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USING SOME ORGANIC SUBSTANCES TO ALLEVIATE DELETERIOUS IMPACTS OF SOIL SALINITY ON FENNEL PLANT

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ABSTRACT: Two factorial experiments in split plot design were carried out during the two successive growing seasons of 2018/2019 and 2019/2020 at Soils, Water, and Environ. Res. Inst. Farm in Sahl El-Tina Agric. Res. Station, Port Saied Governorate, Agric., Res. Center, Egypt to investigate the effects of some plant growth promoters (PGPs) (*Azospirillum lipoferum*, *Azotobacter chroococcum*, *Bacillus subtilis*, and *Bacillus polymyxa*) alone or with different organic substances (compost (Com) at 4 ton/fed, ascorbic acid (AsA), compound amino acids (CAA) at 200 ppm for each) and their interactions on fennel (*Foeniculum vulgare* Mill.) growth and soil chemical properties under saline-sodic soil conditions. Significant increases in plant height (cm), number of branches and umbels/plant, fresh and dry weights/plant (g), weight of 100 fruits (g), fruit yield/plant (g), essential oil % and yield/plant (ml) were recorded. The interaction between all organic substances and PGPs treatments decreased the estragole content values. The percentage of total carbohydrates, N, P, and K in fruits as well as soil dehydrogenase and nitrogenase activities increased with the tested treatments, especially Com + AsA + CAA with (PGPs). Proline content in fresh leaves decreased, and soil pH and EC were enhanced especially in the case of organic substances with PGPs treatments which reflected in fennel quantity and quality. The application of organic substances (Com at 4 ton/fed, AsA and CAA at 200 ppm for each) with PGPs (*A. chroococcum*, *A. lipoferum*, *B. polymyxa*, *B. subtilis*) could be recommended for enhancing fennel yield and essential oil under saline-sodic soil conditions.

Keywords: *Foeniculum vulgare*, compound amino acids, plant growth promoters, estragole, proline, carbohydrates, nitrogenase, dehydrogenase

INTRODUCTION

The increasingly high average temperatures and drought that have been occurring due to global climatic changes are causing soil salinization. Every year, large amounts of cultivable land, covering hundreds of hectares, are lost as a result of salinization (about 950 million ha which represents 10% of the land surface worldwide), and it is expected to be exacerbated (Meena and Verma, 2018, Corwin, 2020, and Liu *et al*., 2020).

Salinity can greatly impact plant growth and productivity. This is due to an imbalance of ions and osmotic stress in plants, consequentially affects plant physiology, decreases biochemical processes and biomass, and ultimately causes plant injury or even death (Islam *et al*., 2019). In Egypt, most of the salinity-affected soils are allocated in the northern central part of the Nile Delta and on its western and eastern sides. As a result of wrong agricultural practices such as flood irrigation, an incomplete irrigation system, and the continuous increase in the groundwater level, the rapid salinization of Egyptian soils would be an acute problem (Kotb *et al.*, 2000).

One of the primary significant metabolites in plant cells is amino acids. Nevertheless, they are frequently regarded as secondary metabolites, particularly when it comes to betaine, proline, and glycine. All plant parts (organs, tissues, and cells) physiochemical characteristics are influenced by amino acids presence (Marschner, 2011). Biologically, amino acids have critical roles in cell life. They are considered the proteins building units, as the living cells' main component which have essential roles in many metabolic reactions of the cell, also, they serve as precursors of other nitrogen-containing compounds like nucleic acids (Bashir *et al*., 2018). Moreover, in plant cells, amino acids perform a wide range of vital biological tasks such as metabolism, transferring, vitamin biosynthesis, growth bio-stimulation, maximization of nutrient intake, and the detoxification of heavy metals and other pollutants (Rizwan *et al*., 2017; Hussain *et al*., 2018). Amino acids affect some enzymes synthesis and activities, redox homeostasis, and gene expression (Fahimi *et al*., 2016). They also improve environmental stress tolerance like salinity, cold, and drought conditions, besides they also used in the production and synthesis of amino-chelate fertilizers (Souri and Hatamian, 2019).

Plant growth promoting substances (PGPs) can supply cross-protection versus many stress conditions which are considerable scientific progress towards agricultural sustainability (Timmusk, 2017). The rhizosphere bacteria (especially of the genera *Azotobacter, Aeromonas, Bacillus, Pseudomonas, Burkholderia, Rhizobium,* and *Enterobacter*) contribute to plants' auxin pool. The immediate bacterial auxins secretion effect is an accelerating root hairs' elongation, root growth and biomass, root surface, as well as modification of the root system architecture (Bashan and De-Bashan, 2010). PGP have numerous ways to improve their plants' symbionts growth, such as producing phytohormones (gibberellins, auxins, and cytokinins), supplying with atmospheric nitrogen, synthesizing siderophores, solubilizing minerals and phosphorus, besides stress-alleviating enzymes synthesizing (such as cell-wall degrading enzymes, and 1-aminocyclopropane-1-carboxylate (ACC) -deaminase) (Sessitsch *et al*., 2019). Bacteria of *Bacillus*, *Rhizobium*, and *Azospirillum* genera control the activity of 1-aminocyclopropane-l-carboxylate (ACC)-deaminase. ACC-deaminase converts ACC to ammonia and α-keto-butyrate hence decreasing ethylene levels in plants and then plant growth stimulating (Compant *et al*., 2019).

Ascorbic acid (vitamin C), is one of the main non-enzyme antioxidants which has a vital role in intermediating many oxidative resulting from biotic or abiotic stresses on plant (Akhlaghi *et al*., 2018; Sharma *et al*., 2019). Ascorbic acid (AsA) exogenous application is quite efficacious for boosting growth and development through changing oxidative protection systems, ion transporting, phytohormones signaling, cell expansion, as well as other related processes in plants under stress conditions (Darvishan *et al*., 2013). Asc is considered the plant defense's first line against oxidative stress through removing several free radicals (like HO, H_2O_2, and O^{2-}), acting as an antioxidant (APX) which is an integral enzyme for the Ascorbate–glutathione cycle. Furthermore, it can enhance plant growth, boost plant ability to hold stresses and synthesize Hyper-crosslinked polymers (HCPs) (Bilska *et al*., 2019). Ascorbate is a crucial cofactor in various cellular enzymes, like violaxanthin de-epoxidase (VDE), which plays a vital role in photo-protection through the xanthophyll cycle. Additionally, Ascorbate is directly involved in removing ROS, inhibiting lipid peroxidation, and decreasing MDA content in plant tissues. As a result, it boosts the overall antioxidant capacity of the plant's tissues (Zhou *et al.*, 2016).

Adding compost is an approach to improve soil organic matter, aeration, and structure thus creating a better plant growth environment. It also reduces waste disposal problems and minimizes the environmental pollution resulting from applying mineral fertilizers (Radwan, *et al.*, 2019). Compost is applied to soil to enhance plant growth, yield, and quality even without adding mineral fertilizers besides boosting soil properties (biological, physical, and chemical). Compost has various characteristics such as high water-holding capacity, high porosity, mineral elements absorption and storage, especially nitrogen, phosphorous, and potassium, as well as micronutrients, and their liberalization gradually hence, preventing nutrients leaching, enhancing plant growth and horticultural crops' quality, besides it has a major function in soil fertility and productivity, consequently developing sustainable agriculture. (Golijan and Marković, 2018).

Fennel (*Foeniculum vulgare* Mill.) is an annual herbaceous plant of Apiaceae family. Fennel is originally from the Mediterranean region, but can now be seen in various parts of the globe. It is a medicinal plant and a flavorful culinary herb. Apart from its many culinary uses, it can be used as a carminative, diuretic, and galactagogue (Pashtetsky *et al.*, 2018). Fennel fruits (seeds) are abundant in strong antioxidants such as limonene, chlorogenic acid, and quercetin, which provide a wide array of health benefits that provide inflammatory, antioxidant, anti-and antibacterial effects (Rather *et al.*, 2016). Fennel fruits are beneficial for various digestive problems including heartburn, appetite loss, abdominal bloating, intestinal gas, and infant colic as it contains fiber, calcium, potassium, and magnesium. It is also used for coughs, upper respiratory tract infections, bronchitis, backache, bedwetting, cholera, and visual problems. Fennel powder is used as a poultice for snakebites (Akhbari *et al.*, 2019). A volatile oil can be extracted from mature fennel fruits (seeds) with a percentage of 3-6% and has antimicrobial, hepatoprotective, as well as antioxidant activity. It contains anethole, fenchone, and methyl chavicol as main components. Anethole as an organic compound has antimicrobial, anticancer, anti-inflammatory, and antiviral properties. Fenchone plays a significant role in pharmaceutical, confectionery, and many other industries. It is also used as a flavoring agent in some laxatives and as well as a fragrance component in cosmetics and soaps (Telci *et al.*, 2009).

Salinity impacts on agriculture is a serious issue in Egypt, so in this concern, the goal of this investigation is to define the relationships between applying amino acids, Ascorbic acid, and compost with or without plant growth promoters (PGPs) on growth, fruit yield, and essential oil productivity of fennel under salinity stress conditions.

MATERIALS AND METHODS

This study was conducted during the two growing seasons of 2018/2019 and 2019/2020 in a clayey soil at Sahl El-Tina Agric. Res. Station, North Egypt. The objective of this study was to investigate the effect of plant growth promoters (PGPs) and different organic substances on the production and quality of fennel (*Foeniculum vulgare*, Mill) under saline soil conditions. Fennel seeds (fruits) were obtained from the Medicinal and Aromatic Plants Research Department, Dokki, Giza, Egypt. The seeds (fruits) were sown on the 5th and 7th of November for the two seasons directly into the soil at a distance of 30 cm between hills (2-3 seeds/hill), and 100 cm between rows. The practice of thinning was done and only the best and strongest two plants per hill were left to thrive. Some physical and chemical properties of the studied soil and irrigation water are presented in Tables (a and b) respectively, according to (Chapman and Pratt, 1982).

The experimental design was a split-plot using a randomized complete block design (RCBD) with three replicates. Plant growth

Table a. The main physical and chemical properties analyses of experimental soil.

Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Soil Texture	OM (%)	CaCO$_3$ (%)
8.71	66.3	11.3	13.7	Loamy sand	0.55	8.2

pH (1:2.5)	EC (dSm^{-1})	Cations (meq/l)				Anions (meq/l)		
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO$^{-}_{3}$	Cl^{-}	SO$^{--}_{4}$
8.51	11.88	7.85	12.63	44.00	2.17	22.18	31.02	24.16

Table b. Physical and chemical analysis of irrigation water.

pH (1:2.5)	EC (dSm^{-1})	Sodium adsorption ratio (SAR)
7.45	2.36	4.75

Macro-micronutrients (mg/l)						
NO$_3$ -N	NH$_4$ -N	P	K	Fe	Mn	Zn
22.03	9.15	3.04	7.26	2.11	2.53	0.86

promoters (PGPs) were set at the main plots, while organic substances were set at the subplots including; compost (Com) at 4 ton/fed, ascorbic acid (AsA), compound amino acids (CAA) at 200 ppm for each one and their interactions. So, the experiment implicated 16 interaction treatments.

Compost (Com) was acquired from the Egyptian Company for Waste Recycling and was incorporated into the soil at 15-20 cm depth, during soil preparations as a single dose on October 25th in both seasons. The physical and chemical properties of the used compost are given in Table (c) according to Brunner and Wasmer (1978).

Ascorbic acid (AsA) was obtained from the (Al Drich Chemical Co., Ltd., Egypt) and was dissolved in tap water and applied as a foliar spraying at the previously mentioned concentration. Plants were sprayed five times throughout the growing season till the runoff point using a hand sprayer. Nestapon as a wetting agent at 1 ml/l was used. The first application was done two weeks after seedling emergence, and the other ones were conducted monthly until the flowering stage.

The source of compound amino acids (CAA), containing methionine, arginine and glutamic acid was Techno Gene Co., Dokky, Giza, Egypt. Fennel seeds (fruits) were soaked in the (CAA) for 30 minutes before sowing. Each experimental unit received 5 liters of solution using a spreading agent (Super Film at the rate of 1 ml/l). The first spray was applied two weeks after planting (seedling emergence) with a portable sprayer, one hour after sunrise, by spraying both surfaces of the leaves, the other sprays were done at 30-days intervals through plant vegetative growth until the flowering stage.

Plant growth promoters (PGPs):

Plant growth promoting rhizobacteria are root associated bacteria including *A. chroococcum*, *A. lipoferum*, *B. polymyxa* and *B. subtilis* were kindly supplied by Microbiology Department, Soil, Water and Environment Research Institute (SWERI), Agriculture Research Center (ARC), Ministry of Agriculture, Giza, Egypt. These PGPs were grown at maximum density in Difico nutrient broth medium Difico Manual (1984) for 24 hrs. These strains were tested for their quantitative abilities to produce endogenous phytohormones and nitrogenase activity. Fennel seeds (fruits) were soaked in the PGPs culture for 30 minutes before sowing. After sowing, plants were sprayed with PGPs until the flowering stage. The determination of cytokinins, indole-acetic acid (IAA) and gibberellins are used according to Rahal *et al*. (2006). Determination of nitrogenase using a colorimetric determination for ethylene according to Larue and Kurz (1973) was shown in Table (d).

Table c. Physical and chemical characteristics of the used compost fertilizer.

The characters	1st season	2ed season
Weight of 1 m^3 (kg)	485	480
Moisture content (%)	8.89	9.10
Organic matter (%)	63.01	63.21
Organic carbon (%)	31.75	33.24
Total N (%)	1.78	1.65
C:N ratio	17.84:1	13.6:1
Total P (%)	0.33	0.54
Total K (%)	1.41	1.63
Fe (ppm)	1854	2025
Mn (ppm)	183	174
Zn (ppm)	142.3	161.4

Table d. Some characteristics of plant growth promoting in the study.

Strain	N_2-ase µmole C_2H_4/ml/hr	Phytohormones (µg/l culture)		
		Indole acetic acid	Gibberellins	Cytokinins
Azotobacter chroococcum	288	72.10	102.2	16.3
Azopirillum lipoferum	65.24	5.20	84.5	28.70
Bacillus polymyxa	58.14	35.7	95.4	97.40
B. subtilis	—	196.30	85.8	22.0

Recorded Data:

Responses of fennel plant to the tested plant growth promoters (PGPs) with some organic substances treatments were noticed and the following data were recorded during the two experimental seasons:

Plant growth:

On vegetative growth completion, just before the flowering phase, three plants from each row were used to determine vegetative growth responses, as plant height (cm), number of branches per plant, and fresh and dry weights per plant (g) were recorded during the two tested seasons.

Fruit yield:

Plants were harvested on May 20^{th} during the two seasons, number of umbels per plant, seed index represented as the weight of 100 seeds (g), and fruits (seeds) yield per plant (g) were recorded.

Essential oil determinations:

Fruit samples of each treatment were taken to extract essential oil using water distillation according to the method of British Pharmacopoeia (1963), and oil percentages were recorded then oil yield per plant was calculated. Samples of the essential oil of the first season (2018/2019) were subjected to gas chromatography (GC) analysis according to Hoftman (1967), and Buzon *et al.* (1969) to determine the main components of the essential oil.

Chemical analysis:

Chemical analyses were determined in leaf samples of the two tested seasons. Total carbohydrate (%) was determined by using the method described by Herbert *et al.* (1971), total nitrogen was determined using the modified micro Kjeldahl method as described by Pregl (1945), phosphorus content was determined according to King (1951), potassium content was determined using the atomic absorption spectroscopy (Rawe, 1973) and free proline content was determined in fresh leaves according to Bates *et al.* (1973) method.

Enzymatic activates:

Samples of fennel rhizosphere soil were taken after harvesting plants in each season to determine the soil's biological activity in terms of nitrogenase activity (N_2-ase) as described by Somasegaran and Hoben (1994). The dehydrogenase activity was also determined according to Skujins and Burns (1976) and the determination of pH, and EC were done according to Page *et al.* (1982).

Statistical analysis:

The collected data were subjected to statistical analysis according to Little and Hill (1978). Mean separation was done using the least significant difference test (LSD) at 5% level.

RESULTS

Vegetative growth characteristics:

Results represented the effect of organic substances (OS), plant growth promoters (PGPs), and their interactions during the two successive seasons are recorded in Table (1).

Applying different organic substance treatments had a considerable effect on the different vegetative growth characteristics of fennel (*Foeniculum vulgare,* Mill) plant expressed as plant height (cm), branches No./plant, fresh and dry weights/plant (g)., as they promoted vegetative growth and caused significant increases in the values of these characteristics, compared to the untreated plants (control). In the above-mentioned traits, gradual increases were noticed in the plants that received Com + AsA + CAA, followed by those treated with Com + CAA and Com + AsA respectively. The above-mentioned results were confirmed during the two successive seasons. Similar favorable effects on plant growth due to the organic applications of (AsA) were noticed by Nassar *et al.* (2019) on basil plant, Azizi *et al.* (2021) on *Calendula officinalis* L., Hassan *et al.* (2021) on *Hordeum vulgare* L., and Novita *et al*. (2022) on *Vetiveria zizanioides* L. However, the results for CAA are as stated with those reported by Junxi *et al.* (2010) on Chinese cabbage, Mohammadipour and Souri (2019) on *Coriandrum sativum* L., and Ahmed *et al.* (2020) on borage plant. However, these results for Com are in harmony with those reported by Abo-Kora and Mohsen (2016) on basil plant, and Golijan and Marković (2018) on fennel plant.

In general, there were significant improvements in vegetative growth due to applying PGPs compared to the untreated plants during the two tested seasons (Table, 1). Similar result was obtained by Abdel-Rahman (2019) on *Rosmarinus officinalis*, Moreira *et al*. (2020) on maize, Zhu *et al.* (2020) on *Medicago sativa* L., and Abdel-Latif *et al.* (2021) on barely plant.

For the interaction between PGPs and organic substances applications, significant responses in vegetative growth characteristics were noticed in both seasons (Table, 1). In general, values of these characteristics were significantly increased by increasing the application of organic substance treatments under tested PGPs.

The combined treatments of Com + AsA + CAA with PGPs followed by Com + CAA with PGPs and Com + AsA with PGPs respectively, were superior in improving growth parameters of fennel plant compared to all other interaction treatments. These results were true during the two successive seasons (Table, 1).

In the existence of PGPs, plant height increased from 112.46 cm in control to 155.73 cm in plants received Com + AsA + CAA treatment compared to the absence of PGPs (from 103.67 for control to 144.07 cm in Com + AsA + CAA treatment). Likewise, the number of branches also increased from 4.02 in control to 13.68 cm for the treatment of Com + AsA + CAA) when PGPs were added against 3.55 to 12.00 cm in the absence of PGPs, respectively. Also, the fresh weight/plant raised from 258.84 g for the control to 462.42 g in Com + AsA + CAA treatment without PGPs whereas, it was increased from 333.08 g (control) to 581.47 g in Com + AsA + CAA treatment with PGPs. Similarly was the trend for dry weight/plant

Table 1. Effect of some organic substances (OS), plant growth promoters (PGPs) and their interaction on plant growth parameters of fennel plant in two seasons.

Organic Substances (OS)	First season: 2018/2019			Second season: 2019/2020		
	Plant growth promoters (PGPs)					
	Without PGPs	With PGPs	Means (OS)	Without PGPs	With PGPs	Means (OS)
			Plant height (cm)			
Control	103.67	112.46	108.07	99.50	109.73	104.62
Com 4 ton/fed	109.37	119.52	114.45	100.72	112.15	106.44
AsA 200 mg/l	110.33	123.08	116.71	105.70	118.33	112.02
CAA 200 mg/l	114.14	131.77	122.96	110.22	124.64	117.43
Com + AsA	133.66	141.14	137.40	129.14	135.33	132.24
Com + CAA	139.30	146.17	142.74	137.07	142.22	139.65
AsA + CAA	128.01	135.22	131.62	124.65	130.14	127.40
Com + AsA + CAA	144.07	155.73	149.90	141.47	149.36	145.42
Means of PGPs	122.82	133.14		118.56	127.74	
L.S.D. 5%	OS= 3.142, PGPs= 4.266, OS×PGPs=			OS= 2.873, PGPs= 3.017, OS×PGPs= 4.134		
			No. of branches/plant			
Control	3.55	4.02	3.79	2.45	3.09	2.77
Com 4 ton/fed	4.00	4.26	4.13	3.05	3.87	3.46
AsA 200 mg/l	4.78	5.17	4.98	3.87	4.07	3.97
CAA 200 mg/l	6.22	7.04	6.63	5.78	5.43	5.61
Com + AsA	10.33	11.68	11.01	8.87	10.00	9.44
Com + CAA	11.10	12.36	11.73	10.17	11.52	10.85
AsA + CAA	9.06	10.55	9.81	7.02	8.60	7.81
Com + AsA + CAA	12.00	13.68	12.84	11.30	12.60	11.95
Means of PGPs	7.63	8.60		6.56	7.40	
L.S.D. 5%	OS= 2.814, PGPs= 1.732, OS×PGPs=			OS= 1.745, PGPs= 1.026, OS×PGPs= 3.972		
			Fresh weight of plant (g)			
Control	258.84	333.08	295.96	238.72	296.33	267.53
Com 4 ton/fed	278.67	351.11	314.89	245.16	305.67	275.42
AsA 200 mg/l	297.62	388.33	342.98	274.12	335.11	304.62
CAA 200 mg/l	343.45	407.12	375.29	317.78	377.34	347.56
Com + AsA	394.20	457.45	425.83	366.05	435.42	400.74
Com + CAA	432.07	508.35	470.21	417.84	485.73	451.79
AsA + CAA	364.21	427.15	395.68	330.43	410.12	370.28
Com + AsA + CAA	462.42	581.47	521.95	440.17	508.80	474.49
Means of PGPs	353.94	431.76		328.78	394.32	
L.S.D. 5%	OS= 6.305, PGPs= 8.640, OS×PGPs=			OS= 5.412, PGPs= 7.416, OS×PGPs= 10.756		
			Dry weight of plant (g)			
Control	167.02	185.58	176.30	150.17	176.45	163.31
Com 4 ton/fed	177.24	202.46	189.85	167.78	184.33	176.06
AsA 200 mg/l	190.33	229.47	209.90	183.08	198.67	190.88
CAA 200 mg/l	204.71	248.22	226.47	199.37	218.41	208.89
Com + AsA	248.07	311.16	279.62	225.31	251.45	238.38
Com + CAA	263.37	333.45	298.41	244.20	277.12	260.66
AsA + CAA	227.67	283.16	255.42	211.70	230.66	221.18
Com + AsA + CAA	301.17	352.11	326.64	281.08	312.67	296.88
Means of PGPs	222.45	268.20		207.84	231.22	
L.S.D. 5%	OS= 3.119, PGPs= 5.017, OS×PGPs=			OS= 2.661, PGPs= 4.017, OS×PGPs= 5.186		

Compost (Com), Ascorbic acid (AsA), Compound amino acids (CAA), plant growth promoters (PGPs).

where the highest value (352.11 g) was recorded in the mixture of all compounds (Com + AsA + CAA) with PGPs while this mixture without PGPs gave 301.17 g. The data obtained in the first season was better than that of the second one. These results are in agreement with those of Abo-Kora and Mohsen (2016) on basil plant, Golijan and Marković (2018) on fennel, El-Sayed and Hagab (2020) on wheat, and Ghabour *et al*. (2020) on roselle plants.

Flowering characteristics:

Regarding the effect of different organic substances treatments, data listed in Table (2) indicate that, in both seasons, these treatments gave a notable increase in number of umbels/plant, the weight of 100 fruits (g), and fruit yield/plant (g), compared to the control. The highest values were achieved in plants that received Com + AsA + CAA followed by the treatments of Com + CAA and Com + AsA, respectively. The AsA favorable effect was confirmed by Nassar *et al.* (2019) on basil plant, Azizi *et al*. (2021) on *Calendula officinalis* L. and Novita *et al*. (2022) on *Vetiveria zizanioides* L. While the results of CAA are in agreement with Junxi *et al*. (2010) on Chinese cabbage, Dawood and Glaim (2018) on *Zea mays* and Mohammadipour and Souri (2019) on *Coriandrum sativum* L.

Table 2. Effect of some organic substances (OS), plant growth promoters (PGPs) and their interaction on plant flowering parameters of fennel plant in two seasons.

Organic substances (OS)	First season: 2018/2019			Second season: 2019/2020		
	Plant growth promoters (PGPs)					
	Without PGPs	With PGPs	Means (OS)	Without PGPs	With PGPs	Means (OS)
				No. of umbels/plant		
Control	25.26	28.33	26.80	20.45	25.70	23.08
Com 4 ton/fed	29.44	33.89	31.67	25.07	30.89	27.98
AsA 200 mg/l	33.45	37.17	35.31	28.15	34.49	31.32
CAA 200 mg/l	40.07	46.35	43.21	35.44	41.45	38.45
Com + AsA	55.78	62.52	59.15	44.36	58.08	51.22
Com + CAA	64.11	76.62	70.37	52.72	63.00	57.86
AsA + CAA	49.33	54.47	51.90	40.33	49.28	44.81
Com + AsA + CAA	73.76	86.00	79.88	68.88	75.11	72.00
Means of PGPs	46.40	53.17		39.43	47.25	
L.S.D. 5%	OS= 2.452, PGPs= 3.604, OS×PGPs= 4.231			OS= 2.011, PGPs= 2.571, OS×PGPs= 3.414		
				Weight of 100 fruit (g)		
Control	0.66	0.80	0.73	0.55	0.68	0.62
Com 4 ton/fed	0.83	1.00	0.92	0.75	0.80	0.78
AsA 200 mg/l	0.95	1.17	1.06	0.87	0.99	0.93
CAA 200 mg/l	1.32	1.47	1.40	1.10	1.22	1.16
Com + AsA	1.50	1.68	1.59	1.33	1.44	1.39
Com + CAA	1.58	1.74	1.66	1.41	1.52	1.47
AsA + CAA	1.46	1.51	1.49	1.28	1.35	1.32
Com + AsA + CAA	1.50	2.08	1.79	1.49	1.64	1.57
Means of PGPs	1.23	1.43		1.10	1.21	
L.S.D. 5%	OS= 0.117, PGPs= 0.176, OS×PGPs= 0.312			OS= 0.101, PGPs= 0.141, OS×PGPs= 0.222		
				Fruit yield/ plant (g)		
Control	40.23	44.16	42.20	37.62	40.84	39.23
Com 4 ton/fed	54.85	61.42	58.14	50.33	59.07	54.70
AsA 200 mg/l	60.32	65.38	62.85	55.76	63.71	59.74
CAA 200 mg/l	65.46	70.59	68.03	61.63	68.47	65.05
Com + AsA	73.42	83.14	78.28	71.33	77.16	74.25
Com + CAA	78.59	87.62	83.11	75.25	82.56	78.91
AsA + CAA	68.55	74.53	71.54	65.45	72.30	68.88
Com + AsA + CAA	80.35	96.04	88.20	78.64	86.45	82.55
Means of PGPs	65.22	72.86		62.00	68.82	
L.S.D. 5%	OS= 4.402, PGPs= 6.250, OS×PGPs=			OS= 3.730, PGPs= 5.319, OS×PGPs= 9.433		

Compost (Com), Ascorbic acid (AsA), Compound amino acids (CAA), plant growth promoters (PGPs).

Data represented in Table (2) also cleared that in both seasons, treating plants with plant growth promoters (PGPs) significantly increased the formation of umbels/plant, weight of 100 fruits (g), and fruit yield/plant (g), in comparison with control. The obtained values were significantly higher than the values recorded without using PGPs. The previous outcomes are in harmony with the results of similar studies on improving growth under saline soil stress reported by Moreira *et al*. (2020) on maize and Zhu *et al.* (2020) on *Medicago sativa* L.

Regarding the effect of interaction between organic substances and plant growth promoters (PGPs), data show that in both seasons, the combination of Com + AsA + CAA with PGPs caused the highest significant effect, followed by the treatment of Com + CAA with PGPs and Com + AsA with PGPs, respectively. (Table, 2). In the case of number of umbels/plant, the mixture of all organic treatments without PGPs increased it to 2.9 fold of the control, whereas the increase reached 3.04 fold with PGPs application. The PGPs mixture with all organic substances was superior compared with the other ones without PGPs by 1.2 fold. The PGPs mixture with all organic substances was superior to those treatments without PGPs by 38.7%. A similar trend was recorded in fruit yield/plant (g), all organic treatment mixtures without PGPs reached 1.9 fold of control, whereas with PGPs this increase reached 2.2 fold of control. The mixture of all organic matter with PGPs was superior to the one without PGPs by 19.5%. These data obtained in the first season was the best. These results are in harmony with those reported by Golijan and Marković (2018) on fennel and Ghabour *et al*. (2020) on roselle plants.

Essential oil productivity:

Data representing essential oil production are shown in Tables (3 and 4).

Table 3. Effect of some organic substances (OS), plant growth promoters (PGPs) and their interaction on oil determinations of fennel plant in two seasons.

Organic substances (OS)	First season: 2018/2019			Second season: 2019/2020		
	Plant growth promoters (PGPs)					
	Without PGPs	With PGPs	Means (OS)	Without PGPs	With PGPs	Means (OS)
	Essential oil (%)					
Control	2.102	2.261	2.182	2.000	2.179	2.090
Com 4 ton/fed	2.197	2.445	2.321	2.134	2.215	2.175
AsA 200 mg/l	2.266	2.506	2.386	2.206	2.366	2.286
CAA 200 mg/l	2.332	2.614	2.473	2.284	2.547	2.416
Com + AsA	2.753	3.017	2.885	2.492	2.962	2.727
Com + CAA	2.942	3.267	3.105	2.734	3.172	2.953
AsA + CAA	2.436	2.753	2.595	2.306	2.753	2.530
Com + AsA + CAA	3.006	3.516	3.261	2.883	3.367	3.125
Means of PGPs	2.504	2.797		2.380	2.695	
L.S.D. 5%	OS= 0.182, PGPs= 0.261, OS×PGPs= 0.432			OS= 0.144, PGPs= 0.212, OS×PGPs= 0.373		
	Essential oil yield/plant (ml)					
Control	0.845	0.998	0.922	0.752	0.890	0.821
Com 4 ton/fed	1.205	1.502	1.354	1.074	1.308	1.191
AsA 200 mg/l	1.367	1.638	1.503	1.230	1.507	1.369
CAA 200 mg/l	1.527	1.845	1.686	1.408	1.744	1.576
Com + AsA	2.021	2.508	2.265	1.778	2.286	2.032
Com + CAA	2.312	2.863	2.588	2.057	2.619	2.338
AsA + CAA	1.670	2.052	1.861	1.509	1.990	1.750
Com + AsA + CAA	2.475	3.201	2.838	2.267	2.911	2.589
Means of PGPs	1.678	2.076		1.509	1.907	
L.S.D. 5%	OS= 0.202, PGPs= 0.316, OS×PGPs= 0.542			OS= 0.164, PGPs= 0.273, OS×PGPs= 0.446		

Compost (Com), Ascorbic acid (AsA), Compound amino acid (CAA), plant growth promoters (PGPs).

Table 4. Effect of some organic substances (OS), plant growth promoters (PGPs) and their interaction on the essential oil components (%) of fennel plant in the first season.

Organic substances (OS)	Plant growth promoters (PGPs)					
	Without PGPs	With PGPs	Mean (OS)	Without PGPs	With PGPs	Mean (OS)
	α- Pinene			**β- Pinene**		
Control	0.70	0.86	0.78	1.16	1.24	1.20
Com 4 ton/fed	0.95	1.25	1.10	1.37	1.67	1.52
AsA 200 mg/l	1.12	1.87	1.50	1.84	2.17	2.01
CAA 200 mg/l	1.30	2.32	1.81	2.74	3.26	3.00
Com + AsA	2.14	3.13	2.64	3.42	4.78	4.10
Com + CAA	1.98	3.07	2.53	3.05	3.86	3.46
AsA + CAA	1.75	2.07	1.91	2.33	2.85	2.59
Com + AsA + CAA	2.58	3.70	3.14	3.73	4.12	3.93
Means of PGPs	1.57	2.28		2.46	2.99	
	Anise aldehyde			**Fenchone**		
Control	6.08	6.27	6.18	17.30	18.80	18.05
Com 4 ton/fed	6.77	7.13	6.95	19.33	20.64	19.99
AsA 200 mg/l	7.35	7.77	7.56	21.52	22.12	21.82
CAA 200 mg/l	7.82	8.78	8.30	22.57	23.43	23.00
Com + AsA	8.73	9.64	9.19	27.01	28.50	27.76
Com + CAA	9.22	10.11	9.67	24.33	26.63	25.48
AsA + CAA	8.46	9.32	8.89	28.76	30.44	29.60
Com + AsA + CAA	9.75	10.62	10.19	32.14	35.37	33.76
Means of PGPs	8.02	8.71		24.12	25.74	
	Anethole			**Estragole**		
Control	13.66	14.36	14.01	43.15	36.46	39.81
Com 4 ton/fed	15.06	16.12	15.59	38.52	35.17	36.85
AsA 200 mg/l	16.17	17.63	16.90	35.71	33.50	34.61
CAA 200 mg/l	17.70	19.70	18.70	33.12	29.40	31.26
Com + AsA	20.35	22.46	21.41	28.77	25.87	27.32
Com + CAA	19.15	20.13	19.64	30.46	27.35	28.91
AsA + CAA	22.45	25.74	24.10	27.08	24.65	25.87
Com + AsA + CAA	24.83	27.57	26.20	24.35	22.40	23.38
Means of PGPs	18.67	20.46		32.65	29.35	

Compost (Com), Ascorbic acid (AsA), Compound amino acid (CAA), plant growth promoters (PGPs).

1. Effect of different organic substances treatments:

Results indicate that fertilization of different organic substance treatments significantly increased essential oil percentage in fruits compared to control plants during the two seasons (Table, 3). The essential oil % means reached 3.261, 3.105, and 2.885% compared to 2.182% in control in the 1st season and reached 3.125, 2.953, and 2.727% compared to 2.09% in control plants in the 2nd season for the treatments of Com + AsA + CAA, Com + CAA and Com + AsA respectively. From the previous results of such research, it could be noticed that organic substance treatments which improved plant growth also increased the fruit essential oil %. Similar enhancing effects on the essential oil% due to applying AsA were noticed by Hashem and Hegab (2018) on *Lavandula pubescens*, Nassar *et al.* (2019) on basil plant and Novita *et al*. (2022) on *Vetiveria zizanioides* L. Whereas the results for CAA are in accordance with the findings reported by Mohammadipour and Souri (2019) on *Coriandrum sativum* L.

For essential oil yield/plant (ml), data presented in Table (3) show that the different organic substances treatments significantly increased the oil yield/plant in comparison with the control in the two seasons. Moreover, Com + AsA + CAA treatment produced the highest oil yield/plant (2.838 and 2.589 ml/plant in the first and second seasons, respectively), while unfertilized plants (control) recorded significantly lower oil yields (0.922 and 0.821 ml/plant in the both seasons, respectively).

Data presented in Table (4) showed the different organic substances' effects on the main components of the obtained essential oil. It is clear that fertilizing fennel plants with Com + AsA + CAA gave the highest percentages of the main essential oil components in comparison with the control or other treatments of organic substances. The essential oil which produced from plants grown under the treatment of Com + AsA + CAA contained the highest percentages of α-Pinene (3.14%) anethole (26.20%), anise aldehyde (10.19%), and fenchone (33.76%). On the opposite, the estragole component gave the lowest percentage (23.38%) compared to (39.81%) of control plants. Similar enhancing effects after organic applications were noticed by Ali *et al.* (2017) on fennel plants.

2. Effect of plant growth promoters (PGPs) treatment:

Data illustrated in Table (3) showed that PGPs untreated plants had significantly lower fruits essential oil % (2.504 and 2.380% during the 1st and 2nd seasons, respectively), than those received PGPs treatment, which produced the highest contents (2.797 and 2.695% in the 1st and 2nd seasons, respectively). Such results were obtained by Abdel-Rahman (2019) on *Rosmarinus officinalis*.

As regards to essential oil yield/plant as affected by plant growth promoters (PGPs) treatments, the results recorded in Table (3) showed that, in general, using (PGPs) treatment had a significant effect on the oil yield/plant (ml) compared to untreated (control) plants during the two seasons. Treating plants with PGPs caused the highest values of essential oil yield/plant (2.076 and 1.907 ml/plant, in the first and second seasons, respectively) whereas the corresponding yields for the unfertilized plants were 1.678 and 1.509 ml/plant in the first and second seasons respectively.

In Table (4) the gas chromatography (GC) analysis of the oil indicated that the highest percentages of α- pinene, β- pinene, anethole, anise aldehyde, and fenchone (2.28, 2.99, 20.46, 8.71 and 25.74%, respectively) were recorded in essential oil obtained from plants treated with PGPs, comparing to control. On the contrary, the same treatment resulted in the lowest estragole percentage (29.35%) compared to 32.65% in the untreated plants.

3. Effect of interaction between organic substances and PGPs treatments:

It is obvious that organic substances and PGPs interaction treatments had significant effects on the essential oil percentages in fennel seeds for both seasons (Table, 3). Plants that received Com + AsA + CAA with PGPs produced the highest essential oil% in comparison with all other treatments in both seasons (3.201 and 2.911% in 1st and 2nd seasons, respectively), followed by plants treated with Com + CAA with PGPs, giving 2.863 and 2.619%, respectively. The least effective combination treatment was Com + AsA with PGPs which recorded (2.508 and 2.286% in the first and second seasons, respectively). These data are in agreement with the conclusions reached by Abo-Kora and Mohsen (2016) on basil plant, and Golijan and Marković (2018) on fennel.

The combination of organic substances (OS) × PGPs application treatments resulted in considerable effects on essential oil yield/ plant (Table, 3). Broadly, the above-mentioned treatments (*i. e.* Com + AsA + CAA or Com + CAA combined with PGPs) gave significant increases in both essential oil % and yield/plant as compared to control and most of the other interaction treatments.

Data in Table (4) revealed that the combined treatment of Com + AsA + CAA and PGPs gave the highest values of α-pinene, anethole, anise aldehyde, and fenchone contents (3.70, 27.57, 10.62, and

35.37%, respectively). While the combined treatment of Com + AsA and PGPs showed the highest value of the β-pinene content (4.78%). Also, the interaction between OS and PGP treatments decreased the values of estragole component compared to the unfertilized plants which recorded the highest value (36.46%). While in plants received Com + AsA + CAA and PGPs resulted in the lowest value of estragole (22.40%) was recorded. Essential oil content was probably increased due to the increase in the metabolic activities as mentioned by Golijan and Marković (2018).

Chemical analysis:

1. Plant constituents:

The results obtained (Figs., 1-5) show the effects of applying plant growth promoters (PGPs), organic substances, and their combination on the chemical analysis of fennel plants.

Respecting the effects of organic substances application effects on chemical analysis of fennel plant, data illustrated in (Figs., 1-5) showed that all organic treatments increased chemical analysis of fennel expressed as total carbohydrates, nitrogen, phosphorus, and potassium. The treatment of Com + AsA + CAA recorded the highest values followed by Com + CAA and Com + AsA treatment, respectively. Contrariwise, the lowest content of free proline was produced from the same treatments. Such results were confirmed during the two tested seasons. Similar enhancement effects on chemical analysis due to applying organic applications were reported by Mohammadipour and Souri (2019) on *Coriandrum sativum* L. Azizi *et al.* (2021) on *Calendula officinalis* L. and Novita *et al*. (2022) on *Vetiveria zizanioides* L.

Regarding (PGPs) effect, generally, there were, improvements in the contents of total carbohydrates, nitrogen, phosphorus, and potassium in fennel plants treated with PGPs compared to the untreated ones during the two tested seasons. Meanwhile, the free proline content in fresh leaves was decreased (Figs., 1 and 2). These results are in line with Moreira *et al*. (2020) on maize, and Zhu *et al.* (2020) on *Medicago sativa* L.

Concerning, the effects of organic substances in combination with plant growth promoters (PGPs) treatment, it was found that the interaction treatments of Com + AsA + CAA with PGPs increased them compared to the control and all other interaction treatments followed by the treatment Com + CAA with PGPs and Com + AsA with PGPs, respectively during the two seasons (Figs., 1 and 2). So, the mixtures of PGPs with all organic substance treatments increased the total carbohydrates by 10.3% than other treatments (without PGPs).

The mixture of treatments with PGPs was also superior to those without PGPs by 5.5, 4.2, and 6.0% for the nitrogen, phosphorous, and potassium percentages, respectively. On the other hand, it was noticed that, the vital action of PGPs resulted in proline reduction.

The mixture of all treatments with PGPs had a considerable effect on proline reduction. The decrease in proline content was nearly 46.4% of control treatment without PGPs, while the reduction was almost 54.0 % of control with PGPs.

2. Soil properties:

The effects of organic substances applications, plant growth promoting (PGPs), as well as their combinations on soil properties are presented in Table (5) and illustrated in Figs. (6 and 7). Results obtained in both seasons show that the different organic treatments were more effective in decreasing soil pH and EC. The mean pH of the soil reached 6.20, 6.31, and 6.53 compared to 7.83 in control in the 1st season and 6.43, 6.60, and 6.72 compared to 8.30 in control plants in the 2nd season for Com + AsA + CAA, followed by the treatment of Com + CAA and Com + AsA, respectively. These results were confirmed by Radwan *et al.* (2019).

On the other hand, the abovementioned treatments increased both dehydrogenase enzyme (DHA) and nitrogenase enzyme (N_2-

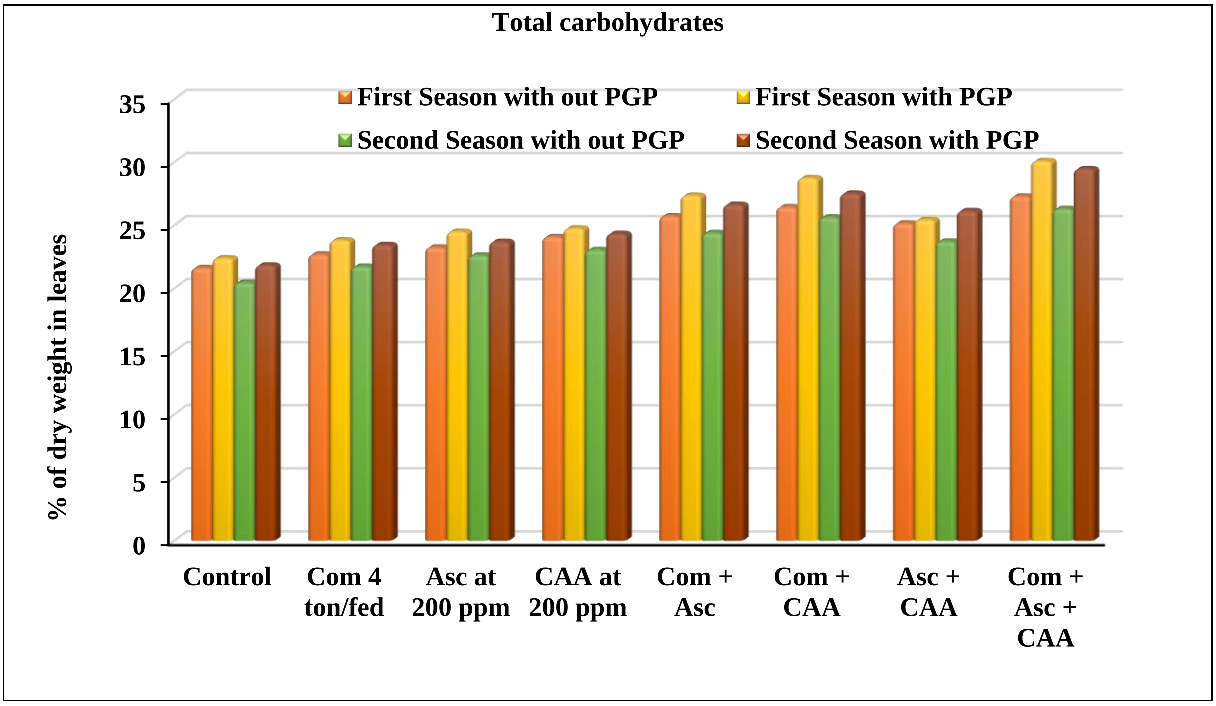

Fig. 1. Response of total carbohydrates percentage in the leaves of *Foeniculum vulgare* Mill. to some organic substances, plant growth promoters, and their interaction in two seasons.

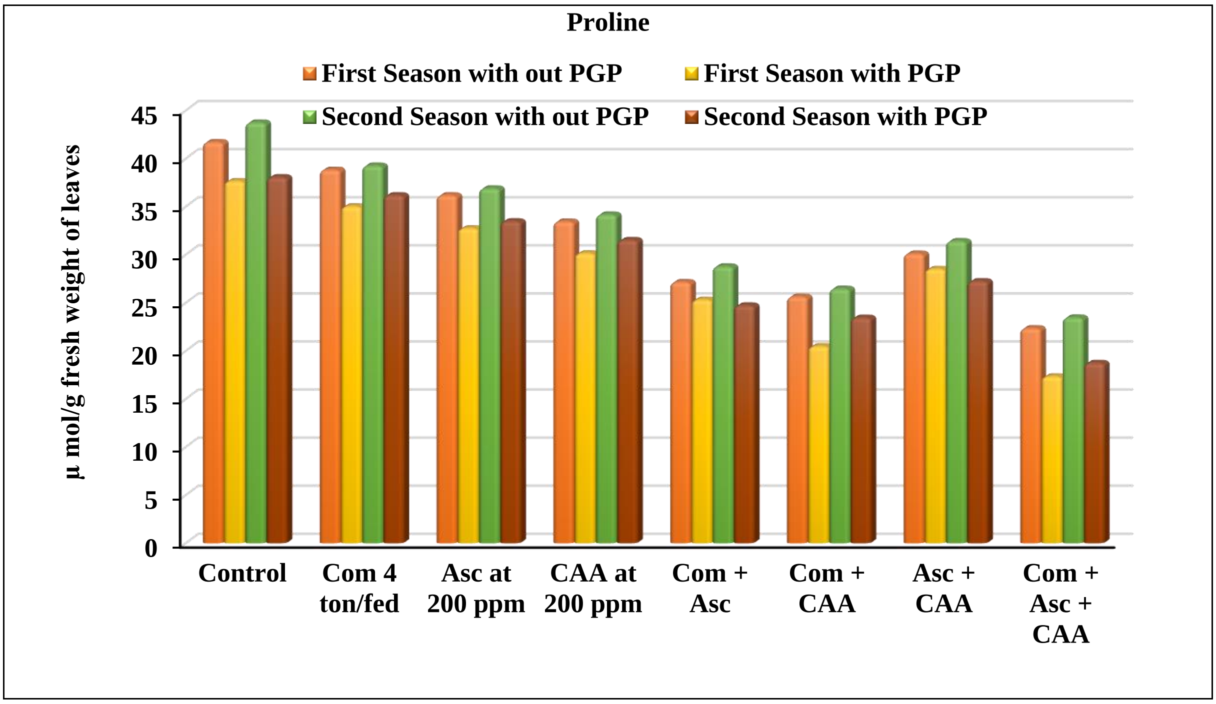

Fig. 2. Response of proline content in the leaves of *Foeniculum vulgare* Mill. to some organic substances, plant growth promoters, and their interaction in two seasons.

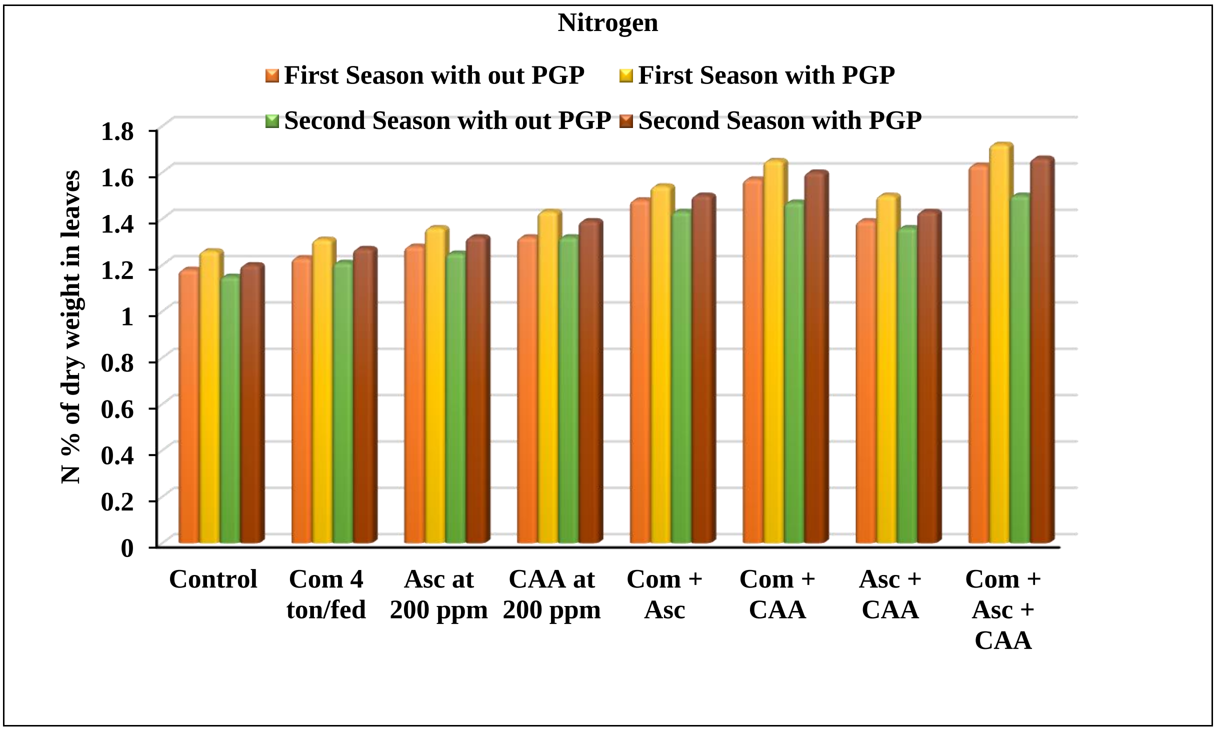

Fig. 3. Response of nitrogen percentage in the leaves of *Foeniculum vulgare* Mill.to some organic substances, plant growth promoters, and their interaction in two seasons.

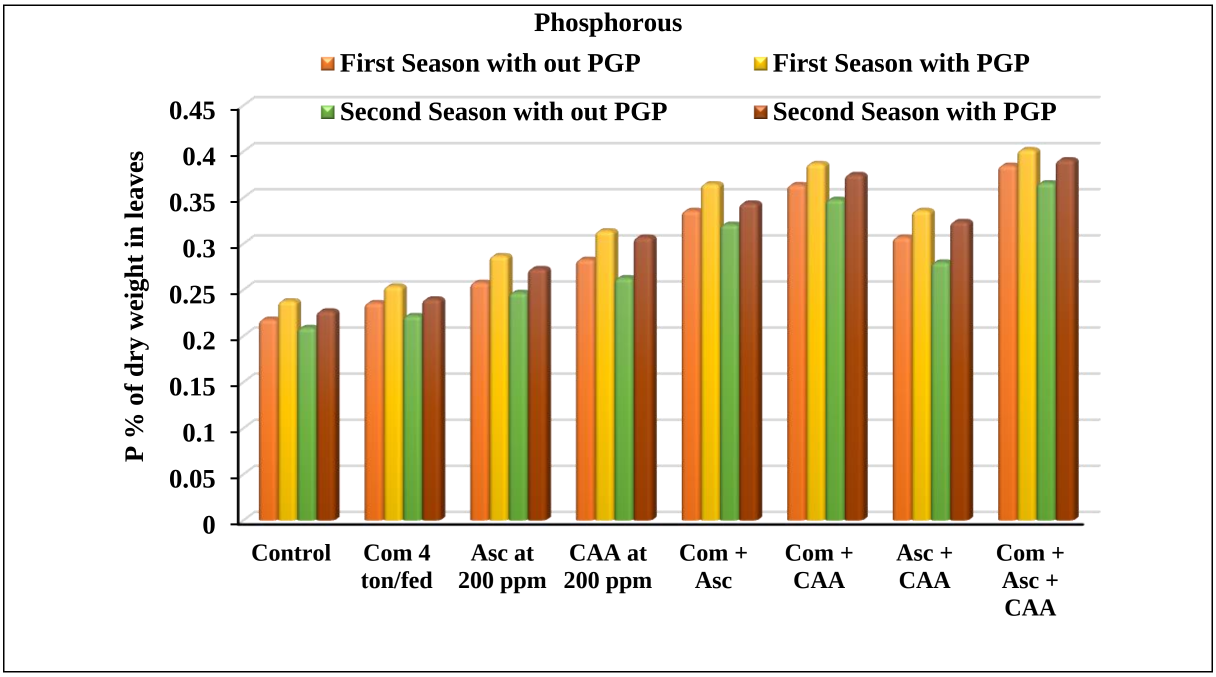

Fig. 4. Response of phosphorous percentage in the leaves of *Foeniculum vulgare* Mill.to some organic substances, plant growth promoters, and their interaction in two seasons.

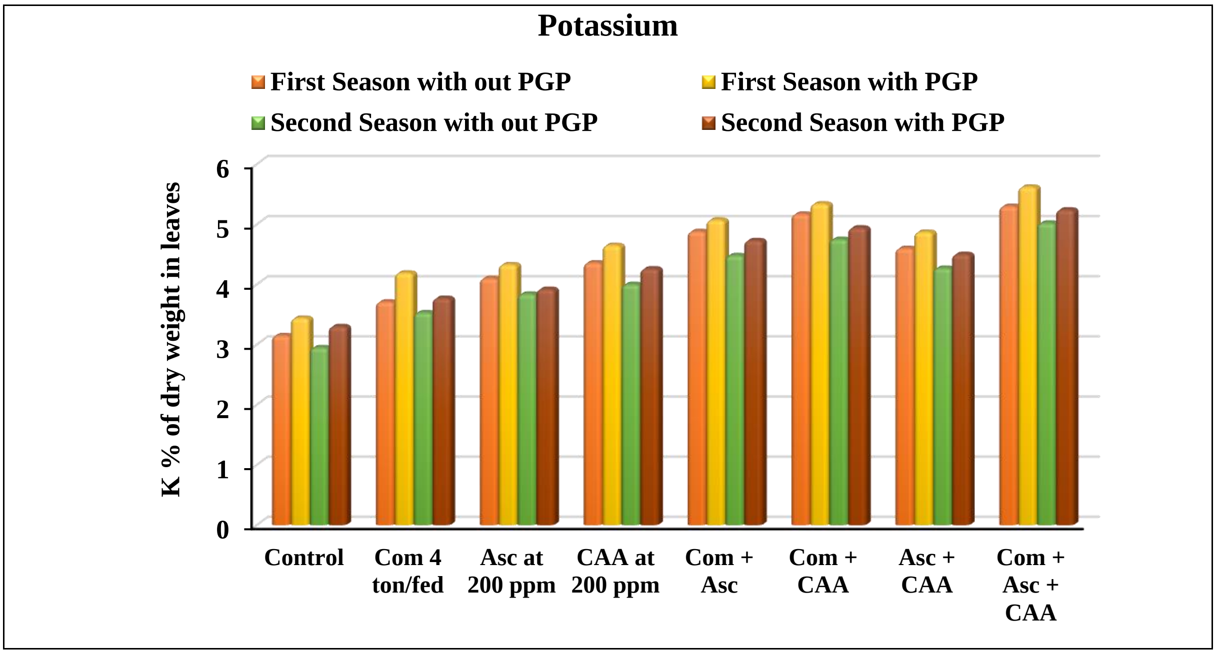

Fig. 5. Response of potassium percentage in the leaves of *Foeniculum vulgare* Mill. to some organic substances, plant growth promoters, and their interaction in two seasons.

Table 5. Effect of some organic substances (OS), plant growth promoters (PGPs) and their interaction on pH (1:2.5) and EC (dSm^{-1}) of the soil that fennel plant which grown in two seasons.

Organic substances (OS)	First season: 2018/2019			Second season: 2019/2020		
	Plant growth promoters (PGPs)					
	Without PGPs	With PGPs	Means (OS)	Without PGPs	With PGPs	Means (OS)
			pH (1:2.5)			
Control	8.01	7.64	7.83	8.45	8.15	8.30
Com 4 ton/fed	7.82	7.31	7.57	7.94	7.76	7.85
AsA 200 mg/l	7.47	7.16	7.32	7.77	7.22	7.50
CAA 200 mg/l	7.08	6.84	6.96	7.42	7.05	7.24
Com + AsA	6.74	6.32	6.53	6.96	6.52	6.74
Com + CAA	6.44	6.18	6.31	6.88	6.31	6.60
AsA + CAA	6.92	6.67	6.80	7.08	6.84	6.96
Com + AsA + CAA	6.30	6.09	6.20	6.64	6.22	6.43
Means of PGPs	7.10	6.78		7.39	7.01	
			EC (dSm^{-1})			
Control	14.88	14.35	14.62	15.07	14.03	14.55
Com 4 ton/fed	13.47	13.22	13.35	14.47	13.42	13.95
AsA 200 mg/l	12.92	12.56	12.74	13.65	12.77	13.21
CAA 200 mg/l	12.57	11.75	12.16	13.05	12.14	12.60
Com + AsA	11.85	10.73	11.29	12.17	11.23	11.70
Com + CAA	11.50	10.44	10.97	11.78	10.94	11.36
AsA + CAA	12.10	11.06	11.58	12.54	11.66	12.10
Com + AsA + CAA	11.28	9.87	10.58	11.44	10.65	11.05
Means of PGPs	12.57	11.75		13.02	12.11	

Compost (Com), Ascorbic acid (AsA), Compound amino acid (CAA), plant growth promoters (PGPs).

ase) activities of the rhizosphere, compared to the control. Com + AsA + CAA treatment gave the highest values (39.29 for DHA and 30.98 for N_2-ase in the first season as the best growth season). While unfertilized (control) plants gave significantly lower value (7.83 in the same season).

Data in Table (5) and Figs. (6 and 7) indicated that in both seasons, plants that received PGPs treatment showed more effect on dehydrogenase (DHA), and nitrogenase (N_2-ase) enzymes' activities in the rhizosphere than the control. However, the same treatments steadily decreased the pH and EC of the soil. The recorded values were lower than those obtained without PGPs (Table, 5). These outcomes are in agreement with those reported by Guangming *et al.* (2017).

In the concern of the effects of both organic substances with PGPs treatments, data listed in Table (5) and illustrated in Figs. (6 and 7) showed that the mixture of all organic treatments with PGPs was more effective in decreasing the pH and EC values of soil than organic substances alone in both seasons.

On the other hand, for dehydrogenase enzyme (DHA), and nitrogenase enzyme (N_2-ase) activities of the rhizosphere, the combination of Com + AsA + CAA with PGPs gave the highest effect, followed by the treatment of Com + CAA with PGPs, and Com + AsA with PGPs, respectively. Adding PGPs to the mixture of organic treatments increased the dehydrogenase activity by 9.2% than without PGPs in the first season. Moreover, it was also superior in nitrogenase activity almost by 4 fold in both seasons.

DISCUSSION

Salinity, as an abiotic stress, has a great impact on plants' growth and productivity. The excessive presence of salt causes osmotic strain and ionic disproportion in plants, causing disruption to their physiological functions and hindering their growth and chemical reactions, potentially resulting in harm or demise. So far, approximately 1125 million hectares have been adversely affected due to the unfavorable repercussions of rising

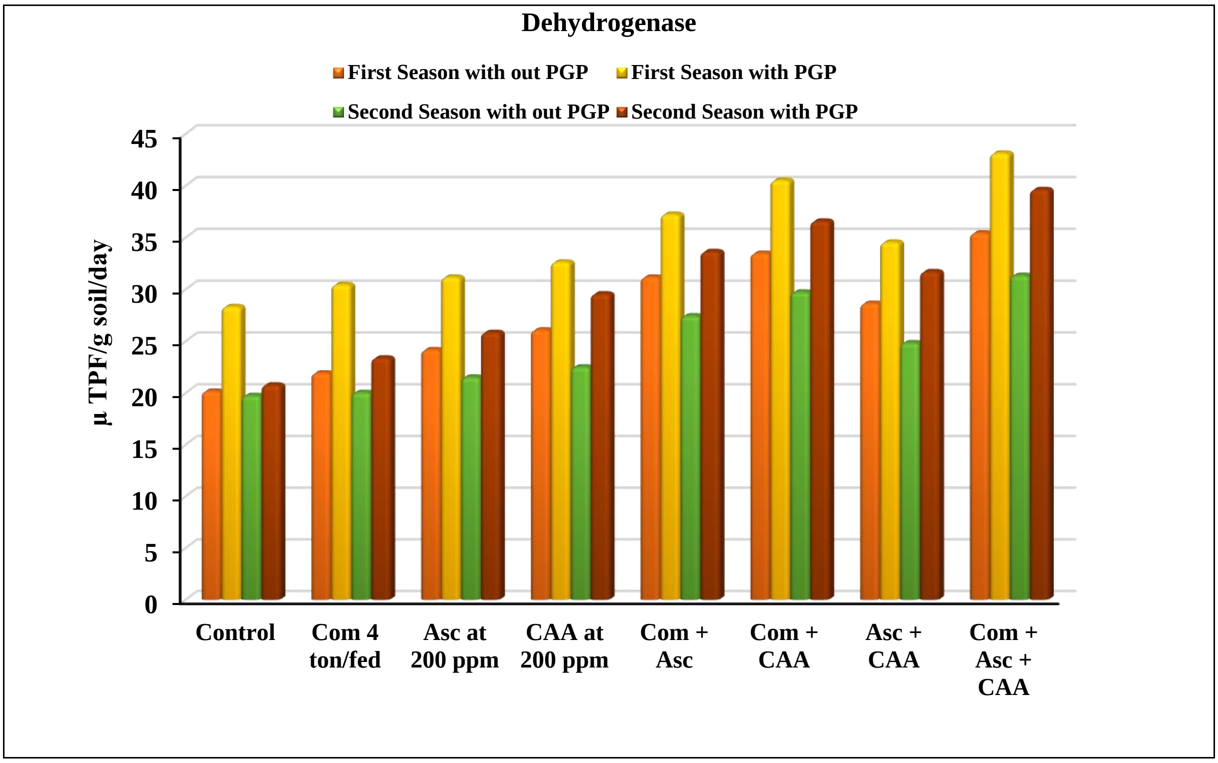

Fig. 6. Response of dehydrogenase enzyme (DHA) activity of fennel soil to some organic substances, plant growth promoters and their interaction in two seasons.

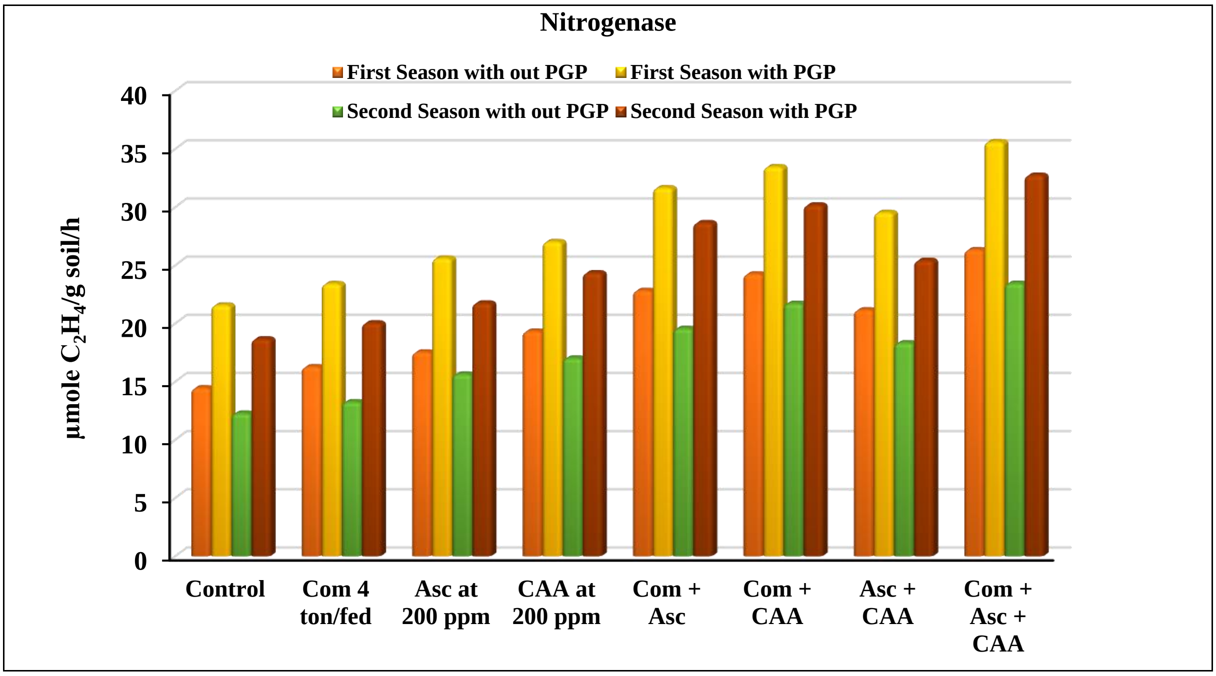

Fig. 7. Response of nitrogenase enzyme (N_2-ase) activity of fennel soil to some organic substances, plant growth promoters and their interaction in two seasons.

salinity levels (Gharsallah *et al*., 2016). The presence of high levels of dissolved mineral salts in soil profiles could be defined as salt-affected soil. As a result, the growth of crops is hindered due to the adverse effects of these dissolved salts. The climate of Egypt is marked by a mild winter, dry and hot summer, high levels of evaporation (ranging from 1500 to 2400 mm per year), and extremely minimal precipitation about 5-200 mm per year (FAO, 2016). The presence of high levels of soil salinity has a detrimental impact on the growth and productivity of plants. This is due to the excessive production of reactive oxygen species (ROS) like hydrogen peroxide (H_2O_2), superoxide, and hydroxyl radical. As they are highly reactive, these substances pose a threat to crucial cellular components such as proteins and lipids, hindering their proper functioning. (Hossain, 2019).

Amino acids are crucial building blocks for synthesizing important substances like nucleotides, vitamins, and plant growth regulators. They are vital parts of both protoplasm and living matter. Additionally, they play a vital role in enzymes production and their reactions within cells. Amino acids are responsible for enhancing plant pigments, cell division, protein contents, and hormones (such as GA_3, IAA, and ethylene). They also act as biostimulants, as they are capable of improving the crops' grain quality by boosting the effectiveness of nutrient and mineral absorption. Amino acids are vital chelating agents for zinc, iron, copper, magnesium, and calcium, enabling these crucial elements to be effortlessly absorbed and transported by plants. Additionally, by striking a balance among soil microorganisms, they enhance the decomposing of organic materials, thereby leading to a nourishing and well-structured soil that plant roots permeate. Amino acids represent an important source of nitrogen, which greatly affects plant growth (Baqir and Al-Naqeeb, 2019). Arginine (Arg), as a growth regulator, has an important role in plants' tolerance to environmental stresses. Applying arginine in the medium of plant roots, the occurrence of lipid peroxidation (such as malondialdehyde and other aldehydes), H_2O_2 content was lessened and the activity of lipoxygenases also decreased. However, there was a boost in the functioning of antioxidant enzymes, specifically Ascorbate peroxidase, cantatas, and guaiacol peroxidase. Along with this, the presence of proline and protein increased as a result of osmotic stress. Therefore, applying arginine greatly enhanced stress tolerance by elevating antioxidant enzymes activities (Kabiri *et al.*, 2016). Arg. application can alleviate oxidative stress caused by salinity in cells by changing cells' biochemical responses under high salt stress patterns by leading carbon inflow to the biosynthesis of non-reducing sugar rather than starch, decreasing hydrogen peroxide levels, and antioxidant enzyme activity (Bamary and Einali, 2021). Glutamic acid (GA) is an essential building block for protein biosynthesis in almost all living organisms. It has shown incredible effectiveness in enhancing various morphological characteristics, even in the face of stress, by increasing its ability to neutralize harmful reactive oxygen species. In addition, GA has been found to strengthen plant defense mechanisms while minimizing damage, ultimately leading to improved tolerance to salinity by maximizing plant growth (Iqbal *et al.*, 2021). Applying glutamic acid exogenously enhanced CAT proteins' production, photosynthetic efficiency, and antioxidant enzymes activity, additionally, there was a modification in the way genes coding for various antioxidant enzymes (specifically APXs, SODs, and CATs) were expressed (Lee *et al.*, 2021). Poly-γ-glutamic acid (γ-PGA), has a significant impact in agriculture. It effectively enhances the water content of soil thanks to its hydrophilic carboxyl and peptide bonds. These bonds have the ability to easily interconnect and become saturated with water, resulting in the formation of hydrogels. This, in turn, increases the ability of soil particles to hold water, making it a valuable water-saving agent. Not only does it improve the drought resistance of seedlings and plants, but it also contributes to adjusting the microbial community structures and helps regulate the soil's moisture levels (Chen *et al.*, 2021). Methionine meaningfully enhanced nutrient uptake (K^+, Ca^{2+}, and Mg^{2+}) which could be due to the presence of the antagonistic role of toxic ions. The increased methionine level could lead to the production of osmolyte antioxidants (i.e., glycine betaine) and reduce the production of ethylene under salinity conditions (Shahid *et al.*, 2022).

Plant growth-promoters (PGPs), due to their high efficiency, environmental-friendly characteristics, and low costs, bio-amelioration by using microorganisms is considered a promised process for the remediation of both saline-sodic and calcareous sodic soil. Some types of bacteria produce (γ-PGA), which could be applied for the amelioration of saline-alkali soil throughout lowering pH soil which is associated with the –COOH ionization, and increasing active phosphate content which is Ascribed to the chelation and adsorption exerted throughout carboxyl and amide bonds, increasing the conductivity of soil solution, and finally inhibition of crystallization. *Bacillus subtilis* inoculation increased phosphate content in the soil solution as a result of its byproducts from fermentation. These products are primarily made up of glutamic acid, which leads to a decrease in soil solution pH and an increase in active phosphate levels. Moreover, the complexation between glutamic acid and Ca^{2+} inhibited Ca/P compounds precipitation (Wang *et al.*, 2021). PGPs can also benefit plant symbionts indirectly through increasing antibiotic or antifungal effects, activating induced systemic resistance, and improving the level of plant cellular metabolites (Compant *et al.*, 2019). *Bacillus subtilis* alleviates plant growth inhibitory effects due to salt stress. When salt-stressed plants are inoculated with *Bacillus subtilis*, growth improves via protecting the cellular membrane safety, increasing NR and GS activities, and provisioning indole acetic acid (IAA) (a growth hormone) as well as, ethylene generation reduction under salt stress by secretion of enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase, thus improve nutrient uptake and plant growth (Abdel-Latif *et al.*, 2021). Using bacterial strains could overcome the detrimental effect of salt stress through the cumulation of sugar, proline, PAL, and TPC, as well as enzyme activity (Saberi-Riseh *et al.,* 2020). Also, Yasmin *et al.* (2020) reported that *Bacillus subtilis* was one of four isolates that showed high salt tolerance among 44 bacterial isolates in vitro testing as they showed ACC deaminase and siderophore activities, besides producing (IAA). *B. subtilis* helps plant tolerance against salinity stress by enhancing relative water content, plant biomass, and osmolytes. Auxin production is a PGPs key mechanism for promoting plant growth which could be auxin-induced changes in PGPs traits and root construction that may increase root surface area.

The constructive antioxidant defense system of plants employs various enzymes, including catalase (CAT), superoxide dismutase (SOD), Ascorbate peroxidase (APX), and peroxidase (POD) which ward off oxidative harm and resist the impact of salt stress. This highly perplexing and bursty defense network works to safeguard plants and maintain their health. (Zhu *et al.,* 2020). Ascorbic acid is a growth regulator familiar with protecting plants from several abiotic stresses through its influence on a range of plant processes like germination, ion uptake, photosynthetic, stomatal closure, cellular membrane permeability, and plant development. It also accumulates in plants under saline conditions and is also known to have an essential role in salt tolerance. Ascorbic acid accumulates in plants grown under saline stress so, plant pretreatment counteracted the negative impact of salinity on photosynthesis, cell division and enlargement, hence plant growth in many crops (Akram *et al*., 2017). The vital role of ascorbic acid (AsA) in toxic free radicals elimination and salinity stress tolerance is conferred through upregulating the abiotic stress-related genes. It is substantial to mention that the application of (AsA) caused an increase in Na^+, K^+, and Ca^{2+} contents in shoots and roots, gas exchange characteristics, photosynthetic pigments, and stomatal properties under all levels of soil salinity. Increasing transpiration rate and net photosynthesis may indicate the beneficial effect of (AsA) may reflect water efficient uptake and utilization or reduce water loss, which consequently increases leaf water potential. This shows that the exogenous application of AsA could have potential as a plant growth regulator, not only enhancing plant physiological and morphological traits but also reducing oxidative stress by increasing the effectiveness of antioxidant enzymes, thereby improving plant resistance to saline stress (Hassan *et al*., 2021). In plants, the enzyme Ascorbate oxidase (AsO) is responsible for oxidizing Ascorbic acid to mono-dehydroAscorbate (MDHA), a compound found in many living organisms. Ascorbic acid may play a part in the growth of plant cells. Interestingly, when the expression of the AsO enzyme is reduced, plants can better tolerate abiotic stresses. Furthermore, the introduction of additional ascorbic acid externally has been found to enhance a plant's resistance to high levels of salt. This highlights the important role of Ascorbic acid in plant toleration against stresses (Abdelgawad *et al.,* 2019).

A direct and favorable correlation between applying both compost and PGPs and crop productivity. The addition of compost enhances the sustainability of agriculture by decreasing chemical fertilizer utilization and improving organic matter in the soil (Golijan and Marković, 2018). Using compost helped maintain the soil's pH level and greatly raised soil stable carbon. The high organic matter content in compost also led to an increase in (OC) and EC in the soil. Furthermore, the addition of compost resulted in elevated levels of soluble Ca^{2+}, K^+, and Mg^{2+} which can be attributed to its chelating properties. This allows these elements to replace harmful soil sodium ions, lowering their absorption and consequently reduction of Na^+ overall soil content. This is also aided by the increased presence of hydrogen ions in soil solution, caused by the decay of compost, which further promotes leaching and alters the levels of soluble calcium, potassium, and magnesium in the soil (Radwan *et al.,* 2019). Compost is known for being an essential provider of vital nutrients, such as soluble salts. Plus, it contains minimal amounts of Cl-. That means it won't have harmful effects on plants when applied over a long time. On top of that, compost may have a significant amount of sulfate. This can either be easily used by plants or transformed through enzyme activities into a readily available form for plant absorption (Guangming *et al.,* 2017).

Conclusively, despite the use of various methods to enhance the growth and yield of fennel plants in the face of high salinity, the most effective treatment was found to be a combination of organic treatments, specifically Com at 4 ton/fed, AsA, CAA at 200 ppm, plus plant growth promoters (PGPs). This treatment resulted in the highest levels of vegetative growth, flowering parameters, and improved soil properties and other successful treatments included Com at 4 ton/fed + CAA 200 and Com at 4 ton/fed + AsA 200 mg/l, in that order.

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استخدام بعض المواد العضوية للتخفيف من التأثير الضار لملوحة التربة على نبات الشمر

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تم إجراء تجربتين عامليتين بتصميم القطاعات المنشقة خلال موسمي النمو المتتاليين ٢٠١٩/٢٠١٨ و٢٠٢٠/٢٠١٩ بمزرعة معهد بحوث الأراضى والمياه والبيئة، مركز البحوث الزراعية بمحطة بحوث سهل الطينة بمحافظة بورسعيد، لدراسة تأثير بعض منشطات نمو النبات (*Azotobacter chroococcum, Azospirillum lipoferum, Azotobacter chroococcum, Bacillus subtilis, and Bacillus polymyxa*) كمحفزات نمو للنبات (PGPs) بمفردها أو مع مواد عضوية مختلفة مثل سماد الكمبوست (Com) بمعدل ٤ طن/فدان، وحمض الأسكوربيك (AsA) والأحماض الأمينية المركبة (CAA) بتركيز ٢٠٠ جزء في المليون وتفاعلاتها على نمو نبات الشمر (*Foeniculum vulgare* Mill.) والخواص الكيميائية للتربة تحت ظروف التربة الملحية الصودية. تم تسجيل زيادة معنوية في كل من ارتفاع النبات (سم) وعدد الأفرع والنورات/نبات، والأوزان الطازجة والجافة/نبات (جم)، ووزن ١٠٠ ثمرة (جم)، محصول الثمار/ نبات (جم)، ونسبة الزيت العطري و محصوله/نبات (مل). أدى التفاعل بين جميع المواد العضوية وPGPs إلى انخفاض قيم محتوى الاستراجول. زادت نسبة الكربوهيدرات الكلية والنيتروجين والفسفور والبوتاسيوم في الثمار وكذلك نشاط إنزيمات nitrogenase و dehydrogenase في التربة مع المعاملات المدروسة وخاصة CAA + Com + AsA مع (PGPs). انخفض محتوى البرولين في الأوراق الطازجة، كما تحسنت درجة الحموضة و التوصيل الكهربى للتربة خاصة في حالة معاملات المواد العضوية مع PGPs مما انعكس على جودة ومحصول الشمر. يمكن التوصية بإضافة بعض المواد العضوية (Com بمعدل ٤ طن/فدان + AsA + CAA بمعدل ٢٠٠ جزء في المليون)، مع *A. chroococcum*، *A. lipoferum*، *B. polymyxa*، *B. subtilis* كمحفزات نمو (PGPs) لتحسين إنتاجية الشمر والزيت العطري تحت ظروف التربة الملحية الصودية.