Licorice-Root Extract and Potassium Sorbate Spray Improved the Yield and Fruit Quality and decreased heat stress of the ‘Osteen’ Mango Cultivar

Adel M. Al-Saif[1]*, Haitham El-khamissi[4], Ibrahim A. Elnaggar[2], Mohammed H. Farouk[3], Magdy A. Omar[5], Abd El-wahed N. Abd El-wahed[2], Ashraf E. Hamdy[2]*, Hosny F. Abdel-Aziz[2]

[1]Department of Plant Production, College of Food and Agriculture Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia.
[2]Department of Horticulture, Faculty of Agriculture, Al-Azhar University, Cairo, 11884, Egypt.
[3]Key Laboratory of Product Quality and Security, Ministry of Education, Jilin Agricultural University, Changchun, PR China.
[4]Department of Agriculture Biochemistry, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt.
[5]Department of Agricultural Botany, Faculty of Agriculture, Al-Azhar University, Cairo, 11884, Egypt.

Corresponding Author:
Adel M. Al-Saif[1] ; Ashraf E. Hamdy[2]
Riyadh 11451, Saudi Arabia., Cairo, 11884, Egypt
Email address: adelsaif@ksu.edu.sa; ashrafezat@azhar.edu.eg

Abstract

Heat stress, low fruit yields, and inconsistent fruit quality are the main challenges for mango growers. Licorice-root extract (LRE) has recently been utilized to enhance vegetative growth, yield, and tolerance of abiotic stresses in fruit trees. Potassium sorbate (PS) also plays a significant role in various physiological and biochemical processes 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 6g/l and PS 0, 1, 2, and 3mM. In mid-May, the mango trees were sprayed with a foliar solution, followed by monthly applications until one month before harvest. The results showed that trees with the highest concentration (6 g/L) of LRE

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exhibited the maximum leaf area, followed by those treated with the highest concentration (3 mM) of PS. Applying LRE and PS to 'Osteen' mango trees significantly enhanced fruit weight and the number of fruits.tree^{-1}, yield (kg/tree), and fewer 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, the 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 KS and 6g/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.

Keywords: *Mangifera indica* L.; bio-stimulates; leaf area; yield increasing%; carotenoids; sunburned

Introduction

Ensuring global food security for a growing population is a major challenge for modern agriculture (Fróna at al., 2019). Several factors compound this challenge. 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).

Biostimulants have been recognized as a promising approach that utilizes natural products in fruit trees (Santini et al., 2021). Biostimulants are a flexible, cost-effective, and widely applicable solution that can sustainably improve agricultural productivity 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).

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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 integrated into diverse food products. Mangoes have an outstanding nutritional profile, filled with both macro and micronutrients (Yahia et al., 2023). Low mango yields and inconsistent fruit are the main challenges for growers. These issues include abnormal flowering, terrible fruit set, and inconsistent fruit development (Shivran et al., 2020). This leads to poor yields, culminating in subpar exceptional and reduced availability at some stage in the year. Fortunately, research suggests a promising solution: strategically applying nutrients and growth regulators (Ram et al., 2020). By influencing flowering and fruiting patterns, these tools can assist us to in releasing the whole potential of various mango cultivars ('Keitt,' 'Tommy Atkins') (Ramírez & Davenport, 2010). This method may boost and stabilize mango production (Tirado-Kulieva et al., 2022).
Potassium is a vital mineral nutrient for plants (Wang et al., 2013). This element is crucial for numerous plant functions, influencing growth, yield, fruit development, quality, and 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 (Sardans & Peñuelas, 2021). It activates numerous enzymes in photosynthesis, sugar production, and overall plant metabolism, ultimately increasing crop yields (Nieves-Cordones et al. 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 an adequate balance of protein and carbohydrate synthesis (Iqbal et al., 2022). Potassium influences stomata function, affecting 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 critical for mango tree production, improving 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 et al., 2015).

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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, it is rich in various elements and nutrients (Husain et al., 2021). Licorice extract is believed to stimulate cellulose enzyme activity, which is 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). Many studies have investigated mango cultivation, but none have examined how licorice root extract and potassium sorbate 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 & 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^{-1}. The mixture was left at room temperature for 24 h, and thoroughly blended before filtering 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^{-1}) was added. This step followed the methodology described by Younes, et al. (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, followed 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 et al., 2019; Rady et al., 2019; Younes et al., 2021)

2.1. Experimental site

This study was conducted on 7-year-old 'Osteen' mango trees on 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 (1250 tree/ha) and irrigated using a drip system. Management practices included regular irrigation, fertilization, and pest and disease control. From mid-May to one month before harvest, the trees were sprayed at monthly intervals with licorice root extract and potassium sorbate

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solutions as follows in Table 3. Moreover, at 7:00 AM, we used backpack sprayers on each tree, applying 5 l (6250 L/ha) of both solutions to the point of runoff.

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2.2. Measurements:

2.2.1. Leaf area:-Twenty leaves below panicles of the spring growth cycle, according to Walworth and Sumner (Walworth & Sumner, 1987) were taken (2nd week of June) for measuring leaf area according of (Ahmed & Morsy, 1999) as the following:

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

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

2.2.3. 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., (Brito et al., 2011), and the results were calculated accordingly (Wellburn, 1994).

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2.2.4. Determination proline content

To estimate proline content, a rapid colorimetric method was used (Bates et al., 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.

2.2.5. Determination of 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 hours at 22°C. After rehydration, the leaves were weighed again. Finally, dry weight (DM) was obtained by oven drying at 80°C for 48 hours. All weights were measured with a balance accurate to 0.001 g. The relative water content was calculated as follows:

$$RWC\ (\%) = [(FM-DM)\ (TM-DM)] \times 100.$$

2.3.7. 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). The mixture was centrifuged at 15,000 x g for 20 min at 4 ◦C. The supernatant was used in an enzyme activity experiment (Esfandiari et al., 2007).

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

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Total phenolic and total flavonoid

According to (Singleton et al., 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.

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

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

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:

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

2.9. 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.

2.10. Chemical characteristics of fruits.

Mango juice Extraction

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 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 in 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).

The 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), 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 present study's design was a randomized complete block design (RCBD). The information used to create the charts comes from three separate times when each treatment

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(9 trees/treatments was applied). The analysis of variance as one-way ANOVA was used through Costat software (Ridgman, 1990), and the means of different treatments were compared using the Duncan test ($p \leq 0.05$).

Results

2.1. Effect of (LRE) and (PS) on leaf area of 'Osteen' mango under heat stress:

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 compared to the control. Additionally, a trend emerged where leaf area increased as the concentration of licorice root extract and potassium sorbate increased. Leaf area promotion depended on applying 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.

2.2. Effect of (LRE) and (PS) on fruit physical properties:

The results in Figures (2a, and b) clearly showed that adding licorice root and potassium sorbate extract at various phenological stages significantly increased fruit weight (g), and No. of fruits/tree of 'Osteen' mango trees compared to those of control in the two studied seasons. These results align with the findings of (Baiea et al., 2015) those who found that spraying Hindi mango trees four times with different types of potassium was very effective in improving the number of fruits or weight (kg/tree) compared 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 trend emerged where fruit weight (g), and No. of fruits/tree increased as the concentration of potassium sorbate and licorice root extract increased.

2.3. Effect of (LRE) and (PS) on fruit yield.$tree^{-1}$:

The results illustrated in Figure (3A and B) 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.

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Specifically, applying 3 mM potassium sorbate or 6.g^{-1} 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.

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2.4. Effect of (LRE) and (PS) on No. 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 compared to the control group in the two studied seasons. The lowest number of sun-burned fruits of ‘Osteen’ mango trees were possessed from LER6 (6 g/l licorice root extract) and or PS3 (3mM 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.

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2.5. 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 figures 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 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 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.

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2.6 The photosynthetic Pigments Leaf of ‘Osteen’ mango cv. Under heat stress

It is clear from Figure 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 PTS concentrations on mango tree leaves resulted in an increase in photosynthetic pigments under heat stress. As shown in Figure 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 PTS concentrations and the control treatment. The value for total pigments (2.219 mg/g fresh weight) was higher than that of the control (non-treated) (1.111 mg/g fresh weight) under heat stress during the 2022-2023 seasons (Figure 6E).

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2.7 Antioxidant activity leaf of ‘Osteen’ mango cv. under heat stress

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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 (Figure 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 Figure 7 A-C, the enzyme activities decreased with increasing concentrations of LRE and PTS 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 3mM 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).

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2.7 Total flavonoids, total phenolic, and proline of Leaf ‘Osteen’ mango cv. Under heat stress

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The content of total flavonoid in leaves of ‘Osteen’ mango is shown in (figure 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,

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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 Figure 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/100g F.W) compared to control and other treatments.

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Discussion

Heat stress causes many disorders in mango growth, which leads 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 that support the use of foliar potassium to enhance plant growth. (Abd El-Rahman, 2021) observed this when adding 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 increase 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.

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Similarly, licorice root extracts improve 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).

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Moreover, it contains a wide range of elements and nutrients (Hamam et al., 2021). Adding a lot of potassium sorbate as a foliar spray at different fruit growth stages 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, reducing overall tree productivity. This study aligns with previous findings by (El-Merghany, et al., 2019) who reported that licorice root extract application to 'Ferehy' date Palm trees significantly increased fruit weight and yield per tree. Similarly, (Ahmed et al., 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, et al. (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 one month later increased fruit yield per tree compared to the control group. The increase in yield /tree of 'Osteen' mango trees might be due to licorice root extract is 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 three weeks after fruit set, significantly increased tree yield compared to the control group.

It could be concluded that applying 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 6g/L (LRE) and 3mM (PS).

Our results align with the findings of (Ahmed et al., 2023), those 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. Various beneficial compounds in licorice root extract, including phenolics, triterpenes, saponins, amino acids, polysaccharides, vitamins, and growth-promoting

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phytohormones, likely contribute 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 the number of sun-burned fruits might be attributed to the enhanced vegetative growth in mango trees caused by potassium application (Baiea, et al., 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 applying potassium sorbate and licorice root extract to 'Osteen' mango trees significantly reduced the number of sun-burned fruits compared to the control. The most effective treatments were 6 g/L licorice root extract and 3mM 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 was very effective in improving enhanced fruit quality. In addition, fruit's total acidity was reduced compared with the control. Likewise, (El-Morsy, et al. 2017) on Red Globe where the highest values of fruit chemical characteristics were obtained with the addition of licorice extract foliar spraying treatments 20 and 15 g/l. Similarly, (Obenland et al., 2015) it was found that potassium sorbate foliar spray at a concentration of 1.3g/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 catalyzes numerous biological processes within the trees, improving 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 mevalonic acid in the extract. Mevalonic acid is 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, the total acidity percentage in 'Osteen' mango fruits significantly decreased in response to the foliar spray. The most effective treatments were 3mM (PS) and 6g/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,

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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 reduced 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 creating chlorophyll, these minerals play a significant role in 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 et al., 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 3mM (PS) and 6g/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 et al., 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 (Figure 7A-C). 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

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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. (2013) discovered that foliar application of potassium reduced SOD, CAT, and PPO activities in well-watered Squash plants(Azab et al., 2022). 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.(Rady et al., 2019) found that licorice root extract (LRE) application increased the activity of antioxidant enzymes (POX, CAT) and decreased hydrogen peroxide (H2O2) and superoxide radical (O2•–) 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 PPO, POX, and CAT activities all declined with increasing concentrations of LRE and PTS 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).

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According to (Tohidi, et al., 2017), these substances have a wide range of biochemical and molecular functions in plants, including 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 (figure 8A-B). 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.(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

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contain a variety of low-molecular-weight substances, including proline and ascorbic acid (Rady et al., 2019). All treatments with LRE and PTS resulted in reduced proline levels compared to control. This decrease is likely due to LRE and PTS 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 PTS 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, et al., 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.

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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 decreased 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 PTS (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/100g fresh weight (FW) compared to the control value of 0.280 mg/100g FW. This suggests that this concentration of LRE may inhibit proline production.

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These results are consistent with the findings in numerous studies that support foliar potassium's use to enhance plant growth. (Abd El-Rahman, 2021) observed this when adding 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 increase 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 improve the vegetative growth of plants (Nasir et al., 2016).

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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 PTS) 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 due to improved fruit quality parameters such as fruit weight and yield.

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Conflicts of Interest

The authors declare no conflicts of interest

Author Contributions

Conceptualization, H.F.A. and A.E.H.; methodology, EAE; software, M.O.; validation, H.F.A. and A.E.H.; and A.N.A; formal analysis, H.K; investigation, H.F.A.; resources, H.K.; data curation, M.O.; writing—original draft preparation, A.E.H. and H.K; writing—review and editing, M.H.F.; visualization, A.E.H.; supervision, A.E.H.; project administration, A.M.S.; funding acquisition, A.M.S. All authors have read and agreed to the published version of the manuscript.

Data Availability

The following information was supplied regarding data availability: The raw measurements are available in the Supplemental File.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.17378#supplemental-information

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