to be 7-20% of the world's irrigated areas (Gopalakrishnan and Kumar, 2020).

Bernstein (1964) classified mangoes as salinity-sensitive plants. Thus, when grown under salinity stress, mango trees are expected to lose 10-25% of their yield, like many other agricultural crops, at least in part, due to excessive levels of sodium chloride (Shahid *et al.*, 2018). High levels of sodium chloride disrupt the normal physiological and metabolic activities of plants, ultimately reducing their growth and productivity because of hypertonic and hyperosmotic damage (Ma *et al.*, 2020).

Salicylic acid is an important plant key phytohormone in many physiological and biochemical processes under stresses and consequently modulates plant tolerance capacity (Nazar, *et al.*, 2011).

Increased soil and irrigation water salinity significantly reduces the growth, nutritional status of trees, yield, and fruit quality of various fruit crops. Previous findings published by Ali-Mervat *et al.* (2013), Ibrahim and Al-Wasfy (2014), Taha-Nevine and Sherif-Hanna (2015), El-Hanafy (2017) and Salama and Radwan (2018) have established the deleterious effects of soil and water salinity. Moreover, the studies of Abdel-Kader *et al.* (2002) and El-Sabagh *et al.* (2011) added more evidence on salinity-induced deterioration of growth and fruiting. On the other hand, the work of Ahmed–Nada (2017), El-Hanafy (2017) and Rizk (2017) showed that potassium silicate could mitigate these salinity-induced adverse effects. Similarly, previous studies illustrated the salinity-antagonizing beneficial effects of supplementing fruit crops with salicylic acid (Delany, 2004; Ahmed, 2011; El-Khawaga, 2013; Amiri *et al.*, 2014; Mohamed-Attiat, 2016; Abd El-Rady, 2015 and El- Sayed- Eman, 2017), mannitol (Cha-Mm *et al.*, 2010 and Kaya *et al.*, 2013), proline (Caronia *et al.*, 2010 and El-Sayed-Omima *et al.*, 2014), and amino acids (Khattab–Magda *et al.*, 2012 El-Shenewai *et al.*, 2015 and El- Hanafy, 2017).

The aim of this study was how to mitigate the negative effects of salinity on the growth and fruiting of mango trees.

2. Materials and methods

Twenty-one uniform-in-vigour 10-year-old Keitte mango trees that were planted onto seedling rootstocks were selected for this study during 2021 and 2022. The private mango orchard (west Minia district, Minia Governorate, Egypt) is characterized by sandy soil, regular planting dimensions of 4.0 x 2.0 meters between the chosen trees, tree density of 525 trees per fed, and drip irrigation system. The salinity levels of the irrigation water and soil were 4.51 and 3.03 ds/m, respectively, while standard horticultural practices were implemented on all the trees. Table 1 presents the soil analysis results at the test site based on the method described by Wilde *et al.* (1985).

The current study followed a randomized complete Block Design (RCBD), and the experimental protocol involved the following seven treatments:

T_1- Control: distilled water sprayed.

T2- Arginine: trees received arginine (500 ppm).

T_3- Mannitol: trees received mannitol (a sugar alcohol, 500 ppm).

T_4- Proline: trees received proline (500 ppm).

T_5- Salicylic acid: trees received salicylic acid (500 ppm).

T_6- Seaweed extracts: trees received seaweed extracts (500 ppm).

T_7- Potassium silicate: trees received potassium silicate (500 ppm).

Each treatment was executed in triplicates (three trees per group). Each of the six materials: Arginine, mannitol, proline, salicylic acid, seaweed extracts, and potassium silicate was applied to the foliar parts of the tress in the form of fine spray at three different times: at growth start (the last week of February), immediately after fruit setting (the first week of April), and in the first week of May. A few drops of ethyl alcohol were used to solubilize salicylic acid. All spraying solutions as well as the control trees received 0.5 ml/L (0.05%) of Triton B as a wetting agent, and spraying continued until runoff.

Table 1. Soil Analysis of the orchard soil at the test site.

Constituents	Values	Constituents	Values
Sand %	81.3	Total N %	0.014
Silt %	12.0	Available P ppm	2.5
Clay %	6.7	Available K ppm	14.8
Texture	Sandy	Fe ppm	1.5
pH (1:2.5 extract)	7.96	Zn ppm	1.1
E.C. (1: 2.5 extract) mmhous	4.51	Mn ppm	0.9
O.M. %	0.18		
$CaCO_3$ %	2.33		

During the 2021 and 2022 seasons, the study determined the following parameters:

1- Vegetative growth characteristics such as the shoot length (cm) and the mean leaf area (cm^2) were measured in the Spring growth cycle as previously shown (Ahmed and Morsy, 1999).
2- Chlorophyll A, chlorophyll B, total chlorophylls, and total carotenoids were determined as the major leaf pigments (mg/g F.W.) according to previously established procedures (Von-Wettstein, 1957).
3- The leaf content of nitrogen (N), phosphorus (P), and potassium (K) were measured in the leaves of non-fruiting shoots during the spring growth cycle and calculated as percentages of leaf weight (Summer, 1985 and Wilde *et al.*, 1985).
4- The initial fruit setting as well as the fruit retention were calculated as percentages.
5- At the time of harvest, the total number of fruits was counted for each tree and the calculated average was considered as the yield per tree, while the mean fruit weight was measured (kg).
6- The physical characteristics that reflect the fruit quality such as fruit weight (g) as well as the percentages of fruit peels, seed, total fiber, and pulp relative to the total fruit weight were determined (%). Determination of the chemical indicators of fruit quality included total soluble solids percentage (TSS%), the total acidity (calculated as g citric acid/100 ml juice), and the percentages of total and reducing sugars as described previously (Lane and Eynon, 1965). In addition, the fruit content of vitamin C (mg/100 mL juice) (A.OA.C., 2000).

All data were tabulated analyzed for statistical significance by one-way analysis of variance (ANOVA) followed by determination of the least significant difference (New LSD) at 5% to compare the means of different treatments according to Mead *et al.* (1993).

3. Results

3.1. *Vegetative growth characteristics*

Data in Table (2) illustrate the effects of Arginine, mannitol, proline, salicylic acid, seaweed extracts and potassium silicate, each at 500 ppm, on the vegetative growth characteristics of Keitte mango trees grown under high salinity conditions. Spraying any of the above treatments three times (as described in Methods) significantly increased the shoot length and the leaf area (cm^2) in comparison with the untreated trees maintained under salinity stress. The significant improvements in these growth aspects were observed, in ascending order, in trees treated with arginine, mannitol, proline, salicylic acid, seaweed extracts and potassium silicate (each at 500 ppm). The results show that treating Keitte mango trees with potassium silicate or seaweed extracts (500 ppm; three times per season) significantly maximized these growth aspects. Importantly, induction of salinity stress (4.51 ds/m in soil and 3.03 ds/m in irrigation water) in the untreated trees gave the lowest growth values. During the 2021 and 2022 seasons, the highest values of spring shoot length (54.0, 54.8 cm) and leaf area (80.5, 81.0 cm^2), respectively, were observed with potassium silicate treatment. The results were reproducible in both seasons.

Table 2. Effect of spraying some anti-salinity materials on some growth characters and chlorophylls A, B and total chlorophylls in the leaves of Keitte mango trees during 2021 and 2022 seasons.

Treatments / Anti- salinity	remove shoot length (cm)		Leaf area $(cm)^2$		Chlorophyll a (mg/ g/ F.W.)		Chlorophyll b (mg/ g/ F.W.)		Total chlorophylls (mg/ g/ F.W.)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
T_1- Control	46.5	46.8	71.0	71.8	3.1	3.2	1.2	1.2	4.3	4.4
T_2- Spraying Arginine at 500 ppm	47.6	48.0	73.0	73.5	3.8	3.9	1.4	1.5	5.2	5.4
T_3- Spraying Mannitol at 500 ppm	48.0	48.5	74.8	75.2	4.1	4.2	1.8	1.9	5.9	6.1
T_4- Spraying Proline at 500 ppm	49.4	50.0	76.0	76.2	4.4	4.5	2.0	2.1	6.4	6.6
T_5- Spraying Salicylic acid at 500 ppm	51.0	51.5	78.0	78.8	4.6	4.7	2.2	2.3	6.8	7.0
T_6- Spraying seaweed extracts at 500 ppm	52.2	53.0	79.0	79.5	4.8	4.9	2.4	2.5	7.2	7.4
T_7- Spraying potassium silicate at 500 ppm	54.0	54.8	80.5	81.0	5.1	5.2	2.7	2.8	7.8	8.0
New L.S.D. at 5%	0.7	0.9	1.2	1.3	0.5	0.6	0.2	0.3	0.8	0.9

3.2. Plant pigments as well as the leaf content N, P, and K.

The current results (Tables 2 and 3) demonstrate that treating Keitte mango trees with any one of six investigated materials (Arginine, Mannitol, proline, salicylic acid, seaweed extracts and potassium silicate, each at 500 ppm) significantly increased the foliar content of major plant pigments: chlorophylls (a , b , and total) and total carotenoids as well as the percentages of N, P and K in comparison with the untreated control trees exposed to similar salinity stress conditions. The observed anti-salinity effects of the studied materials on plant pigments and nutrients were highest with potassium silicate, seaweed extracts, salicylic acid, proline, mannitol, and lowest with arginine treatment, in descending order. The best results were obtained from the leaves of potassium silicate-treated trees regarding chlorophyll a, b, and total (5.1, 5.2; 2.7, 2.8; and 7.8, 8.0 mg/g F.W., respectively, in both seasons) and total carotenoids (2.7, 2.8 mg/ g F.W.). Similar results were observed in potassium silicate-treated trees regarding the percentages of N (1.82 , 1.83 %) , P (0.25, 0.26 %), and K (1.46, 1.47 %) during both seasons, respectively.

3.3. Fruit setting % and fruit retention %

Under high salinity stress, the untreated Keitte mango trees displayed the lowest initial setting and fruit retention (Table 4). On the other hand, treating the salinity-exposed trees with arginine, mannitol, proline, salicylic acid, seaweed extracts, or potassium silicate significantly improved these aspects. The best results concerning initial setting and retention of fruits were observed in potassium silicate-treated trees showing initial fruit setting of 16.7 and 16.8%, and fruit retention values of 1.30 and 1.33% (500 ppm; in 2021 and 2022, respectively), followed by seaweed extracts, salicylic acid, proline, mannitol, and arginine, in descending order. The same trend was observed in 2021 and 2022 seasons.

Table 3. Effect of spraying some anti-salinity materials on total carotenoids and percentages of N, P and K in the leaves of Keitte mango trees during 2021 and 2022 seasons.

Treatments / Anti- salinity	Total carotenoidsmm (mg/ g F.W.)		Leaf N %		Leaf P %		leaf K %	
	2021	2022	2021	2022	2021	2022	2021	2022
T_1- Control	1.1	1.1	1.62	1.66	0.13	0.14	1.29	1.31
T_2- Spraying Arginine at 500 ppm	1.4	1.5	1.68	1.71	0.15	0.16	1.33	1.35
T_3- Spraying Mannitol at 500 ppm	1.7	1.9	1.71	1.72	0.17	0.18	1.35	1.36
T_4- Spraying Proline at 500 ppm	2.0	2.1	1.75	1.76	0.19	0.21	1.38	1.39
T_5- Spraying Salicylic acid at 500 ppm	2.2	2.4	1.77	1.78	0.22	0.23	1.41	1.42
T_6- Spraying seaweed extracts at 500 ppm	2.4	2.6	1.81	1.82	0.24	0.25	1.44	1.46
T_7- Spraying potassium silicate at 500 ppm	2.7	2.8	1.82	1.83	0.25	0.26	1.46	1.47
New L.S.D. at 5%	0.2	0.3	0.06	0.07	0.01	0.01	0.04	0.05

Table 4. Effect of spraying some anti-salinity materials on percentages of initial fruit setting, fruit retention, numbeof fruits / tree/ yield and fruit weight of Keitte mango trees during 2021 and 2022 seasons.

Treatments	Initial fruit setting %		Fruit retention %		Number of fruits/ tree		Yield/ tree (kg.)		Fruit weight (g.)	
Anti- salinity	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
T_1- Control	13.0	13.5	0.92	0.96	46.0	47.0	17.02	17.63	370.0	375.0
T_2- Spraying Arginine at 500 ppm	14.0	14.1	0.98	1.00	49.0	50.5	18.72	19.59	382.0	388.0
T_3- Spraying Mannitol at 500 ppm	14.8	15.0	1.06	1.11	51.6	52.2	20.38	20.88	395.0	400.0
T_4- Spraying Proline at 500 ppm	15.5	15.9	1.13	1.15	53.0	54.0	21.62	22.14	408.0	410.0
T_5- Spraying Salicylic acid at 500 ppm	16.1	16.3	1.20	1.22	55.2	56.0	22.91	23.52	415.0	420.0
T_6- Spraying seaweed extracts at 500 ppm	16.5	16.6	1.24	1.28	57.5	58.2	24.15	24.74	520.0	425.0
T_7- Spraying potassium silicate at 500 ppm	16.7	16.8	1.30	1.33	58.5	59.5	25.15	26.18	430.0	440.0
New L.S.D. at 5%	0.2	0.3	0.08	0.09	1.3	1.5	2.20	3.00	3.0	3.2

3.4. Yield per tree

Induction of salinity stress significantly decreased the yield (17.02 , 17.63 kg per tree, in both seasons, respectively) and the total number of fruits/tree of the untreated Keitte mango trees in comparison to the anti-salinity materials-treated ones (Table 4). Significant improvements in the number of fruits/tree and the total yield (kg)/tree resulted from treating the trees with arginine, mannitol, proline, salicylic acid, seaweed extracts, or potassium silicate (each at 500 ppm). However, the type of anti-salinity treatment greatly determined the magnitude of such improvement in yield per tree. In descending order, the best yield-related parameters were determined in trees treated with potassium silicate (25.15, 26.18 kg) followed by seaweed extracts (24.15, 24.74 kg), salicylic acid (22.91, 23.52 kg), proline (21.62, 22.14 kg), mannitol (20.38, 20.88 kg), and arginine (18.72, 19.59 kg), respectively, in both seasons.

Interestingly, both potassium silicate and seaweed extracts increased the yield by 47.8, 42.0% in 2021 and 48.5, 40.3% in 2022, respectively. The same trend was observed in 2021 and 2022 seasons.

3.5. Physicochemical aspects of the fruits

As illustrated by the data in Tables 4, 5, and 6, spraying Keitte mango trees with arginine, mannitol, proline, salicylic acid, seaweed extracts, or and potassium silicate, each at 500 ppm, significantly protected the fruits against salinity-induced deterioration of quality. The treated trees displayed significantly higher fruit weight and pulp percentages, while showing significantly reduced percentages of seeds and fruit peel. Chemically, the anti-salinity materials-treated trees produced mango fruits with higher percentages of TSS, total sugars, reducing sugars, and vitamin C, which was accompanied by significant reductions in the percentage of total acidity compared with the untreated control trees under salinity stress.

Table 5. Effect of spraying some anti-salinity materials on some physical characteristics of the fruits of Keitte mango trees during 2021 and 2022 seasons.

Treatments Anti- salinity	Seeds %		Fruit peel %		Pulp %	
	2021	2022	2021	2022	2021	2022
T_1- Control	12.2	12.0	18.5	18.3	69.3	69.7
T_2- Spraying Arginine at 500 ppm	11.8	11.6	18.2	18.0	70.0	70.4
T_3- Spraying Mannitol at 500 ppm	11.5	11.4	18.0	17.7	70.5	70.7
T_4- Spraying Proline at 500 ppm	11.3	11.1	17.8	17.5	70.9	71.4
T_5- Spraying Salicylic acid at 500 ppm	11.1	11.0	17.6	17.4	71.3	71.6
T_6- Spraying seaweed extracts at 500 ppm	10.8	10.7	17.2	17.0	72.0	72.3
T_7- Spraying potassium silicate at 500 ppm	10.6	10.5	16.8	16.5	72.6	73.0
New L.S.D. at 5%	0.3	0.4	0.5	0.6	0.3	0.4

Table 6. Effect of spraying some anti-salinity materials on some chemical characteristics of the fruits of Keitte mango trees during 2021 and 2022 seasons.

Treatments Anti- salinity	TSS%		Total acidity %		Total sugars %		Reducing sugar %		Vitamin C (mg/ 100 g pulp)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
T_1- Control	9.4	9.6	1.160	1.130	7.3	7.5	2.6	2.8	41.0	41.4
T_2- Spraying Arginine at 500 ppm	10.2	10.5	1.090	1.050	8.1	8.4	2.9	3.1	41.6	41.9
T_3- Spraying Mannitol at 500 ppm	10.5	10.8	1.000	1.000	8.4	8.7	3.1	3.2	42.0	42.8
T_4- Spraying Proline at 500 ppm	10.9	11.2	0.950	0.940	8.8	9.1	3.2	3.3	42.6	43.5
T_5- Spraying Salicylic acid at 500 ppm	11.4	11.6	0.930	0.920	9.3	9.5	3.4	3.5	43.0	44.0
T_6- Spraying seaweed extracts at 500 ppm	11.8	12.0	0.900	0.880	9.6	9.8	3.6	3.7	43.5	44.5
T_7- Spraying potassium silicate at 500 ppm	12.2	12.5	0.880	0.860	10.0	10.3	3.8	3.9	44.2	45.5
New L.S.D. at 5%	0.4	0.5	0.025	0.030	0.3	0.3	0.2	0.2	0.4	0.5

The best fruits were obtained from trees sprayed with potassium silicate followed by seaweed extracts, salicylic acid, proline, mannitol, and arginine (each at 500 ppm), in decreasing order. On the contrary, fruits of the untreated trees demonstrated the lowest quality-related physical and chemical aspects. The same trend was observed in 2021 and 2022 seasons.

4. Discussion

The adverse impact of salinity on the growth and fruiting of Keitte mango trees may be due to its detrimental effects on various biological processes such as cell division, plant metabolism, pigmentation, cytoplasm, water and nutrient uptake in respiration, and photosynthesis (Jacoby, 1999; Munns and Tomeat, 1996).

In the current study, salicylic acid (SA) antagonized the adverse effects of salinity on nutritional status, growth, yield and fruit quality of Keitte mango trees. Salicylic acid was reported to promote cell mitosis and stimulate the synthesis of plant pigment and other macromolecules necessary to cell metabolism and photosynthesis. In addition, the antioxidant effects of SA were demonstrated by its ability to reduce the cellular output of reactive oxygen species (ROS). Thus, SA might play an essential role fighting oxidative stress and enhancing the cellular defense mechanisms against biotic and abiotic stresses (Ozeker, 2005; Joseph *et al.,* 2010). The results obtained in this study in the SA-treated Keitte mango trees are supported by the work of El-Khawaga (2013), Amiri *et al*. (2014), Mohamed-Attiat (2016) and El-Sayed-Eman (2017).

Mannitol is a sugar alcohol that commonly results from the metabolic reduction of mannose. The ability of mannitol to enhance the osmotic pressure in plant tissues and its positive effect on cellular proline production might explain its anti-salinity effects observed in Keitte mango trees grown under high salinity conditions in the current study results. (Cha-Mm *et al.,* 2010; Kaya *et al.,* 2013).

Potassium silicate (a source of silicon) was reported to modulate ROS production and its detoxification and enhance cellular metabolism and increase the availability of essential macromolecules (Liu *et al.,* 2019). These effects are important in the mitigation of biotic and abiotic stress-induced deterioration of plant cellular function. The present results illustrated the ameliorative effects of potassium silicate on the salinity-induced adverse effects on growth, yield and fruit quality of Keitte mango trees. These results are in line with previous studies (Ahmed-Nada, 2017; El-hanafy, 2017; Rizk, 2017).

Amino acids have a well-established positive effect on cell division, production of natural hormones, and plant pigments. Besides, amino acids can mitigate ROS-mediated cellular injury. Seaweed extracts are rich in essential nutrients, vitamins, amino acids, antioxidants, and natural hormones, which make them highly beneficial. These attributes of seaweed extracts could explain some of the observed outcomes in the current study. Moreover, previous research highlighted the role of seaweed extracts in enhancing the trees' resilience to drought, pests, salinity, and other adverse environmental factors (Tung *et al.,* 2003). These results are corroborated by the work of others (Mohamed *et al.,* 2008; Abd El- Motty- Elham *et al.,* 2010).

5. Conclusion

To mitigate the adverse effects of soil- and irrigation water-induced salinity on the growth and fruiting of Keitte mango trees, it is suggested to apply potassium silicate or seaweed extracts at a concentration of 500 ppm three times during the growth phase: at the start of growth, just after fruit setting, and one month later.

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Conflicts of Interest
The authors disclosed no conflict of interest starting from the conduct of the study, data analysis, and writing until the publication of this research work.

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