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The potential of some ameliorative substances in improving growth, yield and quality of carrot under heat stress conditions

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Abstract

A field experiment was carried out in two successive seasons of 2019 and 2020 on the late planting of carrot *cv.* Chantenay in El-Badrasheen, Giza, Egypt, to study the effect of sowing dates and foliar spray applications by using some growth natural and chemical stimulants to increase the plant's ability to withstand heat stress. The experiment was established in a split-plot design with two sowing dates on 15 February and 15 March as the main factors and six treatments of exogenous foliar spray applications as submain factors as follows: untreated plants (control); potassium silicate K-Si at 2g/L; salicylic acid at 2mM; glycine betaine at 100 mM; moringa leaf extract (MLE) at 3.3% and date palm pollen grain extract (DPPGE) at 2g/L. Results revealed that sowing carrots in February significantly increased vegetative growth characteristics, *i.e.*, plant height in both seasons and fresh and dry weight in the second season. Also, the fresh weight of roots in the second season and total marketable yield in both seasons were significantly increased with February sowing. All chemical parameters, either quality or heat stress indicators, were significantly enhanced with March sowing as a reaction to heat stress. Moreover, all foliar spray treatments gained the highest significant values of vegetative growth, yield, quality characteristics, and chemical parameters [N, P, K, Ca, Mg, proline, antioxidant activity DPPH, total carbohydrates, total carotenoids, total chlorophyll, and total phenols] as compared with untreated plants. In conclusion, foliar spray treatments with MLE and DPPGE are promising materials for heat stress-tolerant applications.

Keywords: Heat stress, carrot, *Moringa oleifera* leaf extract, date palm pollen grain extract, antioxidants, foliar spray, bio-stimulants

Introduction

In recent years, global warming has played an important role in climatic changes, causing continuous temperature increments in several areas that have negatively affected crop production (Hassan *et al.,* 2021). Heat stress is one of the major abiotic stresses (*i.e.*, drought, cold, and salinity) that occur individually or in combination at any stage of plant growth. Heat stress significantly affects physiological, biochemical, morphological, and molecular aspects of plant growth that reflect productivity and yield (Hasanuzzaman *et al.,* 2013; Carmody *et al.,* 2020).

Carrot (*Daucus carota* L.) is one of the root vegetables belonging to the family Umbeliferae (Apiaceae). Carrot is grown widely for its nutritious and economic value in horticulture (Ladumor *et al.,* 2020). In Egypt, carrot is grown for fresh root, storage, industrial purposes, and exportation. In 2020, the total area in Egypt grown with turnip and carrot was 6758 ha (16212.98 fed) with a total production of 235191 tons (FAOSTAT, 2022).

Carrot is a biannual cool-season root crop, and it has been cultivated in different temperatures and several seasons throughout the year, but the optimum temperature to give the best growth, yield and quality ranges between 18 -22 °C (Bolton *et al.,* 2019), Also, the optimum day and night temperatures for plant growth are between 21 and 22°C and 18 and 20°C, respectively. On the other hand, carrot plants can tolerate summer temperatures moderately, but temperatures above 30 °C reduce yield and quality. The damage of heat stress increases with increasing temperature. Generally, the delay in sowing carrots may cause a significant reduction in growth and yield because of heat stress (Resende *et al.,* 2016; Karakan *et al.,* 2019; Ladumor *et al.,* 2020). The high temperature negatively affected growth, yield and quality (Manosa, 2011).

Therefore, in summer, there is a gap in fresh carrots in the Egyptian markets because farmers avoid sowing carrots after March. Attempts have been made to successfully grow this crop to achieve high yields by applying some strategies, including some ameliorative chemicals and natural substances used to increase plant abiotic tolerance.

Chemical and natural biostimulants are products or materials used for several purposes in plant production, depending on the aim of use. Biostimulant effects depend on nutrient content and its components. Biostimulants can improve plant growth by increasing the efficiency of nutrients used and plant tolerance to abiotic stress and increasing fruit set, yield and quality properties. Conversely, using some natural biostimulants as an eco-friendly input in the agriculture industry is a new trend in organic farming instead of chemical materials (Poberezny *et al.,* 2020).

Many chemical and natural biostimulants have been evaluated, such as potassium silicate in potato (Abd El-Gawad *et al.,* 2017) and squash (Laane, 2018; El-Shoura, 2020). Salicylic acid in carrots (Eraslan *et al.,* 2007), in common beans (Rady and Mohamed, 2015) and in potatoes (Alhoshan *et al.,* 2019). Glycine betaine (Annunziata *et al.,* 2019; Ali *et al.,* 2020), *Moringa olivera* leaf extract (Yasmeen *et al.,* 2012; Rady *et al.,* 2015; El-Serafy and El-Sheshtawy, 2020) and Date palm pollen grains (DPPGE) in the bird of paradise (*Strelitzia reginae*) plants (Abou-Sreea and Yassen, 2016), in common bean (Byan, 2020) and in sweet basil (*Ocimum basilicum* L.) (Taha *et al.,* 2020).

Carrot production on summer sowing dates has a problem with high temperatures, especially during root forming, which negatively affects yield and quality. So, the current work aimed to study the effect of using some chemical and natural stimulants on carrot growth, productivity and quality under heat stress conditions.

Materials and methods

Location, climatic conditions, plant materials for experiments, and soil properties: A field experiment was performed at a private farm located in El-Badrasheen, Giza, Egypt, located in (29.852 N- 31.276°E) during the period from February to July in two successive seasons of 2019 and 2020. Seeds of carrot *cv.* (Fire Wedge F1), Kuroda type, produced by Taki Seeds, Japan, was used in the present study. The soil of the experiment was clay in texture with 7.43 pH, 1.76 EC, 13.2 mg/L N-NH4, 4.5 mg/L N-NO_3, 43 mg/L P, 103.6 mg/L K, 3.22 mg/L Fe, 6.87 mg/L Mn, 1.56 mg/L Zn, 2.13 mg/L Cu, 0.00 $CO^{-}3$, 5.8 meq/L HCO_{-3}, 12.0 meq/L Cl^{--}, 12 meq/L $SO4^{--}$, 8 meq/L Ca^{++}, 10 meq/L Mg^{++}, 0.59 meq/L K^{+}, 11.3 meq/L Na^{++} according to the analyses performed by the method described by Piper (1950). The average monthly minimum and maximum of the 2-meter height air temperatures (°C) during the experiment from February to July 2019 and 2020 are shown in Fig.1, taken from the online public database of Power Data Access Viewer (2022).

The present study was set up in a split-plot design with 3 replicates and included 12 treatments (2 sowing dates × 6 foliar spray treatments) as follows: Main plot (2 sowing dates): 15 February and 15 March. Subplot (6 foliar spray): Control, Potassium Silicate (K-Si), Salicylic Acid (SA), Glycine Betaine (GB), Moringa Leaf Extract (MLE) and Date Palm Pollen Grain Extract (DPPGE).

During the two successive seasons of 2019/2020, the soil of the experiment was well plowed; half of the experimental field was sown on 15 February and the other half was sown on 15 March. Seeds of carrot that were mixed with a proper amount of sand were handily sown on the two sides of ridges (50 cm width) at 10 cm between hills within the row. Each experimental plot was six rows of 5 m length. After germination, four weeks after sowing, the plants were thinned to one plant per hill. In the field, all agricultural practices of weed control as well as irrigation, fertilization program and pest control were applied according to recommendations of the Egyptian Ministry of Agriculture for carrot production.

Foliar spray treatments started 40 days after sowing and continued to 100 days from sowing. Plant was weekly sprayed with K-silicate at 2g/L, salicylic acid at 2mM, glycine betaine at 100 mM, MLE at 3.3% and DPPGE at 2g/L.

Potassium silicate (K-Si), salicylic acid and glycine betaine materials were obtained from Fooding Group Limited Company, China.

Preparation of foliar spray agents

Moringa leaf extract (MLE) preparation: Moringa young fresh leaves and branches were collected from a moringa tree (*M. oleifera*) located on the campus of the Faculty of Agriculture, Cairo University, Egypt, then MLE was prepared by the method described by Yasmeen *et al.* (2012), where 10 kg of fresh material (leaves and soft branches) were ground with 1L water in an electric blender. After grinding, the extract was filtered twice with muslin cloth followed by Whatman No.1 filter paper and diluted 30 times to application as a foliar spray at a ratio of 3.3% that each 1L of water contained 3.3 mL of MLE. According to Latif and Mohamed (2016), MLE contains 365.4 mg g^{-1} amino acids, 35.2 mg g^{-1} proline, 325.8 mg g^{-1} total sugars, 4.5 mg g^{-1} total phenol, 8.19 mg g^{-1} total flavonoid, 8.10 mg g^{-1}ascorbic acid and hormones (0.62 mg 100 g^{-1} indole acetic acid, 6.09 mg 100 g^{-1} gibberellin, 2.14 mg g^{-1} kinetin, 0.29 mg g^{-1} benzyl adenine and 0.061 mg g^{-1} abscisic acid.

Date palm pollen grains extract (DPPGE): Date palm pollen grains were obtained from an Egyptian Date Palm (*Phoenix dactylifera* L. cv male). El-Sewy at the end of March from El-Badrasheen, Giza, Egypt. According to Taha *et al.* (2020), twenty-gram powder of palm pollen grains was soaked in 200 mL ethanol. Then, the mix was left for three days until dissolved and ethanol volatilized. After that, the suspension was filtered twice using Whatman No.1 filter paper, followed by muslin cloth. After that, the filtered extract preparation from 20 g powder of pollen grains was diluted with 10 L distilled water to get a 2g/L concentration. The solution was ready to use immediately as a foliar spray. The chemical constituents of DPPGE are 30.2 g 100 g^{-1}, amino acids, 0.34 g100 g^{-1} Free proline 14.2 g^{-1} soluble sugar, 9.04 g kg^{-1} phosphorus (P), 2.49 g kg^{-1}, calcium (Ca), 3.42 g kg^{-1} magnesium (Mg), 8.63 g kg^{-1} potassium (K), 6.16 g kg^{-1} sulfur (S), 2.94 g kg^{-1} molybdenum (Mo), 2.98 g kg^{-1} boron (B), 4.55 g kg^{-1} Iron (Fe), 2.92 g kg^{-1} manganese (Mn), 2.72 g kg^{-1} zinc (Zn), 3.03 g kg^{-1} copper (Cu), 0.52 g kg^{-1} sodium (Na), 0.72 g kg^{-1} soluble phenols, 0.61 g kg^{-1} total flavonoids, 14.2 g kg^{-1} Total carotenoids, 1.06 vitamin C (ascorbic acid), 747 IU kg^{-1} vitamin A, 335 IU kg^{-1} vitamin E, 85.2 % DPPH (antioxidant activity), 4.92 mg kg^{-1} phytohormones (Indole-3-acetic acid, 6.74 mg kg^{-1} gibberellin, and 7.87 kg^{-1} cytokinins (Taha *et al.,* 2020).

Vegetative and quality parameters: Plant fresh weight, fresh weight of shoots, plant height, fresh weight of roots, plant dry weight, root length, and root diameter were recorded 90 days after sowing (DAS).

Physiological parameters, 90 DAS: The physiological parameters included stomatal conductance, transpiration rate using a portable photosynthesis system (Steady State Prometer Model LI-1600) equipment on sunny days under light conditions between 9.00 and 12.00 h. Total chlorophyll % of leaves was measured spectrophotometrically using a UVVIS spectrophotometer (Model SM1200; Randolph, NJ, USA) as described by Holden (1965).

Chemical parameters: Proline content of leaves and roots, total phenols of roots and free radical scavenging effect, were measured 90 days after sowing. Proline content of leaves and roots was extracted from plant tissues and determined according to the method described by Bates *et al.* (1973). Total phenols of roots were measured by the method described by Singleton and Rossi (1965). Antioxidant activity in roots, as free radical scavenging effect of plant extracts, was assessed by the discoloration ethanolic solution of DPPH radical 0.2 aromatic in ethanol, according to Elslimani *et al.* (2013).

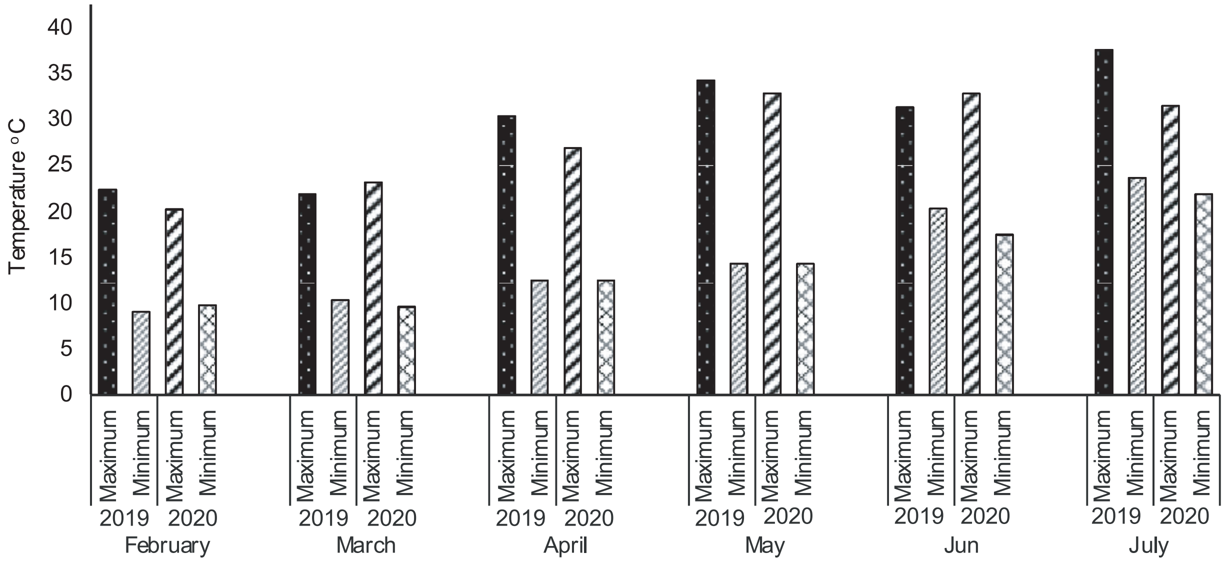

Fig. 1. Average of monthly minimum and maximum temperature from February to July months of 2019 and 2020 seasons.

Root nutrient contents: Root nutrient contents of N, P, K, Ca, and Mg were determined in the oven-dried root samples taken 90 days after seed sowing. Total nitrogen (N) content was determined using the modified micro-Kjeldahl method as described by Helrich (2012). Phosphorus (P) was determined colorimetrically by using the chlorostannous molybdophosphoric blue colour method in sulphuric acid, according to Jackson (1959). Potassium (K) was determined using the flame photometer apparatus (CORNING M 410, Germany), according to Piper (1950). Furthermore, Ca and Mg were determined using an atomic absorption spectrophotometer with air-acetylene and fuel (PyeUnicam, model SP-1900, US), according to Richard (1954).

Root chemical quality, 120 DAS: Total carbohydrates in root samples were determined by the phosphomolybdic acid method according to Helrich (2012). Coumarin in roots was estimated in carrot with Ati-Unicumgas-liquid chromatography, 610 Series, equipped with a flame ionization detector according to the method described by Sproll *et al.* (2008). The fiber was also estimated in carrot by a non-enzymatic-gravimetric method according to Nawirska and Kwaśniewska (2005). Vitamin C was determined according to the method mentioned by Dubois *et al.* (1951). Total soluble solids (TSS) in roots were measured by using Zeiss laboratory refractometer. Total carotenoids of roots were determined spectrophotometrically using a UVVIS spectrophotometer (Model SM1200; Randolph, NJ, USA). (Holden, 1965).

Yield parameters: All plants from each plot were harvested 120 days after sowing and were separated to two groups, first group was the marketable roots that, were weighed and recorded as a marketable yield and the other group was weighed as an unmarketable yield that contained all roots with disorders or distortion and not suitable for marketing, such as the green shoulders roots, forked roots, cracked roots and hairiness roots.

Statistical Analysis: Data were statistically analyzed using MSTAT-C v. 2.1 (Michigan State University, Michigan, USA), and mean comparisons were based on the least significant differences (LSD $\leq$ 0.05) test (Maxwell and Delaney, 1989).

Results

Effect of sowing date

Vegetative growth: The data presented in Table 1 revealed that plant fresh and dry weight at 90 DAS significantly increased with March sowing in the first season and decreased with March sowing in the second season compared to February sowing. On the other hand, sowing in March significantly increased the fresh weight of shoots in both seasons, but plant height significantly increased in February sowing in both seasons.

Yield and quality: Table 2 shows that the fresh weight of roots at 90 DAS was significantly higher with March sowing in the first season than in the second. Also, root diameter significantly increased with February sowing in the first season, and no significant differences were observed between sowing dates in root length in the second season. Furthermore, the total marketable yield of roots obtained from the February sowing date was significantly higher than the March sowing, but the total unmarketable yield significantly increased with the March sowing date in both seasons.

Physiological parameters: Total chlorophyll, transpiration, and stomatal conductance of carrot leaves, 90 DAS were significantly higher at the March sowing date compared to February (Table 3).

Chemical parameters: In both the 2019 and 2020 seasons, the 15 March sowing date exhibited notable enhancements compared to the February sowing. Specifically, it led to significant increases in nutrient elements (N, P, K, Ca, and Mg) in roots at 90 days after sowing (DAS), as well as elevated levels of total phenols, antioxidant activity (DPPH), proline content in roots, proline content in leaves at 90 DAS, and various other factors such as total carotenoids, total carbohydrates, total soluble solids (TSS), fiber percentage, vitamin C, and coumarin content in roots (Tables 4, 5, and 6).

Effect of foliar spray treatments

Vegetative growth: As shown in Table 1, data indicated that all foliar spray treatments significantly enhanced vegetative growth parameters (plant fresh and dry weight, fresh weight of shoots and plant height) at 90 DAS in both seasons compared to the control treatment but treatments of DPPGE and MLE gave the highest significant records compared with the other treatments.

Yield and quality of carrot root: Data in Table 2 showed that DPPGE and MLE treatments gained the highest significant marketable yield of roots in the two seasons, while quality parameters (fresh weight of roots, root length and root diameter at 90 DAS) were significantly increased by all foliar spray treatments, especially DPPGE and MLE treatments in both seasons. Conversely, the lowest values of unmarketable roots were noticed with all foliar application treatments compared to untreated control in both seasons.

Physiological parameters: Data presented in Table 3 revealed that treatments of glycine betaine, DPPGE and MLE recorded the highest significant values of total chlorophyll and lowest values of transpiration in leaves. In contrast, the lowest readings of stomatal conductance were noticed in the DPPGE treatment at 90 DAS in both seasons.

Chemical parameters: Results of Tables 4, 5 and 6 concluded that all foliar spray treatments positively enhanced all chemical parameters of roots and leaves, but the highest readings were achieved by treatments of DPPGE and MLE in both seasons, except for the root fibre percentage, where the highest values of fibre % were found in the control treatment.

Effect of the interaction between sowing date and foliar spray

Vegetative growth: The interaction between sowing date and foliar applications significantly affected vegetative parameters at 90 DAS. Plant fresh and dry weight was significantly enhanced by DPPGE treatment with March sowing in both seasons, while treatments of DPPGE and MLE achieved the highest plant height with February sowing in both seasons (Table 1).

Yield and quality: Data in Table 2 revealed that treatment of DPPGE with a March sowing date in the first season and MLE with a February sowing date in the second season achieved the highest significant fresh weight of root 90 DAS. Moreover, a significant increase in root length and root diameter 90 DAS was observed with treatments of DPPGE and MLE at both sowing dates in the two seasons. The lowest marketable yield in both seasons and the highest unmarketable yield in the first season were obtained from control plants with a March sowing date. DPPGE treatment significantly increased marketable yield with the March sowing date in the two seasons.

Physiological parameters: Data presented in Table 3 showed that treatments of DPPGE and MLE gave the highest readings of total chlorophyll of leaves with March sowing date and the lowest values of transpiration with the February sowing date 90 DAS in both seasons but the lowest stomatal conductance was observed in the treatment of DPPGE with February sowing at 90 DAS in the second season.

Chemical parameters: Tables 4, 5 and 6 showed that all chemical measurements were positively induced on the sowing date of March with all foliar spray treatments compared to the control treatment in both seasons. Furthermore, DPPGE, MLE and glycine betaine treatments recorded the best values of all chemical parameters with the March sowing date, except for the fibre % in roots, where control and K-Si treatments gained the highest values of fibre % with March sowing in both seasons.

Discussion

Temperature is a primary factor affecting the rate of plant growth and development. Each plant species represents a certain growth and productivity temperature regime with a minimum, maximum, and optimal range. The present study indicated that the fresh weight of shoots was significantly higher on the second date (15 March) than on the first date (15 February) in both seasons. These results may be attributed to the high temperature on the second sowing date that increased water consumption and uptake of macro-elements of carrot plants. These results were also observed due to increasing proline concentration at the March sowing date, which supports the ability of carrot plants to face

Table 1. Effect of sowing date, foliar spray treatments and their interaction on plant fresh weight of carrot, fresh weight of shoots, plant height and plant dry weight 90 days after sowing, in the two seasons of 2019 and 2020

Sowing dates	Foliar spray treatments	Plant fresh weight (g)		Fresh weight of shoots (g)		Plant height (cm)		Plant dry weight (g)	
		Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
15 February	Control	59.33h	70.67g	23g	26.3g	28.7d	28.7cd	6.02i	2.22i
	K-Si	78.0g	120.3d	25.3fg	32f	33.0c	32.0b	9.73g	14.39f
	Salicylic acid	120e	113.3e	41.3d	38.3e	34.0bc	33.3b	15.02f	14.68f
	Glycine betaine	104.3f	98.67f	28.67cd	32.7f	34.3abc	29.7c	14.57f	13.65g
	Moringa leaf extract	126de	142.7b	43.7cd	46.7d	35.3ab	32.7b	18.74d	19.69c
	Palm pollen grain extract	127cd	144.3b	41.7d	61.3a	35.7a	36.0a	19.57c	21.46b
Mean		102.44	115**	33.94	39.56	33.5**	32.06**	13.94	15.18*
15 March	Control	58.3h	48.0h	23.3g	18.7h	17.3g	15.3i	5.85i	4.99j
	K-Si	74.67g	71.0g	31e	26.7g	22.0f	20.3h	8.90h	8.52h
	Salicylic acid	121de	119.0d	46.7c	45.7d	25.3e	23.7g	15.81e	15.62e
	Glycine betaine	132.7c	127c	51.3b	51c	25.67e	25.7f	18.69d	16.65d
	Moringa leaf extract	144.7b	142b	53.3b	55.3b	27.3d	26.7ef	20.67b	19.77c
	Palm pollen grain extract	153.3a	151.3a	59a	52c	28.3d	27.3de	23.10a	22.75a
Mean		114.11**	109.7	44.11**	41.56**	24.3	23.17	15.50**	14.72
	Control	58.83e	59.33f	23.17e	22.5e	23.0d	22.0e	5.93f	6.10e
	K-Si	76.33d	95.67e	28.17d	29.3d	27.5c	26.2d	9.32e	11.46d
	Salicylic acid	120.5c	116.2c	44b	42c	29.7b	28.5c	15.41d	15.15c
	Glycine betaine	118.5c	112.8d	40c	41.8c	30.0b	27.7c	16.63c	15.15c
	Moringa leaf extract	135.3b	142.3b	48.5a	51b	31.3a	29.7b	19.70b	19.73b
	Palm pollen grain extract	140.2a	147.8a	50.33a	56.7a	32.0a	31.7a	21.34a	22.11a

Table 2. Effect of sowing date, foliar spray treatments and their interaction on fresh weight of roots, root length, root diameter, 90 days after sowing (DAS) and total marketable and unmarketable yield of carrot (Ton/fed) in the two seasons of 2019 and 2020

Sowing dates	Foliar spray treatments	Fresh weight of roots (g)		Root length (cm)		Root diameter (cm)		Total marketable yield (Roots) Ton/fed		Total unmarketable yield (Roots) Ton/fed	
		Season 1	Season 2	Season1	Season 2	Season 1	Season 2	Season 1	Season 1	Season 1	Season 2
15 February	Control	39.3f	44g	14.7f	14.3g	1.9d	2.23cd	3.31f	3.763g	0.86b	0.67cde
	K-Si	53.3e	87.7d	17.3de	15.7efg	2.04cd	2.13de	4.537e	7.017d	0.40f	0.65cde
	Salicylic acid	64.3d	76e	18.3cd	16.3def	2.10c	2.37bc	6.987c	6.417e	0.43ef	0.48fg
	glycine betaine	74.3bc	63.3f	17.0e	15.3fg	2.10c	2.17d	6.853c	5.740f	0.37f	0.54ef
	Moringa leaf extract	69cd	102.7a	18.0cde	16.7def	2.33ab	2.4bc	7.047c	8.840a	0.15g	0.40gh
	Palm pollen grain extract	68cd	93.7c	18.7bc	17.7bcd	2.40ab	2.73a	8.087b	8.230b	0.15g	0.31h
Mean		61.39	77.89**	17.3ns	16.0ns	2.15ns	2.34*	6.137*	6.668**	0.393	0.509
15 March	Control	35f	30h	12.7g	11.7h	1.97cd	1.87f	2.280g	2.143i	1.16a	0.73bc
	K-Si	43.7ef	43.7g	15.3f	14.7g	2.10c	1.97ef	3.573f	3.093h	0.86b	0.56def
	Salicylic acid	73.3bcd	73e	17.7cde	17.0cde	2.27b	2.13de	6.303d	5.943f	0.68c	0.70bcd
	glycine betaine	80.7b	76.3e	18.3cd	18.3abc	2.33ab	2.23cd	6.370d	6.470e	0.61cd	0.74abc
	Moringa leaf extract	91.3a	86.7d	19.7ab	19.0ab	2.43a	2.40bc	8.020b	7.497c	0.53de	0.82ab
	Palm pollen grain extract	94.3a	98.3b	20.3a	19.7a	2.47a	2.50b	8.813a	8.600a	0.58cd	0.88a
Mean		69.7*	68.0	17.3ns	16.7ns	2.26ns	2.18	5.893	5.624	0.737**	0.738**
	Control	37.2d	37e	13.7d	13.0d	1.93d	2.05d	2.795e	2.953d	1.012a	0.70a
	K-Si	48.5c	65.7d	16.3c	15.2c	2.07c	2.05d	4.055d	5.055c	0.63b	0.61ab
	Salicylic acid	68.8b	74.5b	18.0b	16.7b	2.18b	2.25c	6.645c	6.180b	0.56bc	0.59b
	glycine betaine	77.5a	69.8c	17.7b	16.8b	2.22b	2.20c	6.612c	6.105b	0.49c	0.64ab
	Moringa leaf extract	80.2a	94.7a	18.8a	17.8a	2.38a	2.4b	7.533b	8.168a	0.34d	0.61ab
	Palm pollen grain extract	81.2a	96a	19.5a	18.7a	2.43a	2.62a	8.450a	8.415a	0.36d	0.59b

Table 3. Effect of sowing date, foliar spray treatments and their interaction on total chlorophyll, transpiration and stomatal conductance of carrot leaves 90 days after sowing (DAS), in the two seasons of 2019 and 2020.

Sowing dates	Foliar spray treatments	Total chlorophyll (mg/g F.W.)		Transpiration (mmol H_2O m^{-2} s^{-1}		Stomatal Conductance (mmol CO_2m^{-2} s^{-1})	
		Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
15 February	Control	22.49h	27.54h	3.12cd	6.14b	1.54b	3.40ab
	K-Si	26.8g	31.83f	2.62d	5.20bc	1.57b	2.68cd
	Salicylic acid	33.18ef	36.55d	2.66d	3.29de	1.68b	2.27cd
	Glycine betaine	34.91de	36.91cd	2.29d	3.61de	1.51b	2.86bc
	Moringa leaf extract	38.16bc	39.98b	2.24d	2.79e	1.40b	2.04de
	Palm pollen grain extract	39.87ab	40.21b	2.12d	2.50e	1.40b	1.50e
Mean		32.57	35.50	2.51	3.92	1.52	2.46
15 March	Control	30.9f	30.21g	6.37a	7.86a	2.54a	3.59a
	K-Si	36.22cd	34.88e	5.82a	7.44a	2.65a	3.64a
	Salicylic acid	34.92de	38.25c	5.65a	5.42bc	2.61a	2.81bc
	Glycine betaine	39.62ab	40.58b	5.64a	5.31bc	2.72a	2.66cd
	Moringa leaf extract	41.69a	41.29b	4.21b	4.28cd	2.75a	2.39cd
	Palm pollen grain extract	41.94a	42.96a	3.75bc	4.97bc	2.57a	2.49cd
Mean		37.55**	38.03**	5.24**	5.88*	2.64**	2.93*
	Control	26.7e	28.88e	4.75a	7.00a	2.04a	3.50a
	K-Si	31.51d	33.35d	4.22ab	6.32a	2.11a	3.16ab
	Salicylic acid	34.05c	37.4c	4.16ab	4.36bc	2.14a	2.54cd
	Glycine betaine	37.92a	38.75b	3.97b	4.46b	2.11a	2.76bc
	Moringa leaf extract	39.92a	40.64a	3.22c	3.53c	2.07a	2.21de
	Palm pollen grain extract	40.9a	41.59a	2.93c	3.73bc	1.98a	1.99e

high temperatures.

Sowing in February caused a significant increment in fresh and dry weight. This result may be attributed to a heat wave in April in the first season, where the maximum temperature reached 40 ºC, and the average monthly maximum temperature was 30 ºC, which negatively affected some parameters of vegetative and root growth in the season of 2019. Resende *et al.* (2016), Karakan *et al.* (2019) and Ladumor *et al.* (2020) also reported that heat stress negatively affected vegetative growth parameters.

Regarding the effect of the sowing date on root quality and yield, it was clearly shown that the values of root diameter and marketable root yield at the sowing date of February were higher than the sowing date of March in both seasons. These results may be due to the devastating effects of increasing temperature during the late growth stage, reflected in plant metabolism and carbohydrate accumulation efficiency. These results were confirmed by increasing transpiration rate and stomatal conductance at the second sowing date, which caused high stress on plant development. These results align with those found by Manosa (2011), who indicated that increasing temperatures above 30°C reduced yield and quality.

All physiological and chemical measurements were significantly higher at the second sowing date than at the first one. These results may be attributed to increased stomatal conductance and transpiration with rising temperatures, which allows plants to benefit from increased evaporative cooling during heat waves.

Table 4. Effect of sowing date, foliar spray treatments and their interaction on carrot roots content of N, P, K, Ca and Mg, 90 days after sowing (DAS), in the two seasons of 2019 and 2020.

Sowing dates	Foliar spray treatments	N %		P %		K %		Ca %		Mg %	
		Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
15 February	Control	0.79d	0.78g	0.073d	0.08g	0.20e	0.193e	0.0737g	0.0743g	0.0093g	0.0096f
	K-Si	0.92cd	0.91f	0.113cd	0.113f	0.23cde	0.23de	0.0790f	0.0783fg	0.0102f	0.0103e
	Salicylic acid	0.96cd	0.90fg	0.127cd	0.13ef	0.25bcd	0.25cd	0.0803f	0.0813efg	0.0113e	0.0112d
	Glycine betaine	0.92cd	0.92f	0.15cd	0.15e	0.24bcd	0.263cd	0.0847de	0.0830d-g	0.0122cd	0.0123c
	Moringa leaf extract	1.15c	1.13e	0.15cd	0.15e	0.27b	0.267cd	0.0880cd	0.0877de	0.0127bc	0.0125bc
	Palm pollen grain extract	1.60b	1.4d	0.19c	0.183c	0.21de	0.34ab	0.0877d	0.0877de	0.0128b	0.0128b
Mean		1.058	1.0	0.134	0.134	0.23	0.26	0.0822	0.0821	0.0114	0.0114
15 March	Control	0.89d	0.91fg	0.157cd	0.15de	0.21de	0.237de	0.0817ef	0.0823d-g	0.0100f	0.0099ef
	K-Si	0.98cd	0.97f	0.19c	0.19c	0.24bcd	0.277cd	0.0863d	0.0870def	0.0117de	0.0116d
	Salicylic acid	1.17c	1.12e	0.203c	0.20c	0.26bc	0.280cd	0.0913c	0.0913cd	0.0126bc	0.0125bc
	Glycine betaine	1.60b	1.59c	0.18c	0.177cd	0.25bc	0.277cd	0.0967b	0.0980bc	0.0126bc	0.0126bc
	Moringa leaf extract	1.90a	1.88b	0.443b	0.28b	0.32a	0.300bc	0.0990ab	0.1023b	0.0131ab	0.0133a
	Palm pollen grain extract	2.02a	2.02a	0.993a	0.977a	0.32a	0.360a	0.1017a	0.1163a	0.0135a	0.0137a
Mean		1.43**	1.41**	0.361**	0.329**	0.27**	0.29**	0.0928**	0.0962**	0.0122**	0.0123**
	Control	0.84e	0.85e	0.115c	0.117d	0.207d	0.215c	0.0777e	0.0783e	0.0097e	0.0097f
	K-Si	0.95de	0.94d	0.152c	0.152c	0.233c	0.248bc	0.0827d	0.0827de	0.0110d	0.0109e
	Salicylic acid	1.07d	1.01d	0.165c	0.165c	0.253bc	0.265b	0.0858c	0.0863cd	0.0119c	0.0119d
	Glycine betaine	1.26c	1.26c	0.165c	0.163c	0.245bc	0.270b	0.0907b	0.0905bc	0.0124b	0.0125c
	Moringa leaf extract	1.53b	1.51b	0.297b	0.215b	0.293a	0.283b	0.0935a	0.0950b	0.0129a	0.0129b
	Palm pollen grain extract	1.81a	1.71a	0.592a	0.58a	0.267b	0.35a	0.0947a	0.1020a	0.0132a	0.0132a

Table 5. Effect of sowing date, foliar spray treatments and their interaction on total phenols, antioxidant activity (DPPH), proline content in roots and proline content on leaves of carrot 90 days after sowing (DAS), in the two seasons of 2019 and 2020.

Sowing dates	Foliar spray treatments	Total phenols (mg/g F.W.)		Antioxidant activity (IC 50 %)		Proline content in roots (mg/g D.W.)		Proline content in leaves (mg/g D.W.)	
		Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
15 February	Control	0.0130g	0.0153g	88.30e	88.24h	1.327g	1.248h	0.046l	0.051i
	K-Si	0.0187f	0.0197f	93.48bc	93.26def	1.673f	1.455g	0.059k	0.069g
	Salicylic acid	0.0230de	0.0233e	91.67d	92.21f	1.661f	1.477g	0.064j	0.071fg
	Glycine betaine	0.0250cd	0.0257c-e	92.57cd	93.50cde	1.724ef	1.627f	0.069i	0.075f
	Moringa leaf extract	0.0257cd	0.0267cd	94.27ab	94.89b	1.878d	1.838e	0.073h	0.087e
	Palm pollen grain extract	0.0267bc	0.0280bc	95.26a	94.31bcd	1.937d	1.990d	0.076g	0.094d
Mean		0.0220	0.0231	92.59ns	92.73	1.70	1.606	0.065	0.076
15 March	Control	0.0210ef	0.0203f	89.34e	90.54g	1.864de	1.872de	0.080f	0.063h
	K-Si	0.0250cd	0.0247de	91.60d	92.53ef	2.385c	2.290c	0.11e	0.095d
	Salicylic acid	0.0270bc	0.0260cd	93.21bc	93.47cde	2.374c	2.548b	0.14d	0.12c
	Glycine betaine	0.0260c	0.0257c-e	94.28ab	94.46bc	2.569b	2.576b	0.15c	0.14b
	Moringa leaf extract	0.0290ab	0.0300ab	94.88a	96.14a	2.732a	2.715a	0.22b	0.19a
	Palm pollen grain extract	0.0307a	0.0307a	94.94a	96.58a	2.681ab	2.776a	0.24a	0.19a
Mean		0.0264**	0.0262**	93.04ns	93.95*	2.434**	2.463**	0.157**	0.134**
	Control	0.0170e	0.0178d	88.82d	89.39d	1.595d	1.560f	0.063f	0.06f
	K-Si	0.0218d	0.0222c	92.54bc	92.9c	2.029c	1.872e	0.082e	0.082e
	Salicylic acid	0.0250c	0.0247b	92.44c	92.84c	2.018c	2.012d	0.10d	0.097d
	Glycine betaine	0.0255bc	0.0257b	93.43b	93.98b	2.146b	2.102c	0.11c	0.12c
	Moringa leaf extract	0.0273ab	0.0283a	94.57a	95.51a	2.305a	2.276b	0.15b	0.14b
	Palm pollen grain extract	0.0287a	0.0293a	95.10a	95.44a	2.309a	2.383a	0.16a	0.14a

Moreover, increased proline accumulation under heat stress can potentially protect plants under abiotic stress. It plays important roles in different plant mechanisms, *e.g.*, antioxidant defence systems that increase growth factors like chlorophyll content in leaves and improve nutrient absorption. These results agree with those found by Kaushal *et al.* (2011), who reported that proline significantly enhanced the growth parameters of plants under heat stress. Proline alleviated the harmful effects of heat by decreasing the content of H_2O_2 and MDA and enhancing the activities of antioxidants. Proline proved beneficial in reducing cellular injury and protecting several enzymes associated with carbon and oxidative metabolisms in plants. Proline increment inside plants may cause a positive effect on carrot growth under heat stress. Still, these positive effects may be achieved until certain limits, after which a negative effect of proline accumulation may occur due to a disturbance in the catabolism of amino acids related to the breakdown of protein that leads to senescence of the plant, which explains the decrease in carrot yield under heat stress. In this respect, Ali *et al.* (2020) and Hassan *et al.* (2021) reported that heat stress causes a possible effect on different parts of the plant. In roots, it can lead to a reduction in mineral uptake by roots and antioxidant enzymes. Photosynthesis rate, chlorophyll content, stomatal conductance, water use efficiency, antioxidant enzyme activities, and carbohydrate metabolism significantly decrease in shoots.

On the other hand, all foliar spray treatments enhanced growth, root quality, marketable yield, and physiological and chemical measurements of carrots compared to untreated plants. The

Table 6. Effect of sowing date, foliar spray treatments and their interaction on total carotenoids, total carbohydrates, total soluble solids (TSS), fiber %, vitamin C and coumarine content of carrot roots 120 days after sowing (DAS), in the two seasons of 2019 and 2020.

Sowing dates	Foliar spray treatments	Total carotenoids (mg/g F.W.)		Total carbohydrates (%)		TSS (%)		Fiber (%)		Vitamin C (mg/g F.W.)		Coumarine (mg/g F.W.)	
		Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
15 February	Control	82.94fg	83.49f	9.23e	9.22f	12.0cd	12.33e	1.93e	1.91e	0.0533f	0.0547f	0.0160e	0.0160h
	K-Si	89.18de	88.54e	9.70bcd	9.46ef	12.67c	12.33e	1.72gh	1.85f	0.0643e	0.0600e	0.0173de	0.0170gh
	SA	91.88cd	89.22e	9.47bc	9.69de	12.67c	12.67de	1.65h	1.73g	0.0687de	0.0727c	0.0170e	0.0180fg
	GB	95.27ab	93.91d	9.77bc	9.76cd	13.83ab	13.33cd	1.78fg	1.74g	0.0717cd	0.0733c	0.0170e	0.0170gh
	MLE	97.27a	96.28bc	9.89b	9.84cd	12.67c	12.67de	1.79fg	1.84f	0.0763bc	0.0760bc	0.0173de	0.0173fgh
	PPGE	97.23a	98.26a	9.90b	9.93cd	13.67b	13.67bc	1.82f	1.81f	0.0763bc	0.0773bc	0.0187d	0.0190ef
Mean		92.30ns	91.62	9.66	9.65	12.92	12.83	1.78	1.81	0.0684	0.0690	0.0172	0.0174
15 March	Control	80.55g	83.20f	9.36de	9.32f	11.33d	12.33e	2.35a	2.42a	0.0640e	0.0650d	0.0220c	0.0200de
	K-Si	83.93f	90.37e	9.63bcd	9.81cd	14.67a	14.33e	2.27ab	2.32bc	0.0713cd	0.0730c	0.0233bc	0.0220bc
	SA	88.27e	93.33d	9.79bc	9.96c	14.33ab	13.67bc	2.24bc	2.25d	0.0790b	0.0783b	0.0243ab	0.0210cd
	GB	92.88bc	94.49cd	10.71a	10.43b	14.0ab	14.33ab	2.20bc	2.30bc	0.0800b	0.0803b	0.0230bc	0.0230b
	MLE	96.61a	97.9ab	10.97a	10.97a	14.3ab	14.33ab	2.05d	2.35b	0.0883a	0.0870a	0.0250a	0.0250a
	PPGE	97.49a	99.83a	11.05a	10.92a	14.67a	14.67a	2.17c	2.28cd	0.0903a	0.0897a	0.0250a	0.0250a
Mean		89.96ns	93.79*	10.25**	10.23**	13.89*	13.94**	2.21**	2.32**	0.0788**	0.0789**	0.0238**	0.0227**
	Control	81.75e	83.35f	9.30c	9.27e	11.67b	12.33d	2.14a	2.16a	0.0587d	0.0598d	0.0190d	0.0180d
	K-Si	86.56d	89.45e	9.67b	9.63d	13.67a	13.33bc	1.99b	2.09b	0.0678c	0.0665c	0.0203bc	0.0195c
	SA	90.07c	91.27d	9.63b	9.83c	13.5a	13.17c	1.95bc	1.99d	0.0738b	0.0755b	0.0207bc	0.0195c
	GB	94.07b	94.20c	10.24a	10.10b	13.92a	13.83ab	1.99b	2.02cd	0.0758b	0.0768b	0.0200cd	0.0200bc
	MLE	96.94a	97.09b	10.43a	10.4a	13.5a	13.5bc	1.92c	2.09b	0.0823a	0.0815a	0.0212ab	0.0212ab
	PPGE	97.36a	99.05a	10.48a	10.43a	14.17a	14.17a	1.99b	2.05c	0.0833a	0.0835a	0.0218a	0.0220a

SA: Salicylic acid, GB: Glycine betaine, MLE: Moringa leaf extract, PPGE: Palm pollen grain extract

highest values were achieved with PPGE and MLE treatments. These results may be back to the ability of all anti-transpirations, especially DPPGE, MLE, and GB treatments, to increase plant tolerance to heat stress through the increase of proline content, nutrient absorption, and total phenols and to decrease transpiration rate and stomatal conductance, as compared with control treatment. The great values of growth parameters under heat stress achieved by using PPGE and MLE may also be attributed to the structures of the two compounds, which are considered sources of hormones or growth regulators and growth-promoting substances. These results are in agreement with those found by Rady *et al.* (2015); Latif and Mohamed (2016), El-Serafy and El-Sheshtawy (2020), who indicated that moringa leaf extract has been introduced to overcome stressful conditions, especially in late sowing of winter crops Furthermore, The positive effects of using DPPGE and MLE may be a comeback to their high contents of nutrients, vitamins, and phytohormones (Latif and Mohamed, 2016; Taha *et al.,* 2020).

Moreover, Annunziata *et al.* (2019) and Ali *et al.* (2020) reported that glycine betaine plays an essential role in preserving membrane dehydration and adjusting the osmotic pressure inside plant cells. So, when glycine betaine was sprayed on plant leaves, it was rapidly and easily absorbed, mostly in the cytosol, and then translocated into chloroplasts. Glycine betaine accumulation increased antioxidant enzymes and chlorophyll pigments as a response to stress.

This study underscores the intricate relationship between sowing dates, foliar spray treatments, and temperature conditions in shaping carrot plants' growth, yield, and physiological characteristics. The research illuminates the nuanced influence of sowing dates on vegetative growth, yield, and root quality, revealing the delicate balance between temperature stress and productivity. Furthermore, the efficacy of foliar spray interventions, particularly DPPGE and MLE, in enhancing plant resilience to heat stress and improving physiological and chemical attributes is demonstrated. This investigation emphasizes the potential for tailored strategies to optimize crop performance in the face of varying environmental challenges.

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