Licorice-root extract and potassium sorbate spray improved the yield and fruit quality and decreased heat stress of the 'osteen' mango cultivar

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ABSTRACT

Heat stress, low mango yields and inconsistent fruit quality are main challenges for growers. Recently, licorice-root extract (LRE) has been utilized to enhance vegetative growth, yield, and tolerance to abiotic stresses in fruit trees. Potassium sorbate (PS) also plays a significant role in various physiological and biochemical processes that are essential for mango growth, quality and abiotic stress tolerance. This work aimed to elucidate the effects of foliar sprays containing LRE and PS on the growth, yield, fruit quality, total chlorophyll content, and antioxidant enzymes of 'Osteen' mango trees. The mango trees were sprayed with LRE at 0, 2, 4 and 6 g/L and PS 0, 1, 2, and 3 mM. In mid-May, the mango trees were sprayed with a foliar solution, followed by monthly applications until 1 month before harvest. The results showed that trees with the highest concentration (6 g/L) of LRE exhibited the maximum leaf area, followed by those treated with the highest concentration (3 mM) of PS. Application of LRE and PS to Osteen mango trees significantly enhanced fruit weight, number of fruits per tree, yield (kg/tree), yield increasing%, and reduced number of sun-burned fruits compared to the control. LRE and PS foliar sprays to Osteen mango trees significantly enhanced fruit total soluble solids °Brix, TSS/acid ratio, and vitamin C content compared to the control. Meanwhile, total acidity percentage in 'Osteen' mango fruits significantly decreased after both LRE and PS foliar sprays. 'Osteen' mango trees showed a significant increase in leaf area, total chlorophyll content, total pigments, and leaf carotenoids. Our results suggest that foliar sprays containing LRE and PS significantly improved growth parameters, yield, fruit quality, antioxidant content, and total pigment concentration in 'Osteen' mango trees. Moreover, the most effective treatments were 3 mM PS and 6 g/L LRE. LRE and PS foliar spray caused a significant increase in yield percentage by 305.77%, and 232.44%, in the first season, and 242.55%, 232.44% in the second season, respectively.

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INTRODUCTION

Ensuring global food security for a growing population is a major challenge for modern agriculture (*Fróna, Szenderák & Harangi-Rákos, 2019*). This challenge is compounded by several factors. Climate change has reduced the productivity of fruit trees. Additionally, the decline of usable land and the intensification of agricultural practices further complicate the situation (*Pandey, 2020*). To achieve sustainable farming, there is a growing interest in finding environmentally safe organic materials (*Durán-Lara, Valderrama & Marican, 2020*).

Among tropical fruits, the mango stands out as one of the most essential globally, prized for its flavor and nutritional value (*Hussain et al., 2021*). This fruit may be enjoyed sparkling, juiced, or maybe integrated into diverse meals products. Mangoes boast an outstanding nutritional profile, filled with both macro and micronutrients (*Yahia et al., 2023*). Low mango yields and inconsistent fruit are main challenges for growers. These issues with flowering and fruiting, along with abnormal flowering, terrible fruit set, and inconsistent fruit development (*Shivran et al., 2020*). These changes led to lower yields, culmination of subpar exceptional and restrained availability at some stage in the year. Fortunately, research suggests a promising solution: strategic application of nutrients and growth regulators (*Ram, Rahim & Alam, 2020*). By influencing flowering and fruiting patterns, these tools can assist us release the whole potential of various mango cultivars ('Keitt', 'Tommy Atkins') (*Ramírez & Davenport, 2010*). This method has the energy to seriously boom and stabilize mango production (*Tirado-Kulieva et al., 2022*).

Biostimulants have been recognized as a promising approach that utilizes natural products (*Santini et al., 2021*). Biostimulants are a flexible, cost-effective, and widely applicable solution that can improve agricultural productivity in a sustainable manner and mitigate the effects of climate change (*Fallovo et al., 2008*; *Rouphael & Colla, 2018*). Generally, biostimulants have the potential to enhance crop productivity through three key mechanisms: (i) optimizing root system architecture to improve water and nutrient uptake, (ii) maximizing photosynthetic capacity to promote growth, and (iii) reducing oxidative stress in plants by enhancing the antioxidant defense system (*De Pascale & Rouphael, 2018*; *Rouphael & Colla, 2018*).

Recent research has explored the potential of plant extracts, like licorice root, to enhance fruit tree growth and yield (*Nasir et al., 2016*). Licorice (*Glycyrrhiza glabra*), belonging to the Leguminoseae family, thrives in Egypt and many other regions globally (*Vlaisavljević et al., 2018*). The licorice root boasts some nutritional value and unique chemical compounds, including gleserezin, glycyrrhejel. Additionally, rich in various elements and nutrients (*Husain et al., 2021*). Licorice extract is believed to stimulate cellulose enzyme activity, crucial for cell expansion, ultimately accelerating plant growth. It might also help reduce transpiration rates, minimizing water loss and maintaining cell turgor (*Peng et al., 2023*).

Potassium is a vital mineral nutrient for plants (*Wang et al., 2013*). This element is crucial for numerous functions within plants, influencing growth, yield, fruit development, quality, and even their ability to withstand stress (*Shahid et al., 2020*). Studies have shown that potassium improves fruit quality parameters like sugar content, color, and overall taste (*Hernández-Pérez et al., 2020*). Beyond its role in fruit development, potassium is essential for plant life itself (*Sardans & Peñuelas, 2021*). It activates numerous enzymes involved in photosynthesis, sugar production, and overall plant metabolism, ultimately leading to increased crop yields (*Nieves-Cordones, Al Shiblawi & Sentenac, 2016*). Potassium also regulates various physiological processes like water movement, respiration, and nutrient translocation within the plant. Additionally, it activates enzymes like nitrate reductase and starch synthetase, which contribute to a healthy balance of protein and carbohydrate production (*Iqbal et al., 2022*). Potassium even influences how plants open and close their stomata (tiny pores on leaves). This, in turn, affects photosynthesis, nutrient uptake, and overall plant function, ultimately impacting crop yield and fruit quality (*Devin et al., 2023*). Studies have shown that KNO_3 increases the proportion of flowering shoots, flower clusters, and vegetative growth, key to better yields and decreased alternate bearing (*Alshallash et al., 2023*; *Alebidi et al., 2023*).

Studies show potassium is vital for healthy mango trees and delicious fruit. It improves fruit size, sweetness, and color by strengthening the tree and boosting sugar production (*Andreotti et al., 2022*; *Ahmad et al., 2023*). Field trials confirm that applying potassium, especially through leaves, significantly increases mango yield and fruit quality of 'Hindi' mango trees (*Baiea, El-Sharony & El-Moneim, 2015*).

Many studies have investigated mango cultivation, but none have looked at how licorice root extract (LRE) and potassium sorbate (PS) affect the growth, yield, fruit quality, and antioxidant enzymes of 'Osteen' mangoes. Moreover, this study aimed to elucidate the effects of licorice root extract and potassium sorbate on the growth, yield, fruit quality, total chlorophyll content, and antioxidant enzymes of 'Osteen' mango trees.

MATERIALS AND METHODS

Licorice root extract preparation

To prepare the licorice root extract for commercial use (obtained from the Sekem Group in Cairo, Egypt), it was mixed with water at a concentration of 250 g/L. The mixture was left at room temperature for 24 h, and then thoroughly blended before being filtered through Whatman No. 42 filter papers. This filtration process resulted in obtaining a condensed brown liquid extract. To enhance the properties of the filtered solution, gelatin from Sigma-Aldrich (at a concentration of 2 g/L) was added. This step followed the methodology described by *Younes, Dawood & Wardany (2019)*, *Younes et al. (2020)*. The resulting mixture was heated at a temperature of 30 ± 2 °C while stirring was done to ensure proper mixing following by storage for application on mango trees. The chemical composition of the licorice root extract was also analyzed, in Table 1, as reported by *Desoky, Elrys & Rady (2019)*, *Rady et al. (2019)*, *Younes et al. (2021)*.

Table 1 **Chemical analysis of licorice root extract (LRE) according to *Desoky, Elrys & Rady (2019)*, *Rady et al. (2019)* and *Younes et al. (2021)*.**

Constituents	Value
Na^+ (mg 100 mg^{-1} dr.wt.)	101.54
K^+ (mg 100 mg^{-1} dr.wt.)	376.96
Ca^{2+} (mg 100 mg^{-1} dr.wt.)	754.90
Mg^{2+} (mg 100 mg^{-1} dr.wt.)	524.78
Fe^+ (mg 100 mg^{-1} dr.wt.)	32.88
Zn^{2+} (mg 100 mg^{-1} dr.wt.)	0.91
Total phenols (mg of GAE g^{-1} dr.wt.)	4.38
Total flavonoids (mg of QE g^{-1} dr.wt.)	2.14
Total antioxidant capacity (mg of AAE g^{-1} dr.wt.)	72.99
Tannins (mg 100 g^{-1} dr.wt.)	33.98
Saponins (mg 100 g^{-1} dr.wt.)	21.00
Ascorbic acids (mg 100 g^{-1} dr.wt.)	2.77
Ferric reducing antioxidant power (mg 100^{-1} Dr.wt.)	43.90

Note:
Aae, L-ascorbic acid equivalent; dr.wt, dry weight; GAE, gallic acid equivalent; QE, quercetin equivalent; mg, milligram.

Table 2 **Weather data of El Salheya El Gedida district, El-Sharqia Governorate, Egypt (means 2022 and 2023).**

Months	T2M	TMIN	TMAX	RH2M	RAIN	SRAD
January	12.11	6.68	19.42	51.78	2.20	13.08
February	13.64	7.56	21.63	57.93	5.60	15.29
March	15.81	9.19	23.99	57.68	11.00	19.55
April	19.69	12.34	28.40	51.01	2.40	23.47
May	26.35	17.31	36.70	39.58	0.10	27.32
June	29.57	21.53	38.58	44.71	0.00	27.62
July	30.65	22.43	39.82	44.28	0.00	28.26
August	30.71	22.88	39.60	45.50	0.00	26.21
September	27.69	20.80	36.26	53.63	0.00	22.95
October	24.72	18.75	32.49	61.41	19.40	17.80
November	20.72	15.16	28.72	58.28	0.00	14.73
December	14.91	10.08	21.60	63.37	12.80	12.05
Average and sum	**22.21**	**15.39**	**30.60**	**52.43**	**53.50**	**20.70**

Interpretation	
T2M	Temperature average at 2 m (°C)
TMIN	Temperature at 2 m minimum (°C)
TMAX	Temperature at 2 m maximum (°C)
RH2M	Relative humidity average at 2 m (%)
RAIN	Precipitation (mm)
SRAD	Solar radiation (MJ/m^2/day)

Table 3 **Foliar sprays on mango trees.**

Treatments	Foliar spray material	Concentrations
Control	Water spray	0.0
LRE2	Licorice root extract	2 g/l
LRE4	Licorice root extract	4 g/l
LRE6	Licorice root extract	6 g/l
PS1	Potassium sorbate	1 mM
PS2	Potassium sorbate	2 mM
PS3	Potassium sorbate	3 mM

Experimental site

This study was conducted on 7-year-old Osteen mango trees in a private farm located in the El Salheya El Gedida district, El-Sharqia Governorate, Egypt (30.6547°N, 31.8733°E) weather data Table 2. The trees are planted in sandy soil at a distance of 2 m × 4 m (1,250 tree/ha) and irrigated using a drip system. Management practices included regular irrigation, fertilization, and pest and disease control. From mid-May to 1 month before harvest, the trees were sprayed monthly interval with licorice root extract and potassium sorbate solutions as follows in Table 3. Moreover, at 7:00 AM, we used backpack sprayers on each tree, applying 5 l (6,250 L/ha) of both solutions to the point of runoff.

Measurements

Leaf area

Twenty leaves below panicles of the spring growth cycle according to *Walworth & Sumner (1987)* were taken (2nd week of June) for measuring leaf area according to *Ahmed & Morsy (1999)* as follows:

$$\text{Leaf area} = 0.70\,(L \times W) - 1.06 = \ldots\ldots\ldots\ \text{cm}^2$$

where: L and W = leaf length and width, respectively.

Total pigments

Leaf total chlorophyll content and total carotenoids were extracted from fresh leaves of ‘Osteen’ mango cultivar, following the method of *Brito et al. (2011)*, and the results were calculated according to *Wellburn (1994)*.

Determination proline content

To estimate proline content a rapid colorimetric method was used (*Bates, Waldren & Teare, 1973*). Plant tissue (0.5 g) was homogenized in a solution and filtered. The filtrate was then mixed with a freshly prepared acid solution and heated. The reaction was stopped by cooling, and a specific organic solvent was used to extract a colored compound. The amount of color formed was measured using a spectrophotometer, and the proline content was determined using a standard curve.

Determination relative water content

Leaf relative water content (RWC) was determined following the method of *Yamasaki & Dillenburg (1999)*. Two leaves were randomly selected from the middle portion of each plant replicate. The fresh weight (FM) of each leaf was measured after separation from the stem. To determine the turgid weight (TM), leaves were rehydrated in closed containers with distilled water for 24 h at 22 °C. After rehydration, the leaves were weighed again. Finally, dry weight (DM) was obtained by oven drying at 80 °C for 48 h. All weights were measured with a balance accurate to 0.001 g. The relative water content was calculated as follows:

RWC (%) = [(FM − DM) (TM − DM)] × 100.

Antioxidant enzyme activity

To extract polyphenol oxidase (POX), peroxidase (PPO), and catalase (CAT), fresh leaves (0.5 g) of Osteen mango cultivar were mashed in a mortar with 5 ml of 0.1 M cold phosphate buffer (pH 7.1), and the mixture was centrifuged at 15,000 × *g* for 20 min at 4 °C. The supernatant was used in an enzyme activity experiment (*Esfandiari et al., 2007*).

Peroxidase activity (PPO) was measured using an approach that was based on *Amako, Chen & Asada (1994)*. Polyphenol oxidase (POX) activity was measured in compliance with *Kavrayan & Aydemir (2001)*. The activity of the catalase (CAT) enzyme was measured in compliance with *Aebi (1984)*.

Total phenolic and total flavonoid

According to *Singleton, Orthofer & Lamuela-Raventós (1999)*, the total phenolic content of Osteen mango tree leaves was measured using the Folin–Ciocalteu colorimetric method and represented as (mg/g) using gallic acid as a standard. According to *Escriche & Juan-Borrás (2018)*, the total flavonoid concentration in fresh leaves of the Osteen mango cultivar was measured using the aluminum chloride ($AlCl_3$) colorimetric method, with Rutin serving as a standard and being expressed as mg/g.

Tree yield

We harvested the fruit from each experimental tree when the flesh turned yellow and the shoulders rounded or flattened according to *Ahmed et al. (2023)* Moreover, on the 15th of August in both seasons of the 'Osteen' mango cultivar according to *Khattab et al. (2021)*. According to *Elshahawy et al. (2022)*, the Osteen mango cultivar exhibits regular fruiting behavior.

Then, the average yield was calculating in terms of number of fruits/tree and weight (kg). The yield increasing percentage was computed using the equation of *Abd El-Naby, Mohamed & El-Naggar (2019)*.

$$Fruit\ Yield\ increment\ (\%) = \frac{[Yield\ (treatment) - Yield\ (control)] \times 100}{Yield\ (control)}.$$

To assess the percentage of sunburned fruit, we counted the number of sunburned fruits on each tree at harvest. Then calculated the sunburn rate as a percentage using a formula developed by *Mohsen & Ibrahim (2021)* equation as follows:

$$\text{Sunburned fruits} = \frac{No.of\ sunburned\ fruit/tree}{Total\ No.\ of\ fruits/tree} \times 100.$$

Fruits physical properties

Fruit weight (g) was calculated at harvest time using a sample of five Osteen cv. mangoes. The samples were then chosen and transferred to the horticulture lab.

Chemical characteristics of fruits

Mango juice extraction

A total of 10 g of mango pulp was weighed and added to a 100 ml beaker. The pulp was then homogenized with distilled water using a blender to achieve a uniform mixture. The homogenized mixture was subsequently filtered to remove any particulates. The filtrate was then quantitatively transferred to a 100 ml volumetric flask. Distilled water was further added to the flask to bring the final volume to the mark.

Fruit total soluble solids (TSS) of Osteen mango pulp was determined in two to three drops of each sample juice by using a digital refractometer (force-Gouge ModelIGV-O.SA to FGV-100A. Shimpo instruments) and expressed as °Brix according to *McKie & McCleary (2016)*

Total acidity percentage

A 10 ml aliquot of the pulp solution was measured into a conical flask. Two to three drops of phenolphthalein indicator were added, and the flask was then swirled vigorously to ensure thorough mixing. The solution was immediately titrated with 0.1 N NaOH solution from a burette until a permanent pink endpoint was reached. The volume of NaOH solution consumed was recorded, and the percent titratable acidity was expressed as citric acid (%) according to the method of *McKie & McCleary (2016)*.

Total soluble solids/acid ratio was calculated from the values of total soluble solids divided by values of total acids (*McKie & McCleary, 2016*).

The ascorbic acid content (vitamin C) of fruit juice was determined in triplicate ($n = 3$) for each treatment, with a sample volume of 2.0 ml per replicate. The analysis followed the method described by *McKie & McCleary (2016)*, which is based on the oxidation of ascorbic acid with 2,6-dichlorophenolindophenol dye. The results are expressed as (mg/100 ml) of juice and represent the average value for each treatment.

Statistical analysis

The design of the present study was a randomized complete block design (RCBD). The information used to create the charts comes from three separate times when each treatment (nine trees/treatments was applied). The analysis of variance as one-way ANOVA was used through Costat software (*Ridgman, 1990*), and means of different treatments were compared using the Duncan test ($p \leq 0.05$).

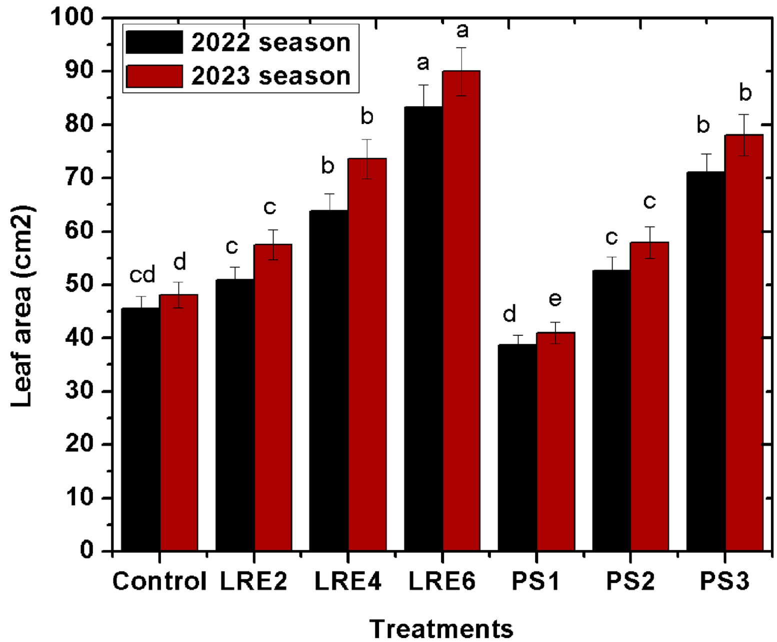

Figure 1 Effect of licorice-root extract and potassium sorbate spray on leaf area of the 'Osteen' mango cultivar in 2022 and 2023 seasons. Control: water spray; LRE2, LRE4, LRE6: 2, 4 and 6 g/L licorice root extract; PS1, PS2 and PS3: 1, 2 and 3 mM potassium sorbate. Different lowercase letters in the figure represent significant differences among treatments at p = 0.05 according to Duncan's test.
Full-size DOI: 10.7717/peerj.18200/fig-1

RESULTS

Effect of LRE and PS on leaf area of 'Osteen' mango under heat stress

The results in Fig. 1 showed that spraying with licorice root extract and potassium sorbate in mid- May significantly increased the leaf area of 'Osteen' mango trees in both studied seasons in comparison to control. Additionally, a trend emerged where leaf area increased as the concentration of licorice root extract and potassium sorbate increased. Leaf area promotion was most dependent on the application of licorice root extract at 6 g/L, followed by 3 mM potassium sorbate. Untreated trees consistently had the lowest leaf area values. This trend was observed in both growing seasons.

Effect of LRE and PS on fruit physical properties

The results in Figs. 2A, and 2B clearly showed that adding licorice root and potassium sorbate extract at various phenological stages significantly increased fruit weight (g), and number of fruits/tree of Osteen mango trees in comparison to those of control in the two studied seasons. These results are in line with findings of *Baiea, El-Sharony & El-Moneim (2015)* who found that spraying Hindi mango trees four times with different types of potassium were very effective in improving number of fruits or weight (kg/tree) comparing with the control. Fruit weight (g), and No. of fruits/tree promotion were most dependent on the application of licorice root extract at 6 g/L, followed by 3 mM potassium sorbate. Trees treated with 6 g/L licorice root extract exhibited the maximum fruit weight (g), and No. of fruits/tree, followed by those treated with 3 mM potassium sorbate. Additionally, a

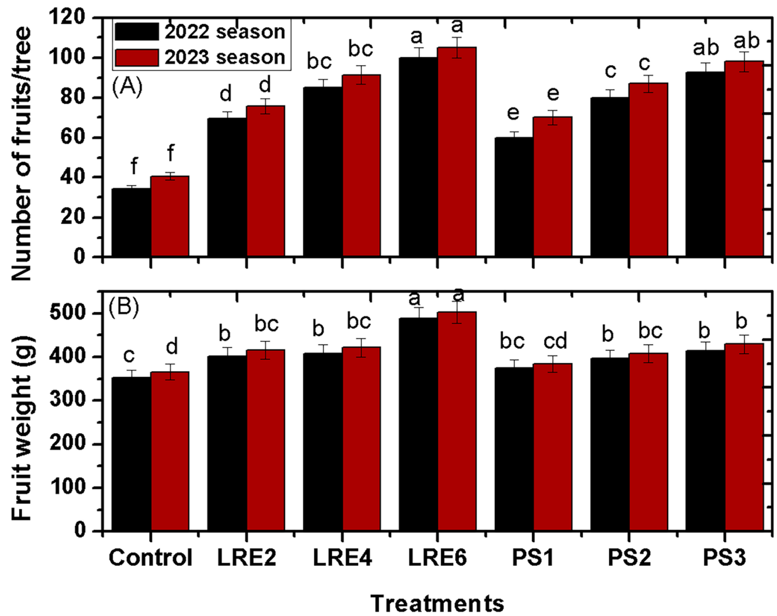

Figure 2 Effect of licorice-root extract and potassium sorbate spray on fruit weight and No. of fruit/tree of the 'Osteen' mango cultivar in 2022 and 2023 seasons. Control: water spray; LRE2, LRE4, LRE6: 2, 4 and 6 g/L licorice root extract; PS1, PS2 and PS3: 1, 2 and 3 mM potassium sorbate. Different lowercase letters in the figure represent significant differences among treatments at $p = 0.05$ according to Duncan's test.

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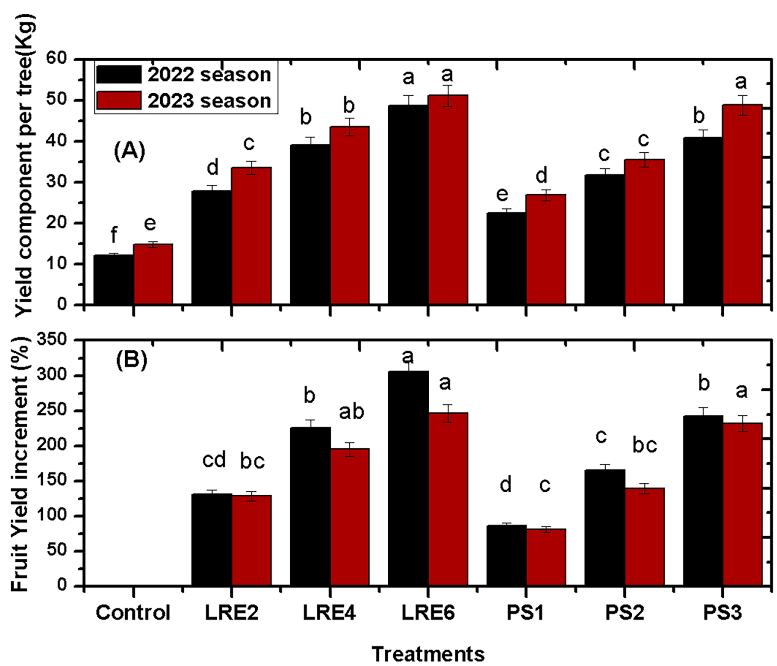

Figure 3 Effect of licorice-root extract and potassium sorbate spray on yield/tree and yield increasing (%) of the 'Osteen' mango cultivar in 2022 and 2023 seasons. (A) Yield component/tree (kg) and (B) yield increasing %. Control: water spray; LRE2, LRE4, LRE6: 2, 4 and 6 g/L licorice root extract; PS1, PS2 and PS3: 1, 2 and 3 mM potassium sorbate. Different lowercase letters in the figure represent significant differences among treatments at $p = 0.05$ according to Duncan's test.

Full-size DOI: 10.7717/peerj.18200/fig-3

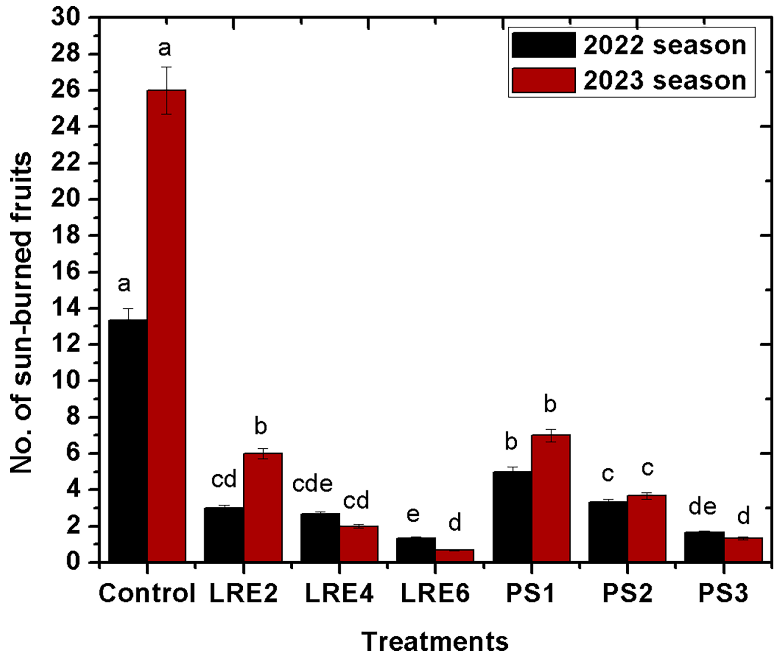

Figure 4 Effect of licorice-root extract and potassium sorbate spray on No. of sun-burned fruits of the 'Osteen' mango cultivar in 2022 and 2023 seasons. Control: water spray; LRE2, LRE4, LRE6: 2, 4 and 6 g/L licorice root extract; PS1, PS2 and PS3: 1, 2 and 3 mM potassium sorbate. Different lowercase letters in the figure represent significant differences among treatments at $p = 0.05$ according to Duncan's test. Full-size DOI: 10.7717/peerj.18200/fig-4

trend emerged where fruit weight (g), and No. of fruits/tree increased as the concentration of potassium sorbate and licorice root extract increased.

Effect of LRE and PS on fruit yield/tree

The results illustrated in Figs. 3A and 3B revealed notable enhancements in fruit yield (kg/tree) and yield increasing (%) when 'Osteen' mango trees were subjected to the addition of licorice root extract and potassium sorbate as foliar spray at different phenological stages. These improvements were observed across various growth stages and were found to be significantly higher compared to the control group in both seasons under investigation. Specifically, the application of 3 mM potassium sorbate or 6 g/L licorice root extract resulted in a more pronounced increase in fruit yield (kg/tree) compared to other treatments or the control group. Licorice root extract and potassium sorbate foliar spray caused a significant increase in yield percentage by 305.77%, and 232.44%, in the first season, and 242.55%, 232.44% in the second season, respectively.

Effect of LRE and PS on number of sun-burned fruits

Figure 4 represents the response of the number of sun-burned fruits of 'Osteen' mango trees to licorice root extract and potassium sorbate foliar spray. Both potassium sorbate and licorice root extract foliar spray significantly reduced the number of sun-burned fruits of 'Osteen' mango trees in comparison to the control group in the two studied seasons. The lowest number of sun-burned fruits of Osteen mango trees were possessed from LER6

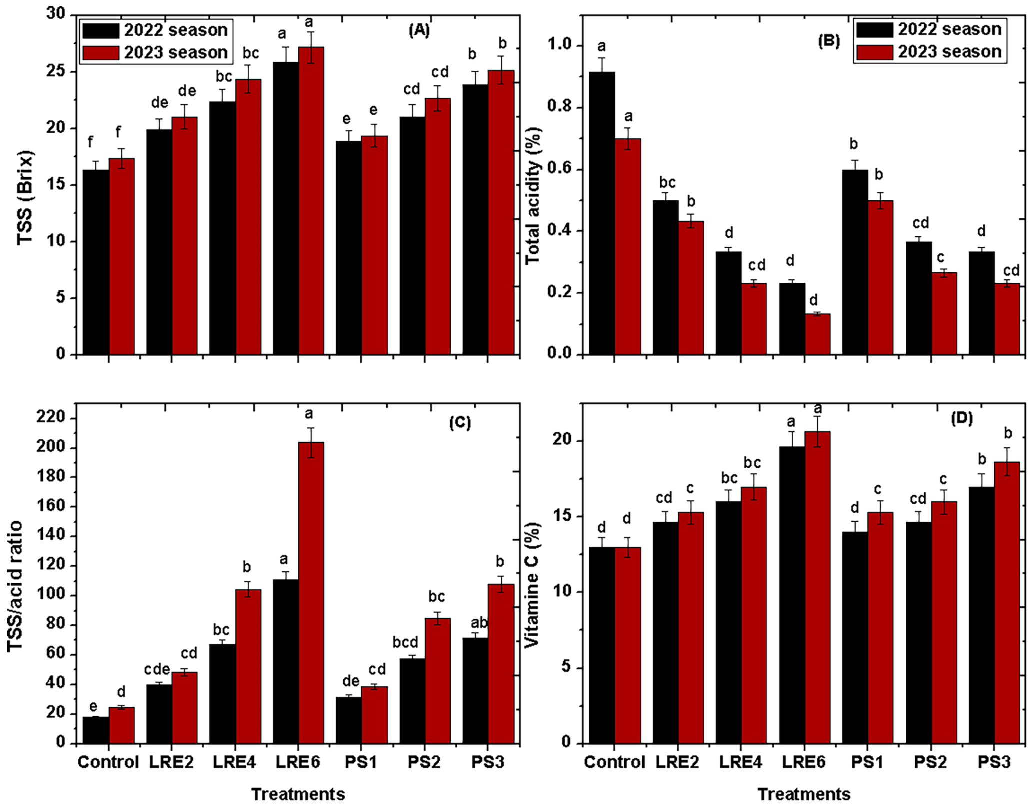

Figure 5 Effect of licorice-root extract and potassium sorbate spray on some of fruit chemical characteristics of the 'Osteen' mango cultivar in 2022 and 2023 seasons. (A) TSS Brix°, (B) total acidity %, (C) TSS/acid ratio and vitamin C. Control: water; LRE2, LRE4, LRE6: 2, 4 and 6 g/L licorice root extract; PS1, PS2 and PS3: 1, 2 and 3 mM potassium sorbate. Different lowercase letters in the figure represent significant differences among treatments at $p = 0.05$ according to Duncan's test.

Full-size DOI: 10.7717/peerj.18200/fig-5

(6 g/L licorice root extract) and or PS3 (3 mM PS). Meanwhile, the control group had the highest number of sun-burned fruits of Osteen mango trees in both seasons. Additionally, a trend was observed: as the level of potassium sorbate and licorice root extract increased, the number of sun-burned fruits of Osteen mango trees decreased.

Effect of LRE and PS on some fruit chemical characteristics

Foliar application of both LRE and PS significantly increased TSS (Brix°), TSS/acid ratio, and Vitamin C in comparison to the control group, as shown in Figs. 5A, 5C, and 5D. Conversely, total acidity% in 'Osteen' mango fruits significantly decreased in response to the foliar application during both study seasons (Fig. 5B). Concerning fruit chemical characteristics, the data revealed that higher levels of LRE and PS applied as foliar sprays were superior to the control group and to treatments with lower spraying concentrations. Among all treatments, 3 mM potassium sorbate (PS3) and 6 g/L licorice root extract (LER6) resulted in fruits with the highest TSS%, TSS/acid ratio, and vitamin C content, compared to the control group and other treatments. On the other hand, 'Osteen' mango

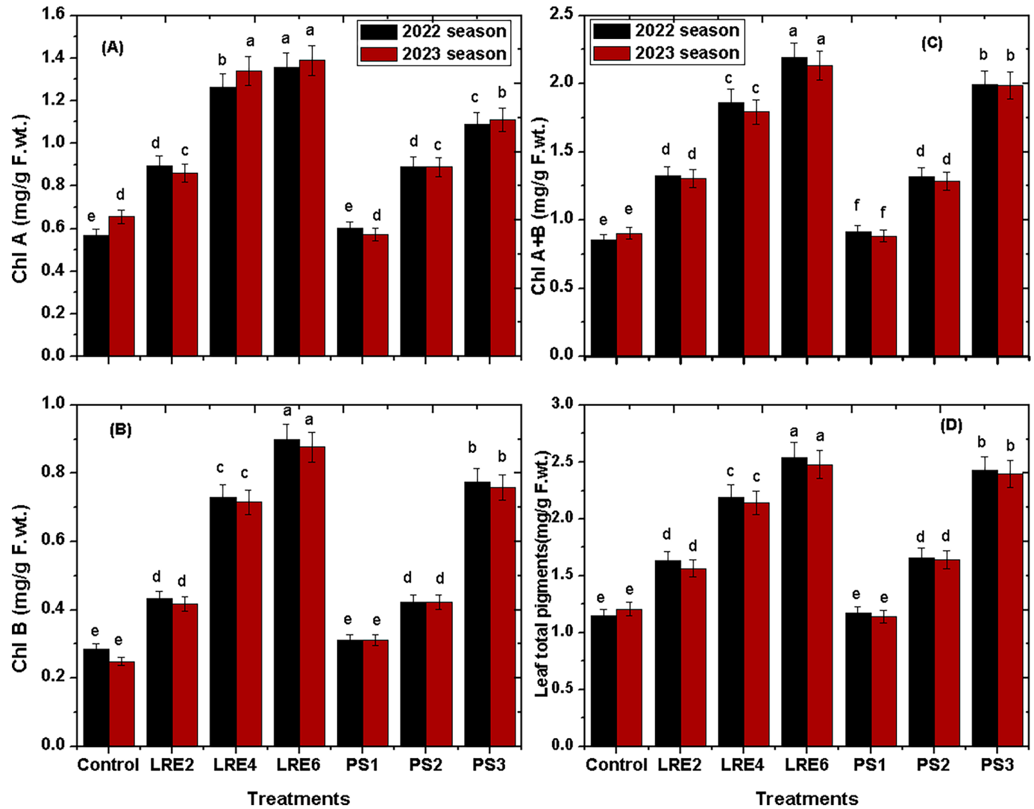

Figure 6 Effect of licorice-root extract and potassium sorbate on the photosynthetic pigments leaf of the 'Osteen' mango cv. under heat stress in 2022 and 2023 seasons. Control: water spray; LRE2, LRE4, LRE6: 2, 4 and 6 g/L licorice root extract; PS1, PS2 and PS3: 1, 2 and 3 mM potassium sorbate. Different lowercase letters in the figure represent significant differences among treatments at $p = 0.05$ according to Duncan's test. Full-size DOI: 10.7717/peerj.18200/fig-6

fruits from treatments T3 and T6 showed the lowest values of total acidity compared with fruits from other foliar spray treatments or the untreated group.

The photosynthetic pigments leaf of 'Osteen' mango cv. under heat stress

It is clear from Fig. 6 that the photosynthetic pigments of leaf Osteen mango CV were significantly influenced by foliar spray with licorice root extract (LRE) and PS during the 2022 and 2023 seasons under heat stress (sunburn). The application of different LRE and PS concentrations on mango tree leaves resulted in an increase in photosynthetic pigments under heat stress. As shown in Fig. 6, increasing the LRE concentrations from 2–6 g/L and PS from 1–3 mM led to an increase in the values of chlorophylls (a and b) and total chlorophyll, carotenoids, and total pigments. With a LRE concentration of 6 g/L (LER6), the highest values for chlorophyll a (1.389), chlorophyll b (0.899), total chlorophyll (2.267), carotenoids (0.433), and total pigments (2.689 mg/g fresh weight) were obtained compared to the control, which had the lowest values for these characteristics under heat stress during both seasons. Additionally, spraying PS at 3 mM (PS3) had the greatest impact on the photosynthetic pigment contents compared to other PS concentrations and the control

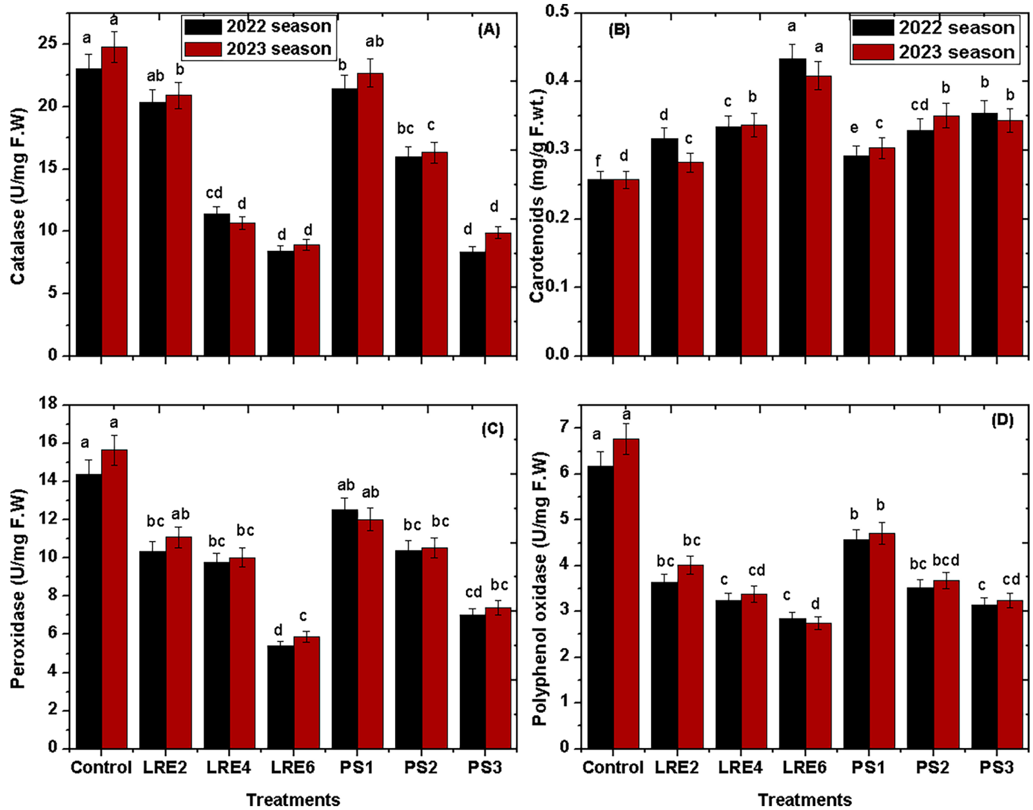

Figure 7 Effect of licorice-root extract and potassium sorbate on carotenoids, catalase activity, peroxidase activity and polyphenol oxidase activity of leaves osteen mango cv. under heat stress in 2022 and 2023 seasons. Control: water spray; LRE2, LRE4, LRE6: 2, 4 and 6 g/L licorice root extract; PS1, PS2 and PS3: 1, 2 and 3 mM potassium sorbate. Different lowercase letters in the figure represent significant differences among treatments at $p = 0.05$ according to Duncan's test.

Full-size DOI: 10.7717/peerj.18200/fig-7

treatment. The value for total pigments (2.219 mg/g fresh weight) was higher than that of the control (non-treated) (1.11 mg/g fresh weight) under heat stress during the 2022–2023 seasons (Fig. 6E).

Antioxidant activity leaf of Osteen mango cv. under heat stress

Polyphenol oxidase (PPO), peroxidase (POX), and catalase (CAT) activities were significantly influenced by the foliar spray of LRE and PS on Osteen mango leaves under heat stress (sunburn) during the 2022 and 2023 seasons (Fig. 7). Based on the results, the highest activities of PPO (6.76 U/g F.Wt), POX (15.66 U/g F.Wt), and CAT (24.81 U/g F. Wt) enzymes were found under control conditions (non-treated). According to Figs. 7A–7C, the enzyme activities decreased with increasing concentrations of LRE and PS sprayed on mango leaves. The lowest activities of PPO (2.75 U/g F.Wt) and POX (5.39 U/g F.Wt) enzymes were observed when spraying Osteen leaves with 6 g/L of LRE (T3), while the lowest activity of CAT (8.35 U/g F.Wt) was recorded at 3 mM of PS (PS3). Agricultural production is adversely affected by global warming and the anticipated rise in temperatures (*Challinor et al., 2014*; *Fahad et al., 2017*).

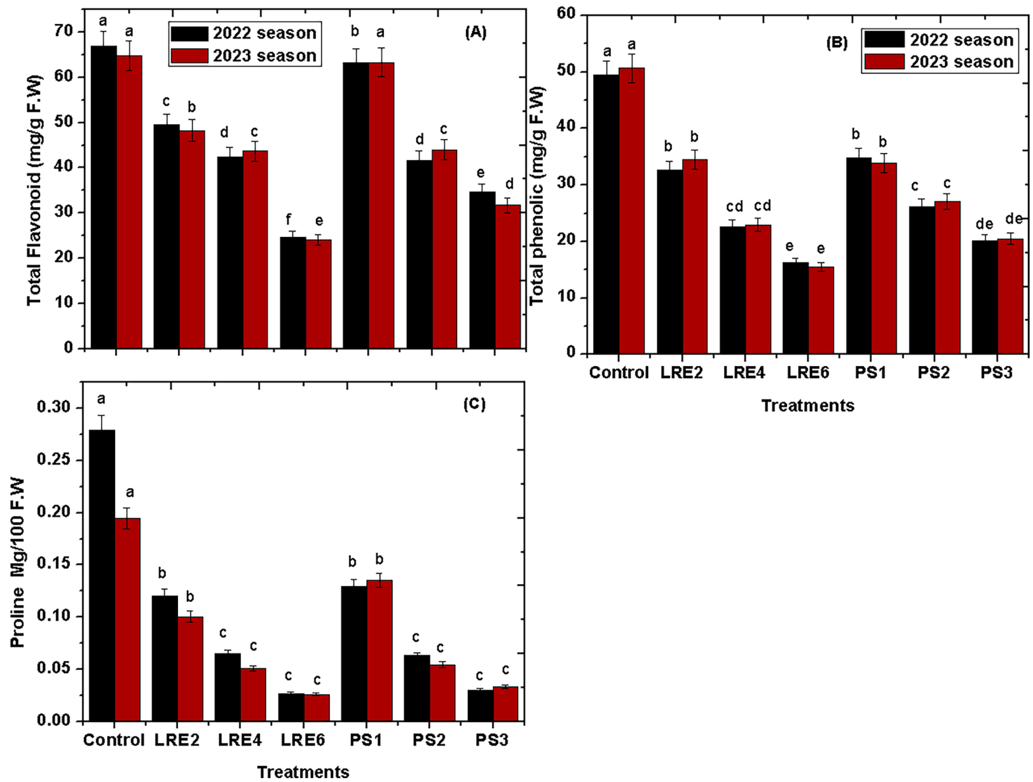

Figure 8 Effect of licorice-root extract and potassium sorbate on total flavonoids, total phenolic and proline of leaves osteen mango cv. under heat stress in 2022 and 2023 seasons. Control: water spray; LRE2, LRE4, LRE6: 2, 4 and 6 g/L licorice root extract; PS1, PS2 and PS3: 1, 2 and 3 mM potassium sorbate. Different lowercase letters in the figure represent significant differences among treatments at p = 0.05 according to Duncan's test. Full-size DOI: 10.7717/peerj.18200/fig-8

Total flavonoids, total phenolic and proline of leaf Osteen mango cv. under heat stress

The content of total flavonoid in leaves of Osteen mango is shown in (Fig. 8A). The highest (66.90 mg/g F.W) and lowest (24.03 mg/g F.W) values were observed with control (heat stress non-treated) and T3 6 g/L LRE, respectively in 2022 and 2023 seasons. Total flavonoid content decreased by 26%, 32.66%, and 63% at 2, 4, and 6 g/L LRE, respectively, and by 2.46%, 32.2%, and 48.28% at 1, 2, and 3 mM PS, respectively. Figure 8B illustrates data about the total phenolic content. The highest amounts of total phenolic (50.67 mg/g F.W) were found in leaves under control and the lowest amount (15.46 mg/g F.W) was treated with T3 6 g/L LRE. Total phenolic decreased by 69.43% and 59.57% at T3 6 g/L LRE and PS3 3 mM PS, respectively. Within the kingdom of plants, flavonoids and phenolics are the most extensively dispersed secondary metabolites. These compounds play a vital role in plant growth and defense mechanisms. The results for proline variation in leaves of treated and non-treated Osteen mango trees under heat stress are presented in Fig. 8C. Osteen mango leaves exposed to high temperatures showed higher proline content. The highest accumulation of proline (0.280 mg/100 g F.W) belonged to control leaves. According to *Bernardo et al. (2018)*, raising temperatures to extremely high levels led to excessive proline production in grapevine. The trees sprayed with T3 6 g/L LRE showed lower proline content (0.026 mg/100 g F.W) compared to control and other treatments.

DISCUSSION

Heat stress causes many disorders in mango growth, which led to a reduction in leaf area. Spraying with LER and PS in our study showed a mitigating effect on heat stress. These results are consistent with the findings in numerous studies support the use of foliar potassium to enhance plant growth. *Abd El-Rahman (2021)* observed this when added potassium silicate to 'Sedika' mango trees, *Ayed et al. (2022)* with 'Keitt' mango trees, and *EL-Gioushy (2021)* with orange trees. All these studies found that foliar application of potassium significantly improved vegetative growth compared to the control group. The leaf area increasing might be due to potassium spray (*Rouphael & Colla, 2018*). Potassium plays a vital role by activating enzymes for organic substance synthesis, promoting photosynthesis, and transporting carbohydrate assimilates to storage organs (*Fallovo et al., 2008*). It is also involved in several basic physiological functions. Similarly licorice root extracts improving the vegetative growth of plants (*Nasir et al., 2016*). The increase in fruit weight of 'Osteen' mango trees could be attributed to the increase in leaf area caused by potassium sorbate and licorice root extract application and subsequently stimulation of photosynthesis intensity shared in increasing the fruit weight. Similarly, the study focused on licorice root extract as a potential vegetarian alternative to synthetic growth regulators. This extract is gaining interest due to its reported ability to improve plant growth and production in practical applications. Licorice root contains glycyrrhizin, a compound composed of calcium and potassium salts of glycyrrhizic acid, a trihydroxy acid (*Rady et al., 2019*). Moreover, it contained a wide range of elements and nutrients (*Hamam et al., 2021*). As a matter of fact, adding a lot of potassium sorbate as foliar spray at different fruit growth stage may be attributed to the physiological role of potassium which is needed for many biochemical processes. Potassium also regulates various physiological processes like water movement, respiration, and nutrient translocation within the plant. Additionally, it activates enzymes like nitrate reductase and starch synthetase, which contribute to a healthy balance of protein and carbohydrate production (*Iqbal et al., 2022*).

Despite being one of the important activities in tropical regions, mango production has been largely ignored in systematic impact analyses of climate change (*Nath et al., 2019*). Heat stress can reduce fruit yield in mango tree cultivars, leading to a decline in overall tree productivity. This study aligns with previous findings by *El-Merghany, El–Desouky & El-Hameid (2019)* who reported that licorice root extract application to 'Ferehy' date Palm trees significantly increased fruit weight and yield per tree. Similarly, *Ahmed, Eliwa & Ismail (2023)* found that adding 4–8 g/L of the extract to red globe grapevines in April to June increased yield per tree compared to the control group. Similarly, in a study by *Yassin, Ataya & Fahmy (2023)*, applying potassium silicate at concentrations of 100, and 200 ppm increased the number of fruits and fruit yield per tree of Wonderful and H116 pomegranate compared to the control group. Additionally, *Silem, Ismail & Mohamed (2023)* reported that applying potassium silicate at a concentration of 500 ppm to mango trees at the beginning of growth, after fruit setting, and 1 month later increased fruit yield per tree compared to the control group. The increasing in yield/tree of 'Osteen' mango trees might be due to licorice root extract has been found to be an amazing biostimulant that increases not only growth but also the yields of various crops (*Alshallash et al., 2022*). According to *Diab & Abd El-hmied (2022)* they found that foliar spraying the 'Kitte' cv. mango with licorice root extract at 5 or 10 g/L concentration on three occasions, at the beginning of growth, after fruit set, and 3 weeks after fruit set, significantly increased tree yield in comparison to the control group.

It could be concluded that application of LRE and PS to Osteen mango trees at different growth stages significantly enhanced fruit weight, number of fruits per tree, yield (kg/tree), and yield increase percentage, compared to the control. The most effective treatments were 6 g/L LRE and 3 mM PS.

Our results align with the findings of *Ahmed, Eliwa & Ismail (2023)*, who reported that foliar spraying the 'Red Glob' cv. grapevine with licorice root extract at a concentration of 4 or 8 g/L, applied three times in mid-April, May, and June, significantly reduced the number of sun-burned fruits. The presence of various beneficial compounds in licorice root extract, including phenolics, triterpenes, saponins, amino acids, polysaccharides, vitamins, and growth-promoting phytohormones, likely contributes to enhanced vegetative growth. These compounds may stimulate activity in the apical meristem, the plant's growth center, by promoting cell division and elongation (*Pandey, 2017*). The reduction in number of sun-burned fruits might be attributed to the enhanced vegetative growth in mango trees caused by potassium application (*Baiea, El-Sharony & El-Moneim, 2015*). Additionally, potassium may influence a tree's canopy size, which could in turn help the tree withstand environmental challenges like drought and high radiation (*Hamdy et al., 2022*; *Alharbi et al., 2022*). It could be concluded that application of potassium sorbate and licorice root extract to Osteen mango trees significantly reduced number of sun-burned fruits, compared to the control. The most effective treatments were 6 g/L licorice root extract and 3 mM potassium sorbate.

The mango fruit quality results in this study were consistent with those reported by *Baiea, El-Sharony & El-Moneim (2015)* found that spraying Hindi mango trees four times with Potassium were very effective in improving enhanced fruit quality. In addition, fruit total acidity was reduced compared with the control. Likewise, *El-Morsy, Mohamed & Bedrech (2017)* on Red Globe where the highest values of fruit chemical characteristics were obtained with addition of licorice extract foliar spraying treatments 20 and 15 g/L. Similarly, *Obenland et al. (2015)* found that potassium sorbate foliar spray at concentration 1.3 g/L significantly increased fruit Flame seedless SSC in comparison to control. Potassium treatments may be responsible for the enhanced chemical characteristics of 'Osteen' mango fruits. This is likely because potassium acts as a catalyst for numerous biological processes within the trees, leading to improved overall tree health and nutrient status (*Amtmann et al., 2005*).

Licorice extract application may be responsible for the observed improvements in physical and chemical fruit quality, as well as increased yield. This effect could be attributed to the presence of mevalonic acid in the extract. Mevalonic acid acts as a precursor to gibberellin, a plant hormone that stimulates leaf cell expansion. These results in increased leaf area and chlorophyll content, ultimately leading to improved fruit set and yield (*Petoumenou & Patris, 2021*). We can conclude that application of LRE and PS to Osteen mango trees significantly enhanced fruit TSS%, TSS/acid ratio, and vitamin C content compared to the control. Meanwhile, total acidity percentage in 'Osteen' mango fruits significantly decreased in response to the foliar spray. The most effective treatments were 3 mM PS and 6 g/L LRE.

High temperatures or severe heat waves are among the abiotic stresses that inhibit mango growth, development, and crop quality (*Muthuramalingam et al., 2023*). A water shortage, often caused by heat and intense light, harms plants' ability to photosynthesize by inducing stomatal closure, mesophyll compactness, and photoinhibition. Mango leaf photosynthesis, transpiration, and water potential can all be impaired when exposed to high temperatures and low air relative humidity (*Faria et al., 2016*; *Khanum et al., 2020*).

Spraying LRE led to a reduction in sunburn and improved the photosynthesis system because it behaves similarly to gibberellin, which promotes vegetative growth. This extract contains nutritive components including N, Mg, Zn, Cu, and Fe. Since nitrogen aids in the creation of chlorophyll, these minerals play a significant role in the process of chlorophyll synthesis. Furthermore, iron contributes to the crucial steps that lead to chlorophyll production by increasing the number and size of chloroplasts and grana (*Venzhik, Shchyogolev & Dykman, 2019*). Spraying mango leaves with PS at different concentrations enhances chlorophyll content and plant pigments because potassium is a major nutrient that directly participates in the vital functions of plants, most notably regulating the photosynthesis process and osmotic regulation of stomatal activity and transpiration. It also plays a crucial role in plant survival under various stresses (*Araujo et al., 2015*; *Tränkner, Tavakol & Jákli, 2018*). *Alsalhy & Aljabary (2020)* discovered that grape cv. Halawany leaf chlorophyll content increased when LRE was applied as a spray at a level of 2.5 g/L. *Silem, Ismail & Mohamed (2023)* reported that the application of potassium silicate as a spray to Keitte mango tree leaves at 500 ppm elevated total chlorophyll contents in leaves during the 2021 and 2022 seasons under salinity stress compared to the control group. These findings align with those of *Younes et al. (2021)* and *Abdel-Mola et al. (2022)*.

We can conclude that application of LRE and PS to Osteen mango trees significantly increased leaf Chl A, Chl B, total chlorophyll content, carotenoids and total pigments under heat stress compared to the control. The most effective treatments were 3 mM PS and 6 g/L LRE.

Elevated temperatures can cause harm to plant cells in various ways, including interfering with protein synthesis and function, enzyme deactivation, and membrane rupture. These processes affect physiological functions such as respiration and photosynthesis. One common issue is an excess of harmful substances, like reactive oxygen species (ROS), leading to oxidative stress (*Hasanuzzaman, Nahar & Fujit, 2013*). In response to stressful conditions, plants exhibit an internal defensive mechanism through

ROS scavenging, which is demonstrated by the activities of enzymatic antioxidants such as superoxide dismutase (SOD), peroxidase (POX), and catalase (CAT) (*You & Chan, 2015*; *Rossi et al., 2017*).

Under heat stress (sunburn), PPO, POX, and CAT enzyme activities increased with increasing ROS levels (*You & Chan, 2015*). Our study's results showed that all treatments decreased the activities of antioxidant enzymes PPO, POX, and CAT (Figs. 7A–7C). This suggests that Osteen mango trees treated with LRE and PTS are more stable, producing fewer ROS and, therefore, requiring less of these enzymes. In contrast, leaves of untreated mango trees are exposed to heat stress, which increases ROS emission and necessitates the upregulation of antioxidant enzyme activities to maintain cellular balance. *Azab et al. (2022)* discovered that foliar application of potassium reduced SOD, CAT, and PPO activities in well-watered Squash plants. However, under drought stress, tomato plants responded more favorably to potassium application in terms of antioxidant enzyme activity than to a well-watered treatment. *Rady et al. (2019)* found that LRE application increased the activity of antioxidant enzymes (POX, CAT) and decreased hydrogen peroxide (H_2O_2) and superoxide radical (O^{2-}) levels in common bean plants under salt stress when compared to the control without LRE. *Hamdy et al. (2022)* found that leaf Keitt mango content of antioxidants, such as CAT, POX, and PPO enzyme activities, decreased under solar radiation (sunburn) following kaolin application. These findings are consistent with *Cabo et al. (2020)*. It could be concluded that enzyme activities of PPO, POX, and CAT all declined with increasing concentrations of LRE and PS sprayed on mango leaves. The lowest activities of PPO (2.75 U/g F.Wt) and POX (5.39 U/g F.Wt) were observed at the highest concentration of LRE (6 g/L, T3). Meanwhile, the lowest CAT activity (8.35 U/g F.Wt) was recorded at the highest concentration of PS (3 mM, T6).

According to *Tohidi, Rahimmalek & Arzani (2017)*, these substances have a wide range of biochemical and molecular functions in plants, including those of signaling molecules, plant defense, regulating auxin transport, antioxidant activity, and free radical scavenging. Phenols and flavonoids, which are non-enzymatic antioxidants, accumulate in different tissues and scavenge free radicals, helping plants tolerate salt stress (*Şirin & Aslım, 2019*). According to our findings, control (heat stress non-treated) significantly increased the amount of total flavonoids and total phenolic (Figs. 8A and 8B). One of the defense strategies employed by plants against oxidative stress is the rise of antioxidants, such as total phenolics and flavonoids, under high temperatures (*Wen et al., 2008*). From these results, we suggest that the increase in phenolic compounds may be due to the activity of phenylalanine ammonia-lyase under high temperatures (*Gebauer, Strain & Reynolds, 1997*). However, spraying the leaves with LRE and PTS at all concentrations caused all the values of flavonoids and phenolics to decrease, likely due to a reduction in the harmful effects of high temperature on the leaves, which lessened the need for phenylalanine to be directed towards synthesizing these compounds. According to *Rady et al. (2019)*, common bean plants grown under salt stress can benefit from the application of LRE as a natural biostimulant that can effectively boost their salt tolerance. Our outcomes were in agreement with those attained by *Dinis et al. (2018)*, *Younes et al. (2021)*. Plant cells exposed to any stress exhibit proline accumulation, which is an indicator of the damage

(*Per et al., 2017*; *Dinis et al., 2018*). Plant antioxidant systems contain a variety of low-molecular-weight substances, including proline and ascorbic acid (*Rady et al., 2019*). All treatments with LRE and PS resulted in reduced proline levels compared to control. This decrease is likely due to LRE and PS mitigating the negative effects of heat stress on Osteen mango leaves through improved physiological performance. Potassium is essential for physiological processes in plants, which helps them endure stressful environments (*Wang et al., 2013*). The findings suggested that spraying LRE and PS reduced the oxidative damage to cell membranes, as seen by the decrease in proline. These results are in agreement with *Cabo et al. (2020)*, *Dbara, Abboud & Bchir (2022)*, and *Shehzad et al. (2020)*, who found that adequate external supply of potassium led to a significant reduction in the activities of antioxidant enzymes and proline in drought-stressed plants. *Younes et al. (2021)* found that applying LRE as a biostimulant may be useful to improve bulb quality and, eventually, the productivity of onion cultivars in field conditions.

It could be concluded that flavonoid content significantly decreased following treatments. Levels dropped by 26%, 32.66%, and 63% at increasingly higher concentrations (2, 4, and 6 g/L) of LRE, respectively. Similarly, PS treatments resulted in a decrease of 2.46%, 32.2%, and 48.28% at concentrations of 1, 2, and 3 mM, respectively. Total phenolic content also showed a substantial reduction. The greatest decline (69.43%) was observed in leaves treated with 6 g/L LRE (T3), while the highest concentration of PS (3 mM, T6) caused a 59.57% decrease. Proline accumulation was highest in untreated leaves (control). Conversely, proline levels were significantly lower in leaves treated with 6 g/L LRE (T3), reaching only 0.026 mg/100 g fresh weight (FW) compared to the control value of 0.280 mg/100 g FW. This suggests that this concentration of LRE may inhibit proline production.

These results are consistent with the findings in numerous studies support the use of foliar potassium to enhance plant growth. *Abd El-Rahman (2021)* observed this when added potassium silicate to 'Sedika' mango trees, *Ayed et al. (2022)* with 'Keitt' mango trees, and *EL-Gioushy (2021)* with orange trees. All these studies found that foliar application of potassium significantly improved vegetative growth compared to the control group. The leaf area increasing might be due to potassium spray (*Rouphael & Colla, 2018*). Potassium plays a vital role by activating enzymes for organic substance synthesis, promoting photosynthesis, and transporting carbohydrate assimilates to storage organs (*Fallovo et al., 2008*). It's also involved in several basic physiological functions. Similarly licorice root extracts improving the vegetative growth of plants (*Nasir et al., 2016*).

CONCLUSIONS

This study demonstrated that foliar application of LRE and PS at specific concentrations (3 mM potassium sorbate and 6 g/L licorice root extract) significantly improved fruit yield, quality, and antioxidant enzyme activity in Osteen mango trees compared to the control. These treatments increased fruit weight, number of fruits, yield per tree, soluble solids content (TSS), TSS/acid ratio, and vitamin C content, while reducing total acidity and fruit enzyme activities (PPO, POX, and CAT). However, both licorice root extract and potassium sorbate caused a decrease in flavonoid and phenolic content, with the highest concentration (6 g/L LRE and 3 mM PS) showing the most significant reductions. Additionally, proline accumulation was inhibited by the highest concentration of licorice root extract (6 g/L LRE). These findings suggest that licorice root extract and potassium sorbate can be effective growth promoters for Osteen mango trees, but their influence on certain fruit quality parameters like fruit weight and yield should be considered.

ADDITIONAL INFORMATION AND DECLARATIONS

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Competing Interests

The authors declare that they have no competing interests.

Author Contributions

- Adel M. Al-Saif conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, funding, and approved the final draft.
- Haitham Ahmed El-khamissi conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Ibrahim Ahmed Elnaggar conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Mohammed Hamdy Farouk conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Magdy Abd El-Wahab Omar conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Abd El-wahed Naser Abd El-wahed conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Ashraf Ezzat Hamdy conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.

- Hosny Fathy Abdel-Aziz conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.

Data Availability

The following information was supplied regarding data availability:

The raw data are available at Figshare: Ezzat, Ashraf; M. Al-Saif, Adel; El-khamissi, Haitham; A. Elnaggar, Ibrahim; H. Farouk, Mohammed; A. Omar, Magdy; et al. (2024). Raw data. figshare. Dataset. https://doi.org/10.6084/m9.figshare.26314171.v1.

Supplemental Information

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REFERENCES

Abd El-Naby SK, Mohamed AA, El-Naggar YI. 2019. Effect of melatonin, Ga3 and NAA on vegetative growth, yield and quality of 'Canino' apricot fruits. *Acta Scientiarum Polonorum Hortorum Cultus* **18(3)**:167–174 DOI 10.24326/asphc.2019.3.16.

Abd El-Rahman A. 2021. Response of mango trees to mineral, bio-organic fertilizers and growth stimulants. *Journal of Plant Production* **12(9)**:981–986 DOI 10.21608/jpp.2021.202613.

Abdel-Mola M, Kenawy A, Ali S, Ayyat A. 2022. Influence of foliar application of gibberellic acid and liquorice root extract on growth, volatile oil yield productivity and antimicrobial activity in geranium (Pelargonium Graveolens l. her.) plants. *Scientific Journal of Flowers and Ornamental Plants* **9(4)**:249–271 DOI 10.21608/sjfop.2022.272767.

Aebi H. 1984. Catalase in vitro. In: *Methods in Enzymology*. Amsterdam: Elsevier, 121–126 DOI 10.1016/S0076-6879(84)05016-3.

Ahmad I, Zhu G, Zhou G, Liu J, Younas MU, Zhu Y. 2023. Melatonin role in plant growth and physiology under abiotic stress. *International Journal of Molecular Sciences* **24(10)**:8759 DOI 10.3390/ijms24108759.

Ahmed M, Eliwa N, Ismail H. 2023. Ameliorative effect of yeast and gamma irradiated licorice extracts on growth, yield, fruit quality and nutrient content of red globe grapevine. *Egyptian Journal of Radiation Sciences and Applications* **36(1–2)**:61–70 DOI 10.21608/ejrsa.2023.239705.1162.

Ahmed N, Ibrahim R, Said H, Hamad EH. 2023. Evaluation of some new mango cultivars under aswan conditions. *Aswan University Journal of Sciences and Technology* **3(2)**:41–55 DOI 10.21608/aujst.2023.325578.

Ahmed FF, Morsy MH. 1999. A new methods for measuring leaf area in different fruit species. *Minia Journal of Agricultural Research and Development* **19**:97–105.

Alebidi A, Abdel-Sattar M, Mostafa LY, Hamad ASA, Rihan HZ. 2023. Synergistic effects of applying potassium nitrate spray with putrescine on productivity and fruit quality of mango trees cv. Ewais. *Agronomy* **13(11)**:2717 DOI 10.3390/agronomy13112717.

Alharbi K, Alshallash KS, Hamdy AE, Khalifa SM, Abdel-Aziz HF, Sharaf A, Abobatta WF. 2022. Magnetic iron-improved growth, leaf chemical content, yield, and fruit quality of chinese mandarin trees grown under soil salinity stress. *Plants* **11(21)**:2839 DOI 10.3390/plants11212839.

Alsalhy BF, Aljabary AM. 2020. Effect of moringa leaves extracts and licorice roots on some growth characteristics and yield of grape (*Vitis vinifera* L.) cv. Halawany. *Plant Archives* **20(2)**:2616–2623.

Alshallash KS, Elnaggar IA, Abd El-Wahed AEN, Hhmdy AE, Abdel-Aziz HF, Omar MA. 2023. Utilization of jojoba oil and salicylic acid as postharvest treatment on storability and fruit quality of 'Late Swelling' peach cultivar. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* **51(2)**:12999 DOI 10.15835/nbha51212999.

Alshallash KS, Sharaf M, Hmdy AE, Khalifa SM, Abdel-Aziz HF, Sharaf A, Ibrahim MTS, Alharbi K, Elkelish A. 2022. Hydrogel improved growth and productive performance of mango trees under semi-arid condition. *Gels* **8(10)**:602 DOI 10.3390/gels8100602.

Amako K, Chen G-X, Asada K. 1994. Separate assays specific for ascorbate peroxidase and guaiacol peroxidase and for the chloroplastic and cytosolic isozymes of ascorbate peroxidase in plants. *Plant and Cell Physiology* **35**:497–504 DOI 10.1093/oxfordjournals.pcp.a078621.

Amtmann A, Hammond JP, Armengaud P, White PJ. 2005. Nutrient sensing and signalling in plants: potassium and phosphorus. In: *Advances in Botanical Research*. Amsterdam: Elsevier, 209–257 DOI 10.1016/S0065-2296(05)43005-0.

Andreotti C, Rouphael Y, Colla G, Basile B. 2022. Rate and timing of application of biostimulant substances to enhance fruit tree tolerance toward environmental stresses and fruit quality. *Agronomy* **12(3)**:603 DOI 10.3390/agronomy12030603.

Araujo L, Bispo WMS, Rios VS, Fernandes SA, Rodrigues FA. 2015. Induction of the phenylpropanoid pathway by Acibenzolar-S-Methyl and potassium phosphite increases mango resistance to *Ceratocystis fimbriata* infection. *Plant Disease* **99(4)**:447–459 DOI 10.1094/PDIS-08-14-0788-RE.

Ayed ME, Sharaf MM, Khamis MA, Atawia AR, BAkry KHA. 2022. Impact of shading and foliar spray with some nutritive solutions on growth, nutritional status, productivity and fruit quality of Keitt mango trees. *Annals of Agricultural Science, Moshtohor* **60(1)**:147–156 DOI 10.21608/assjm.2022.227514.

Azab ES, Alshallash KS, Alqahtani MM, Safhi FA, ALshamrani SM, Ali MAM, El-Mageed TAA, El-Taher AM. 2022. Physiological, anatomical, and agronomic responses of cucurbita pepo to exogenously sprayed potassium silicate at different concentrations under varying water regimes. *Agronomy* **12(9)**:2155 DOI 10.3390/agronomy12092155.

Baiea MHM, El-Sharony TF, El-Moneim EAAA. 2015. Effect of different forms of potassium on growth, yield and fruit quality of mango cv. Hindi. *International Journal of ChemTech Research* **8(4)**:1582–1587.

Bates LS, Waldren RP, Teare ID. 1973. Rapid determination of free proline for water-stress studies. *Plant and Soil* **39(1)**:205–207 DOI 10.1007/BF00018060.

Bernardo S, Dinis L-T, Machado N, Moutinho-Pereira J. 2018. Grapevine abiotic stress assessment and search for sustainable adaptation strategies in Mediterranean-like climates. A review. *Agronomy for Sustainable Development* **38(6)**:66 DOI 10.1007/s13593-018-0544-0.

Brito GG, Sofiatti V, Brandão ZN, Silva VB, Silva FM, Silva DA. 2011. Non-destructive analysis of photosynthetic pigments in cotton plants. *Acta Scientiarum. Agronomy.* **33(4)**:671–678 DOI 10.4025/actasciagron.v33i4.10926.

Cabo S, Morais MC, Aires A, Carvalho R, Pascual-Seva N, Silva AP, Gonçalves B. 2020. Kaolin and seaweed-based extracts can be used as middle and long-term strategy to mitigate negative effects of climate change in physiological performance of hazelnut tree. *Journal of Agronomy and Crop Science* **206(1)**:28–42 DOI 10.1111/jac.12369.

Challinor AJ, Watson J, Lobell DB, Howden SM, Smith DR, Chhetri N. 2014. A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change* **4(4)**:287–291 DOI 10.1038/nclimate2153.

Dbara S, Abboud S, Bchir A. 2022. Foliar potassium nitrate spray induces changes in potassium-sodium balance and biochemical mechanisms in olive *Olea europaea* L. cv Chemlali) plants submitted to salt stress. *Journal of Horticulture and Postharvest Research* **5(4)**:309–322 DOI 10.22077/jhpr.2022.4879.1255.

De Pascale S, Rouphael Y. 2018. Plant biostimulants: innovative tool for enhancing plant nutrition in organic farming. *European Journal of Horticultural Science* **82(6)**:277–285 DOI 10.17660/eJHS.2017/82.6.2.

Desoky ESM, Elrys AS, Rady MM. 2019. Integrative moringa and licorice extracts application improves Capsicum annuum fruit yield and declines its contaminant contents on a heavy metals-contaminated saline soil. *Ecotoxicology and Environmental Safety* **169(4)**:50–60 DOI 10.1016/j.ecoenv.2018.10.117.

Devin SR, Prudencio ÁS, Mahdavi SME, Rubio M, Martínez-García PJ, Martínez-Gómez P. 2023. Orchard management and incorporation of biochemical and molecular strategies for improving drought tolerance in fruit tree crops. *Plants* **12(4)**:773 DOI 10.3390/plants12040773.

Diab SM, Abd El-hmied S. 2022. Improving mango productivity by spraying some natural extracts and adding humic under the conditions of newly reclaimed lands. *Middle East Journal of Agriculture Research* **11(3)**:719–732 DOI 10.36632/mejar/2022.11.3.47.

Dinis LT, Malheiro AC, Luzio A, Fraga H, Ferreira H, Gonçalves I, Pinto G, Correia CM, Moutinho-Pereira J. 2018. Improvement of grapevine physiology and yield under summer stress by kaolin-foliar application: water relations, photosynthesis and oxidative damage. *Photosynthetica* **56(2)**:641–651 DOI 10.1007/s11099-017-0714-3.

Durán-Lara EF, Valderrama A, Marican A. 2020. Natural organic compounds for application in organic farming. *Agriculture* **10(2)**:41 DOI 10.3390/agriculture10020041.

EL-Gioushy SF. 2021. Minimizing 50% of chemical Npk fertilizers by compost and Em and their impact on growth, nutritional status, productivity and fruit quality of Washington Navel orange trees. *Annals of Agricultural Science, Moshtohor* **59(1)**:45–56 DOI 10.21608/assjm.2021.176634.

El-Merghany S, El–Desouky M, El-Hameid S. 2019. Improving productivity and fruit quality of ferehy date palm cultivar under siwa oasis conditions. *Egyptian Journal of Horticulture* **46(2)**:179–193 DOI 10.21608/ejoh.2019.12795.1106.

El-Morsy F, Mohamed M, Bedrech S. 2017. Effect of foliar application and soil addition of licorice and yeast extract: b-vegetative growth and fruiting of red globe grafted grapevines. *Journal of Plant Production* **8(1)**:59–63 DOI 10.21608/jpp.2017.37814.

Elshahawy SA, Nomier SA, Mohsen FS, Gad MM, Kelani RA. 2022. Comparative study on fruit yield and quality traits of the new mango cultivars grown under egypt conditions. *SABRAO Journal of Breeding and Genetics* **54(4)**:864–875 DOI 10.54910/sabrao2022.54.4.17.

Escriche I, Juan-Borrás M. 2018. Standardizing the analysis of phenolic profile in propolis. *Food Research International* **106(5)**:834–841 DOI 10.1016/j.foodres.2018.01.055.

Esfandiari E-O, Shakiba MR, Mahboob SA, Alyari H, Toorchi M. 2007. Water stress, antioxidant enzyme activity and lipid peroxidation in wheat seedling. *Journal of Food Agriculture and Environment* **5(1)**:149–153.

Fahad S, Bajwa AA, Nazir U, Anjum SA, Farooq A, Zohaib A, Sadia S, Nasim W, Adkins S, Saud S, Ihsan MZ, Alharby H, Wu C, Wang D, Huang J. 2017. Crop production under drought and heat stress: plant responses and management options. *Frontiers in Plant Science* **8**:1147 DOI 10.3389/fpls.2017.01147.

Fallovo C, Cristofori V, Mendoza de-Gyves E, Rivera CM, Rea R, Fanasca S, Bignami C, Sassine Y, Rouphael Y. 2008. Leaf area estimation model for small fruits from linear measurements. *HortScience* **43(7)**:2263–2267 DOI 10.21273/HORTSCI.43.7.2263.

Faria LN, Soares In Memoriam AA, Donato SLR, Santos MRD, Castro LG. 2016. The effects of irrigation management on floral induction of 'Tommy Atkins' mango in bahia semiarid. *Engenharia Agrícola* **36(3)**:387–398 DOI 10.1590/1809-4430-Eng.Agric.v36n3p387-398/2016.

Fróna D, Szenderák J, Harangi-Rákos M. 2019. The challenge of feeding the world. *Sustainability* **11(20)**:5816 DOI 10.3390/su11205816.

Gebauer RLE, Strain BR, Reynolds JF. 1997. The effect of elevated CO2 and N availability on tissue concentrations and whole plant pools of carbon-based secondary compounds in loblolly pine (Pinus taeda). *Oecologia* **113(1)**:29–36 DOI 10.1007/s004420050350.

Hamam M, Moustafa Y, Ali SHA, Saleh. 2021. Effect of foliar spray with licorice root extract on production and quality of Egyptian and Chinese garlic. *Journal of Plant Production* **12(8)**:929–940 DOI 10.21608/jpp.2021.198879.

Hamdy AE, Abdel-Aziz HF, El-khamissi H, AlJwaizea NI, El-Yazied AA, Selim S, Tawfik MM, AlHarbi K, Ali MSM, Elkelish A. 2022. Kaolin improves photosynthetic pigments, and antioxidant content, and decreases sunburn of mangoes: field study. *Agronomy* **12(7)**:1535 DOI 10.3390/agronomy12071535.

Hasanuzzaman M, Nahar K, Fujit M. 2013. Extreme temperature responses, oxidative stress and antioxidant defense in plants. In: Vahdati K, ed. *Abiotic Stress—Plant Responses and Applications in Agriculture*. USA: InTech DOI 10.5772/54833.

Hernández-Pérez OI, Valdez-Aguilar LA, Alia-Tejacal I, Cartmill AD, Cartmill DL. 2020. Tomato fruit yield, quality, and nutrient status in response to potassium: calcium balance and electrical conductivity in the nutrient solution. *Journal of Soil Science and Plant Nutrition* **20(2)**:484–492 DOI 10.1007/s42729-019-00133-9.

Husain I, Bala K, Khan IA, Khan SI. 2021. A review on phytochemicals, pharmacological activities, drug interactions, and associated toxicities of licorice (*Glycyrrhiza* sp.). *Food Frontiers* **2(4)**:449–485 DOI 10.1002/fft2.110.

Hussain SZ, Naseer B, Qadri T, Fatima T, Bhat TA. 2021. Mango (Mangifera Indica)-morphology, taxonomy, composition and health benefits. In: *Fruits Grown in Highland Regions of the Himalayas*. Cham: Springer International Publishing, 245–255 DOI 10.1007/978-3-030-75502-7_19.

Iqbal N, Sehar Z, Fatma M, Umar S, Sofo A, Khan NA. 2022. Nitric oxide and abscisic acid mediate heat stress tolerance through regulation of osmolytes and antioxidants to protect photosynthesis and growth in wheat plants. *Antioxidants* **11(2)**:372 DOI 10.3390/antiox11020372.

Kavrayan D, Aydemir T. 2001. Partial purification and characterization of polyphenoloxidase from peppermint (*Mentha piperita*). *Food Chemistry* **74(2)**:147–154 DOI 10.1016/S0308-8146(01)00106-6.

Khanum Z, Tiznado-Hernández ME, Ali A, Musharraf SG, Shakeel M, Khan IA. 2020. Adaptation mechanism of mango fruit (*Mangifera indica* L. cv. Chaunsa White) to heat suggest modulation in several metabolic pathways. *RSC Advances* **10(58)**:35531–35544 DOI 10.1039/D0RA01223H.

Khattab M, Hamed H, Awad NA, ElKorashy HA. 2021. Prolonging the shelf life and maintaining fruit quality of naomi mango cultivar. *Plant Archives* **21(1)**:1667–1675 DOI 10.51470/PLANTARCHIVES.2021.v21.no1.229.

McKie VA, McCleary BV. 2016. A novel and rapid colorimetric method for measuring total phosphorus and phytic acid in foods and animal feeds. *Journal of AOAC International* **99(3)**:738–743 DOI 10.5740/jaoacint.16-0029.

Mohsen F, Ibrahim M. 2021. Reducing fruit sunburn and splitting in Murrcot tangarine fruits by using Silicate application. *Arab Universities Journal of Agricultural Sciences* **29(1)**:437–445 DOI 10.21608/ajs.2021.54154.1314.

Muthuramalingam P, Muthamil S, Shilpha J, Venkatramanan V, Priya A, Kim J, Shin Y, Chen JT, Baskar V, Park K, Shin H. 2023. Molecular insights into abiotic stresses in mango. *Plants* **12(10)**:1939 DOI 10.3390/plants12101939.

Nasir M, Khan AS, Basra SMA, Malik AU. 2016. Foliar application of moringa leaf extract, potassium and zinc influence yield and fruit quality of 'Kinnow' mandarin. *Scientia Horticulturae* **210**:227–235 DOI 10.1016/j.scienta.2016.07.032.

Nath V, Kumar G, Pandey SD, Pandey S. 2019. Impact of climate change on tropical fruit production systems and its mitigation strategies. In: Sheraz Mahdi S, ed. *Climate Change and Agriculture in India: Impact and Adaptation*. Cham: Springer International Publishing, 129–146 DOI 10.1007/978-3-319-90086-5_11.

Nieves-Cordones M, Al Shiblawi FR, Sentenac H. 2016. Roles and transport of sodium and potassium in plants. In: Sigel A, Sigel H, Sigel RKO, eds. *The Alkali Metal Ions: Their Role for Life. Metal Ions in Life Sciences*. Cham: Springer International Publishing, 291–324 DOI 10.1007/978-3-319-21756-7_9.

Obenland D, Feliziani E, Zhu S, Zhao X, Margosan DA, Mlikota Gabler F, Van Zyl S, Romanazzi G, Smilanick JL, Beno-Moualem D, Kaplunov T, Lichter A. 2015. Potassium application to table grape clusters after veraison increases soluble solids by enhancing berry water loss. *Scientia Horticulturae* **187**:58–64 DOI 10.1016/j.scienta.2015.03.005.

Pandey S. 2017. A review on constituents, pharmacological activities and medicinal uses of Glycyrrhiza Glabra. *Universal Journal of Pharmaceutical Research* **2(2)**:6–11 DOI 10.22270/ujpr.v2i2.RW2.

Pandey D. 2020. Agricultural sustainability and climate change nexus. In: Singh P, Singh RP, Srivastava V, eds. *Contemporary Environmental Issues and Challenges in Era of Climate Change*. Singapore: Springer Singapore, 77–97 DOI 10.1007/978-981-32-9595-7_4.

Peng T, Meng L, Wang Y, Jin L, Jin H, Yang T, Yao Y. 2023. Alterations of the rhizosphere soil microbial community composition and metabolite profiles of Angelica sinensis seedlings by co-application of Nitrogen fixing bacteria and amino acids. *Plant and Soil* **493(1–2)**:535–554 DOI 10.1007/s11104-023-06248-4.

Per TS, Khan NA, Reddy PS, Masood A, Hasanuzzaman M, Khan MIR, Anjum NA. 2017. Approaches in modulating proline metabolism in plants for salt and drought stress tolerance: phytohormones, mineral nutrients and transgenics. *Plant Physiology and Biochemistry* **115(70)**:126–140 DOI 10.1016/j.plaphy.2017.03.018.

Petoumenou DG, Patris VE. 2021. Effects of several preharvest canopy applications on yield and quality of table grapes (*Vitis vinifera* L.) Cv. crimson seedless. *Plants* **10(5)**:906 DOI 10.3390/plants10050906.

Rady MM, Desoky ESM, Elrys AS, Boghdady MS. 2019. Can licorice root extract be used as an effective natural biostimulant for salt-stressed common bean plants? *South African Journal of Botany* **121**:294–305 DOI 10.1016/j.sajb.2018.11.019.

Ram RA, Rahim MA, Alam MS. 2020. Diagnosis and management of nutrient constraints in mango. In: *Fruit Crops*. Amsterdam: Elsevier, 629–650.

Ramírez F, Davenport TL. 2010. Mango (Mangifera indica L.) flowering physiology. *Scientia Horticulturae* **126(2)**:65–72 DOI 10.1016/j.scienta.2010.06.024.

Ridgman WJ. 1990. Statistical Methods, 8th edn, by G. W. Snedecor & W. G. Cochran. xx + 503 pp. Ames: Iowa State University Press (1989). $44.95 (hard covers). ISBN 0 8138 1561 6. *The Journal of Agricultural Science* **115**:153 DOI 10.1017/S0021859600074104.

Rossi S, Burgess P, Jespersen D, Huang B. 2017. Heat-induced leaf senescence associated with chlorophyll metabolism in bentgrass lines differing in heat tolerance. *Crop Science* **57(S1)**:1154 DOI 10.2135/cropsci2016.06.0542.

Rouphael Y, Colla G. 2018. Synergistic biostimulatory action: designing the next generation of plant biostimulants for sustainable agriculture. *Frontiers in Plant Science* **9**:1655 DOI 10.3389/fpls.2018.01655.

Santini G, Biondi N, Rodolfi L, Tredici MR. 2021. Plant biostimulants from cyanobacteria: an emerging strategy to improve yields and sustainability in agriculture. *Plants* **10(4)**:643 DOI 10.3390/plants10040643.

Sardans J, Peñuelas J. 2021. Potassium control of plant functions: ecological and agricultural implications. *Plants* **10(2)**:419 DOI 10.3390/plants10020419.

Shahid MA, Sarkhosh A, Khan N, Balal RM, Ali S, Rossi L, Gómez C, Mattson N, Nasim W, Garcia-Sanchez F. 2020. Insights into the physiological and biochemical impacts of salt stress on plant growth and development. *Agronomy* **10(7)**:938 DOI 10.3390/agronomy10070938.

Shehzad MA, Nawaz F, Ahmad F, Ahmad N, Masood S. 2020. Protective effect of potassium and chitosan supply on growth, physiological processes and antioxidative machinery in sunflower (Helianthus annuus L.) under drought stress. *Ecotoxicology and Environmental Safety* **187**:109841 DOI 10.1016/j.ecoenv.2019.109841.

Shivran JS, Jat ML, Jat RK, Jat A. 2020. Adoption of regular bearing in mango over biennial bearing. *International Journal of Current Microbiology and Applied Sciences* **9(5)**:149–154 DOI 10.20546/ijcmas.2020.905.016.

Şirin S, Aslım B. 2019. Determination of antioxidant capacity, phenolic acid composition and antiproliferative effect associated with phenylalanine ammonia lyase (PAL) activity in some plants naturally growing under salt stress. *Medicinal Chemistry Research* **28(3)**:229–238 DOI 10.1007/s00044-018-2278-6.

Silem AEM, Ismail HMH, Mohamed SHF. 2023. Using some anti-salinity materials for alleviating the adverse effects of soil and water salinity on fruiting of Keitte mango trees. *SVU-International Journal of Agricultural Sciences* **5(2)**:85–94 DOI 10.21608/svuijas.2023.215956.1291.

Singleton VL, Orthofer R, Lamuela-Raventós RM. 1999. Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. In: *Methods in Enzymology*. Amsterdam: Elsevier, 152–178 DOI 10.1016/S0076-6879(99)99017-1.

Tirado-Kulieva VA, Gutiérrez-Valverde KS, Villegas-Yarlequé M, Camacho-Orbegoso EW, Villegas-Aguilar GF. 2022. Research trends on mango by-products: a literature review with bibliometric analysis. *Journal of Food Measurement and Characterization* **16(4)**:2760–2771 DOI 10.1007/s11694-022-01400-7.

Tohidi B, Rahimmalek M, Arzani A. 2017. Essential oil composition, total phenolic, flavonoid contents, and antioxidant activity of Thymus species collected from different regions of Iran. *Food Chemistry* **220**:153–161 DOI 10.1016/j.foodchem.2016.09.203.

Tränkner M, Tavakol E, Jákli B. 2018. Functioning of potassium and magnesium in photosynthesis, photosynthate translocation and photoprotection. *Physiologia Plantarum* **163(3)**:414–431 DOI 10.1111/ppl.12747.

Venzhik YV, Shchyogolev SY, Dykman LA. 2019. Ultrastructural reorganization of chloroplasts during plant adaptation to abiotic stress factors. *Russian Journal of Plant Physiology* **66(6)**:850–863 DOI 10.1134/S102144371906013X.

Vlaisavljević S, Šibul F, Sinka I, Zupko I, Ocsovszki I, Jovanović-Šanta S. 2018. Chemical composition, antioxidant and anticancer activity of licorice from Fruska Gora locality. *Industrial Crops and Products* **112**:217–224 DOI 10.1016/j.indcrop.2017.11.050.

Walworth JL, Sumner ME. 1987. The diagnosis and recommendation integrated system (DRIS). In: Stewart BA, ed. *Advances in Soil Science*. New York, NY: Springer New York, 149–188 DOI 10.1007/978-1-4612-4682-4_4.

Wang M, Zheng Q, Shen Q, Guo S. 2013. The critical role of potassium in plant stress response. *International Journal of Molecular Sciences* **14(4)**:7370–7390 DOI 10.3390/ijms14047370.

Wellburn AR. 1994. The spectral determination of chlorophylls a and b, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. *Journal of Plant Physiology* **144(3)**:307–313 DOI 10.1016/S0176-1617(11)81192-2.

Wen PF, Chen JY, Wan SB, Kong WF, Zhang P, Wang W, Zhan JC, Pan QH, Huang WD. 2008. Salicylic acid activates phenylalanine ammonia-lyase in grape berry in response to high temperature stress. *Plant Growth Regulation* **55(1)**:1–10 DOI 10.1007/s10725-007-9250-7.

Yahia EM, Ornelas-Paz JDJ, Brecht JK, García-Solís P, Maldonado Celis ME. 2023. The contribution of mango fruit (Mangifera indica L.) to human nutrition and health. *Arabian Journal of Chemistry* **16(7)**:104860 DOI 10.1016/j.arabjc.2023.104860.

Yamasaki S, Dillenburg LR. 1999. Measurements of leaf relative water content in Araucaria Angustifolia. *Revista Brasileira de Fisiologia Vegetal* **11(2)**:69–75.

Yassin M, Ataya S, Fahmy F. 2023. The effect of spraying with fenugreek extract, salicylic acid and potassium silicate on yield and fruit quality of two pomegranate cultivars. *Egyptian Journal of Desert Research* **73(2)**:713–739 DOI 10.21608/ejdr.2024.245700.1157.

You J, Chan Z. 2015. ROS regulation during abiotic stress responses in crop plants. *Frontiers in Plant Science* **6(e1004112)**:1925 DOI 10.3389/fpls.2015.01092.

Younes NA, Dawood MFA, Wardany AA. 2019. Biosafety assessment of graphene nanosheets on leaf ultrastructure, physiological and yield traits of Capsicum annuum L. and Solanum melongena L. *Chemosphere* **228**:318–327 DOI 10.1016/j.chemosphere.2019.04.097.

Younes NA, Hassan HS, Elkady MF, Hamed AM, Dawood MFA. 2020. Impact of synthesized metal oxide nanomaterials on seedlings production of three Solanaceae crops. *Heliyon* **6(1)**:e03188 DOI 10.1016/j.heliyon.2020.e03188.

Younes NA, Rahman MM, Wardany AA, Dawood MFA, Mostofa MG, Keya SS, Abdel Latef AAH, Tran LSP. 2021. Antioxidants and bioactive compounds in licorice root extract potentially contribute to improving growth, bulb quality and yield of onion (*Allium cepa*). *Molecules* **26(9)**:2633 DOI 10.3390/molecules26092633.