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## The Effectiveness of Safe NPK Alternatives on the Growth, Productivity, and Essential Oil Content of Fennel Plants under Semi-Arid Saline Soils

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RECOGNIZING the importance of fennel as a medicinal plant under challenging soil conditions, it becomes essential to prioritize sustainable cultivation methods. Embracing bio-stimulants as a viable alternative to mineral fertilizers can play a pivotal role in ensuring the continued growth and utilization of fennel for its medicinal properties while safeguarding the environment and fostering long-term agricultural viability. The selected alternatives to NPK-fertilizers were included the foliar application of active yeast (5 g $L^{-1}$), compost tea (2 ml $L^{-1}$), humic acids (2 ml $L^{-1}$), seaweed extract (0.5 g $L^{-1}$), and ascorbic acid (0.5 g $L^{-1}$), comparing with the negative control (tap water)-and positive control as NPK (19:19:19) at 1.5 g $L^{-1}$. The sequence order of the studied treatments from more effective to less effective was as follows: applied active yeast recorded increase in many studied parameters such as number of branches per plants, dry weight, seed yield per fed, crude protein and total carbohydrates in seeds by 88 and 156%; 137 and 133%; 115 and 129%; 111 and 46%; 16.2 and 11.3% in both seasons, respectively comparing with the negative control and other applied treatments. The main components in fennel oil were α-pinene, followed by sabinene, then β-pinene under such saline conditions. The results of this study can support the farmers to reduce the applied NPK-mineral fertilizers with supplying the cultivated fennel under such saline soil conditions. Further studies are needed and more evaluations are required to know the best biostimulants can be applied under such salinity stress.

**Keywords:** Active yeast, Seaweed extract, Humic acid, Chlorophyll, Crude protein.

### 1. Introduction

Fennel (*Foeniculum vulgare*, Mill.), that belongs to the family Apiaceae (Umbelliferae) is one of the most important spices in Egypt and is originated to the Mediterranean basin (Moustafa et al. 2022). This plant is common in the folk medicine due to the medicinal and phytopharmacological properties (Jadid et al. 2023).These pharmacological attributes may involve its activity as antimicrobial, antioxidant, antiviral, anti-anxiety, anti-inflammatory, anti-mutagenic, anti-cancer, anti-diabetic, cardiovascular, gastro-protective, estrogenic-like, lipid, activity, and hepatoprotective properties (Rafieian et al. 2023).Fennel contains phenolic compounds (e.g., ascorbic acid, caffeic acid, chlorogenic acid, ferulic acid, and salicylic acid), flavonoid, and phenolic glycosides (Akbari et al. 2023).This plant has essential oils, which are rich in phenylpropanoids, monoterpenes hydrocarbons, limonene and methyl chavicol (Khammassi et al. 2023). Fennel essential oil (FEO) has distinguished applications in food sector as a flavoring agent in biscuits, bread, cakes, pickles, pastries, and sweets, and chestnuts, besides their natural inhibiting microbial pathogenic in cheese, fish, and meat dishes (Šunic et al. 2023).

With increasing concerns on environmental protection, reducing the usage of agro-chemicals globally have become increasingly important goals for sustainable agriculture. NPK-fertilizers pose a serious risk to human health due to mainly being are not eco-friendly (Roy et al. 2022). This led to searching for more biologically sound alternatives. Biostimulants are important sources for natural ingredients, amino acids, plant extracts, microflora (e.g., algae, bacteria, and mushrooms), metabolites of fermentation, humus substances, and biomolecules (Shahrajabian et al. 2021). These substances have synergistic impact on plant growth, and productivity

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especially under abiotic and biotic stress conditions (Ma et al. 2022; Shahrajabian and Sun 2022). Several studies reported on biostimulants and their role in mitigation of stressful conditions such as salinity (Alzate Zuluaga et al. 2022; Gedeon et al. 2022), water stress (Rezaei-Chiyaneh et al. 2023), and drought (Domingo et al. 2023). The general mechanism of the biostimulants under stress may include enhancing nutrient use efficiency and their translocation, root growth, flowering and production, soil microbial activity and its water holding capacity (Ma et al. 2022). This role of biostimulants was also confirmed in mitigating the effects of climate change on crop productivity (Bhupenchandra et al. 2022), and their alleviation of climate stress for sustainable agriculture (Cao et al. 2023).

Salt-affected soils suffer from salinity and/or sodicity based on values of soil acidity (pH), salinity (EC), sodium adsorption ratio (SAR), and exchangeable sodium percent (ESP), which represent a serious stress on cultivated plants leading to a rapid decline of soil health, losing their capability to grow healthy plants, filtering soil water, soil carbon storing, and other necessary ecosystem functions (El-Ramady et al. 2022). Salt-affected soils are common mainly in arid and semi-arid regions such as in Egypt, Syria, Iran, India, and the USA besides the continental climate in Hungary (Gangwar et al. 2021). Many approaches have been applied to manage saline soils, which mainly focus on decreasing soil salinity in the rhizosphere by leaching or by soil application of certain amendments such as gypsum (Sheikh et al. 2022), Plant Growth Promoting Rhizobacteria (Hafez et al. 2021), nanomaterials (El-Sharkawy et al. 2021), and biostimulants (Mostafa 2015), including biochar (Yao et al. 2022), compost (El-Sherpiny and Kany 2023), active yeast (Taha et al. 2021), and compost tea (Shawky et al. 2023).

In such challenging soil conditions, there is a growing need to adopt sustainable agricultural practices to ensure successful fennel cultivation. One critical aspect is the reduction of reliance on mineral fertilizers. Excessive use of chemical fertilizers can have detrimental effects on the environment, such as soil degradation, water pollution, and disruption of ecological balance.

To address these concerns, the implementation of bio-stimulants emerges as a promising alternative. Bio-stimulants are substances derived from natural sources, including beneficial microorganisms, seaweed extracts, humic acids, and amino acids. When applied to plants, they enhance nutrient uptake, improve plant growth and development, and boost the plant's resilience to environmental stresses.

Therefore, this study was designated for evaluating some alternatives to NPK-fertilizers of fennel production under soil salinity conditions. The content of essential oils and their composition in fennel was also analyzed under such safe alternatives for human health. The tested alternatives under the current study conditions were included active yeast, compost tea, humic acid, potassium humate, seaweed extract, and ascorbic acid.

## 2. Material and Methods

### 2.1 Experimental layout

A field experiment was carried out at the experimental Farm of Faculty of Agriculture, Kafrelsheikh University during 2017 and 2018 winter seasons. Fennel seeds were supplied from the National Research Center, Dokki, Egypt and sown at the end of October in both seasons ~~in plots~~. Each plot was 2×3m with three rows at 50 cm apart and 50 cm between the seed hills within the row, as every plot contained 21 hills / plot and replicated 3 times in a completely randomized block design. One month later, the hills were thinned at two plants/ hill.

### 2.2 Soi preparing for cultivation

The soil used was salt-affected soil, its texture was clay (19.7, 25.0, and 55.3% sand, silt, and clay, respectively). The soil pH, salinity (EC), and sodium adsorption ratio (SAR) were 8.65, 4.49 dS $m^{-1}$, and 19.0, respectively. The cation exchange capacity (CEC) and soil organic matter and soil were 40.5 cmolc $kg^{-1}$ soil and 14.5 g $kg^{-1}$, respectively, whereas the water table was at 90 cm from the soil surface. The available nutrients were 30, 12, and 185 mg $kg^{-1}$for NPK, respectively. The previous soil parameters were determined according to the methods described by **Sparks et al. (2020).** During preparing the soil for cultivation, the compost was added in October ($10m^3$/ fed) and superphosphate as well, as recommended by the Ministry of Agriculture.

### 2.3 Treatments and their application

The treatments of current study included two controls; the negative control (without any addition as a tap water), and the second was a positive control as NPK (19:19:19) to compare with other treatments. The following treatments were foliarly applied NPK (19:19:19) at $1.5gL^{-1}$, active yeast($5gL^{-1}$), compost tea($2mlL^{-1}$), humic acids($2mlL^{-1}$), seaweed extract (0.5 $gL^{-1}$), and ascorbic acid (0.5g $L^{-1}$). Four doses of the used treatments were foliar sprayed, the first one was after one month from sowing and the others were repeated biweekly. A brief on the main treatments and studied parameters during this study was presented in **Figure (1)**.

**2.4 Plant harvesting**

When the flowering of plants was completed by the end of February, the vegetative growth parameters were recorded. The measured vegetative parameters were the plant height, number of branches, fresh and dry weight of plants (**Figure 2**). During May, the seeds were harvested for two weeks and were dried in a semi-shaded, ventilated place until weight stability. Each weight of 1000 seeds and the yield of seeds per plant, as well as the yield of seeds per fed (i.e., feddan (fed) = 4200 $m^2$) were estimated. The collected seeds were air dried till the middle of June. Fennel seeds were hydro-distilled for 6 hours by Clevenger apparatus to extract essential fennel oil that was dried by anhydrous sodium sulphate to remove moisture, and the obtained essential oil was kept at 4°C in the dark bottles (**British Pharmacopoeia 1963**). Essential oil yield per plant and per fed also were measured and calculated as well as the essential oil constituents.

**2.5 Plant biochemical analyses**

For measuring nutrients in plants, plant samples were dried and digested at a temperature of 70 °C for 48 hours till the constant weight. Nitrogen, P, and K were measured in the digested plant samples using Kjeldahl instrument, spectrophotometer (Libra S80PC, Biochrom, Cambridge, UK), and atomic absorption spectrophotometer (PerkinElmer 3300, USA), respectively. Crude protein was calculated after measuring nitrogen *via* multiplying the values of N by a factor of 6.25 according to FAO/WHO (1973). Total carbohydrates were measured according the method of **Dubois *et al*. (1956).** Chlorophyll a and b were measured according to Moran and Porath (1982). Essential oil contents were determined using Gas chromatography-mass spectrometry analysis of essential oil (GC-MS) through separation, identification and quantification of the main constituents of the essential oils. ShimadzuGC-17A gas chromatograph (Shimadzu Corp., Kyoto, Japan), coupled with a Shimadzu mass spectrometer detector (GC-MSQP-5050A) was used. The GC-MS system was equipped with a TRACSIL Meta X5 column (Teknokroma S. Coop. C. Ltd., Barcelona, Spain; 30 m x 0.25 mm i.d., 0.25 $\mu$m film thickness) (Massda1976; Adams 2001).

**2.6 Statistical analyses**

Statistical analyses were performed using the statistical software SAS (version 9.1; SAS Institute, Cary, NC, USA). One-way analysis of variance (ANOVA) and species-wise Duncan's multiple range tests were used to compare the mean values between the two seasons (Duncan 1995).

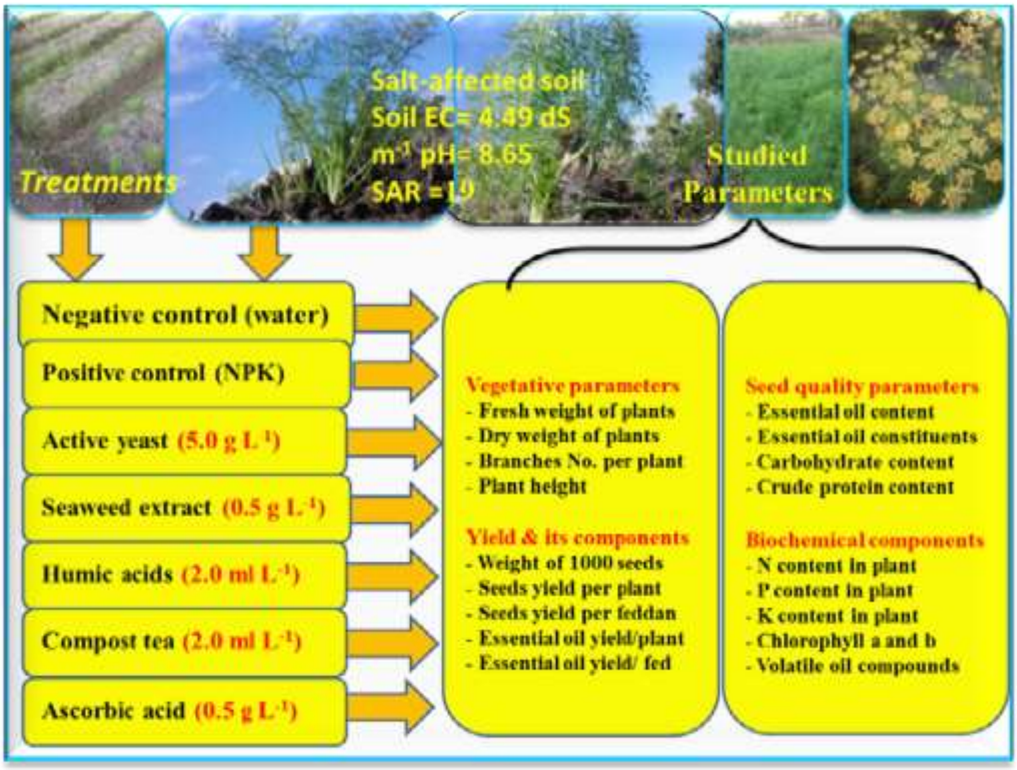


**Fig. 1. The main treatments and measurements in the current study (feddan or fed =4200 $m^2$).**

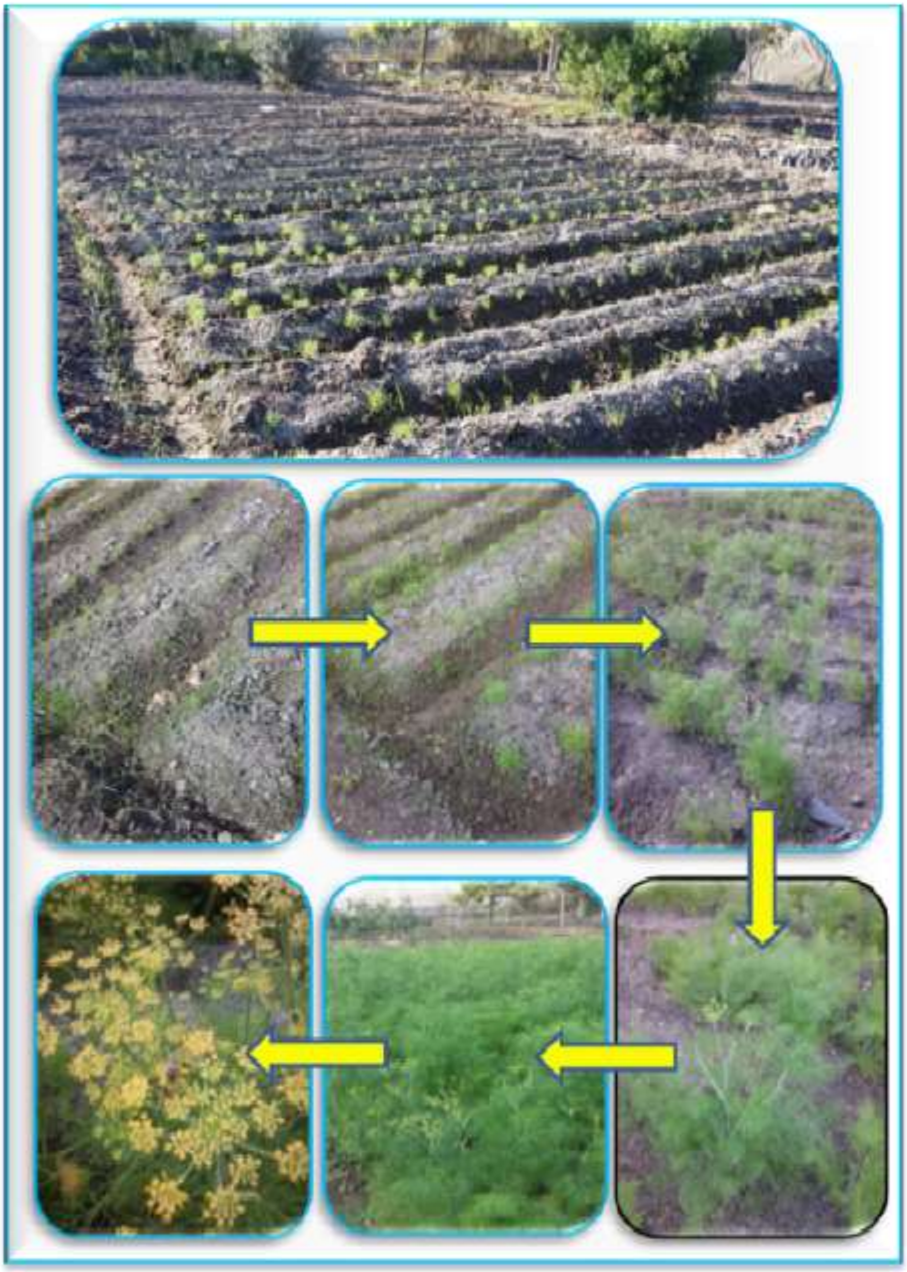

**Fig. 2. General overview on different growing stages of fennel in the current study.**

## 3. Results

### 3.1 Vegetative growth parameters

The effect of applied treatments on some vegetative growth parameters was presented in **Table 1.** Active yeast recorded the highest values for all growth aspects. Plant height, No. of branches per plant, plant fresh and dry weight were recorded the highest values (101 and 105.7cm; 11.3 and 21.3; 132.7 and 149.7 g; 34.0and 77.7 g respectively in both seasons, respectively) after applying active yeast comparing with the control. Branches no. per plant after applying ascorbic acid recorded the same level without significant different as reported by active yeast. In general, the studied treatments had impact on the vegetative growth parameters with the following order active yeast < ascorbic acid < seaweed extract under studied conditions. The increase rate in branches number and plant dry weight after applying active yeast were 88 and 156%; 137 and 133% in both seasons, respectively.

**Table 1. Effect of applied treatments on some plant vegetative parameters.**

| Treatments | Plant height (cm) | | Branches No. per plant | | Plant fresh weight (g $plant^{-1}$) | | Plant dry weight (g $plant^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | First season | Second season | First season | Second season | First season | Second season | First season | Second season |
| Negative control | 81.7cd | 71.3fg | 6.0d | 8.3d | 47.7f | 61.7f | 14.3d | 33.3f |
| Control of NPK | 96.7a | 78.7d | 8.3cd | 17.0b | 75.7e | 116.3e | 22.0c | 56.0e |
| Active yeast | 101a | 105.7a | 11.3a | 21.3a | 132.7a | 149.7a | 34.0a | 77.7a |
| Compost tea | 84.0c | 72.0fg | 7.0d | 11.0c | 99.0d | 114.3e | 22.7c | 48.3f |
| Humic acids | 89.3b | 73.3f | 8.0cd | 18.7ab | 76.3e | 144.7b | 24.7c | 71.7b |
| Seaweed extract | 98.0a | 86.7c | 10.7abc | 18.3ab | 118.0b | 133.7d | 29.7b | 60.0d |
| Ascorbic acid | 98.3a | 103.0b | 11.0ab | 21.0a | 107.7c | 139.7c | 28.3b | 65.7c |

Means in the same column followed by the same letter are not significantly different according to DMRT at (P > 0.05).

### 3.2. Yield of seed and its components

Active yeast still gives the outperforms all other treatments in all seed measurements (**Table 2**). Although active yeast gave the heaviest 1000 seeds (12.8and 18.4 g in both seasons, respectively) comparing with the negative control, this increase was similar to the positive control or NPK (11.5 and 17.4 g) without significant differences between them. Active yeast gave the highest seed yield per plant and per feddan in both seasons (17.9 and 20.3 g $plant^{-1}$; 599 and 682 kg $fed^{-1}$, respectively). The seed production (kg $fed^{-1}$) was achieved without any significant difference by applying many treatments like active yeast, control of NPK, and humic acids. The increase rate in seed yield after applying active yeast was 115 and 129 % in both seasons, respectively.

**Table 2. Effect of applied treatments on seed yield parameters of fennel plant.**

| Treatments | Weight of 1000 seeds (g) | | Seeds yield (g $plant^{-1}$) | | Seeds yield (kg $fed^{-1}$) | |
|---|---|---|---|---|---|---|
| | First season | Second season | First season | Second season | First season | Second season |
| Negative control | 10.1d | 9.9c | 8.3d | 8.8g | 278e | 297e |
| Control of NPK | 11.5bc | 17.4a | 17.5a | 20.2a | 587ab | 678a |
| Active yeast | 12.8a | 18.4a | 17.9a | 20.3a | 599a | 682a |
| Compost tea | 11.5bc | 13.1bc | 16.3b | 14.1c | 546c | 475c |
| Humic acids | 11.4bc | 10.0c | 17.6a | 20.2a | 592ab | 678a |
| Seaweed extract | 12.4ab | 18.1a | 12.7c | 12.6d | 426d | 422d |
| Ascorbic acid | 11.7abc | 13.5b | 17.4a | 17.4b | 585ab | 583b |

Means in the same column followed by the same letter are not significantly different according to DMRT at (P > 0.05).

### 3.3 Essential oil production

Applying active yeast still records the highest yield of the essential oil content and yield (0.93and 1.05 %; 0.167 and 0.215 mL $plant^{-1}$; 5.60 and 7.08 L $fed^{-1}$, in both seasons, respectively) comparing with the control. Some other applied treatments also were recorded similar essential oil measurements (essential oil % and essential oil yield per plant and per feddan) including humic acids, seaweed extract, and ascorbic acid (**Table 3**). The lowest essential oil percent and yield results ever resulted from the negative control treatment for all traits during the two seasons.

**Table 3. Effect of applied treatments on essential oil production of fennel plants.**

| Treatments | Essential oil (%) | | Essential oil yield (mL $plant^{-1}$) | | Essential oil yield (L $fed^{-1}$) | |
|---|---|---|---|---|---|---|
| | First season | Second season | First season | Second season | First season | Second season |
| Negative control | 0.47e | 0.54e | 0.039d | 0.047e | 1.31d | 1.59e |
| Control of NPK | 0.90ab | 1.03ab | 0.157ab | 0.210a | 5.29ab | 7.07a |
| Active yeast | 0.93a | 1.05a | 0.167a | 0.215a | 5.60a | 7.08a |
| Compost tea | 0.63d | 0.83d | 0.111c | 0.167c | 3.73c | 5.61c |
| Humic acids | 0.55e | 0.93abc | 0.097c | 0.187b | 3.26c | 6.28b |
| Seaweed extract | 0.89ab | 1.03ab | 0.114c | 0.129d | 3.83c | 4.34d |
| Ascorbic acid | 0.82bc | 0.98abc | 0.144b | 0.170c | 4.85b | 5.71c |

Means in the same column followed by the same letter are not significantly different according to DMRT at (P > 0.05).

**3.4 Essential oil constituents**

All treatments, including negative control had a positive effect on oil components (%).The first component recorded the highest percent ever in all treatments is α-pinene, followed by sabinene, then β-pinene, and then the rest of the components came in lower proportions (**Table 4**).For the most essential oil components of fennel plants, it recorded the highest percentages for each of α-pinene (3.8745 %), β-pinene (0.6100 %), myrcene (0.0803 %), limonene (0.0239 %), α-terpinene (0.1904 %), linalool (0.0646 %), camphor (0.2568 %), methyl chavicol (0.0710 %) and eugenol (0.0073 %).In the second rank was the treatment of active yeast as recorded the highest essential oil components percent for both 1,8 cineol (0.1554 %), linalool oxide (0.0320 %), isoestragole (0.0714 %) and β-caryophyllene (0.0082 %). Seaweed extract treatment ranked fourth as recorded the highest percentages for three oil components included citronellal (0.6996 %), verbenol (0.0003 %) and isoneral (0.0032 %).

**Table 4. Effect different treatments on essential oil constituents of fennel plants in the second season.**

| Identified compound | Test results of volatile oil compounds (Area, %) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Control | NPK control | Active yeast | Compost tea | Humic acids | Seaweed extract | Ascorbic acid |
| α-Pinene | 3.7900 | 2.8739 | 0.0670 | 3.4382 | 2.9356 | 3.5481 | - |
| Sabinene | 1.5368 | 1.2753 | 1.4226 | 1.3962 | 0.4136 | 1.4119 | 1.4168 |
| β-Pinene | 0.5810 | 0.5141 | 0.5158 | 0.5363 | 0.3584 | 0.5065 | 0.5043 |
| Myrcene | 0.0769 | 0.0839 | 0.0338 | 0.0750 | 0.5410 | 0.0506 | 0.0281 |
| Limonene | 0.0225 | 0.0072 | 0.0193 | 0.0215 | 0.0046 | 0.0198 | 0.0186 |
| 1,8 Cineol | 0.0081 | 0.0117 | 0.1554 | 0.0091 | 0.0232 | 0.0058 | - |
| α-Terpinene | 0.1676 | 0.1208 | - | 0.1530 | 0.0122 | 0.1522 | 0.1613 |
| Linalool oxide | 0.0090 | 0.0131 | 0.0320 | 0.0099 | - | 0.0050 | 0.0037 |
| Linalool | 0.0597 | 0.0367 | 0.0512 | 0.0568 | 0.0399 | 0.0502 | 0.0472 |
| Camphor | 0.2388 | 0.1865 | 0.2244 | 0.2164 | 0.0575 | 0.2256 | 0.2264 |
| Methyl chavicol | 0.0634 | 0.0052 | 0.0571 | 0.0447 | 0.0046 | 0.0542 | 0.0556 |
| Isoestragole | 0.0104 | 0.0270 | 0.0714 | 0.0353 | 0.0035 | 0.0616 | 0.0455 |
| Chavicol | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0267 | 0.0000 | 0.0000 |
| Bornyl acetate | 0.0058 | 0.0001 | 0.0054 | 0.0048 | 0.0040 | 0.0000 | 0.0000 |
| Eugenol | - | 0.0023 | - | - | - | 0.0043 | 0.005 |
| Methyl cinnamate | 0.0010 | 0.0009 | 0.0001 | 0.0007 | 0.0049 | 0.0000 | 0.0000 |
| β -Caryophyllene | 0.0036 | 0.0000 | 0.0082 | 0.0033 | 0.0014 | 0.0019 | 0.0016 |
| Citronellal | 0.5989 | 0.0004 | 0.2790 | 0.0001 | 0.0298 | 0.6996 | 0.0046 |
| Verbenol | 0.0000 | 0.0001 | 0.0001 | 0.0000 | 0.0001 | 0.0003 | 0.0001 |
| Isoneral | 0.0017 | 0.0003 | 0.0024 | 0.0008 | 0.0003 | 0.0032 | 0.0024 |
| Citral | 0.0001 | 0.0097 | 0.0000 | 0.0000 | 0.0013 | 0.0000 | 0.0000 |
| Geraneol | 0.0012 | 0.0001 | 0.0000 | 0.0009 | 0.0004 | 0.0001 | 0.0000 |

**3.5 Biochemical components**

**3.5.1 Chlorophyll content**

Ascorbic acid, active yeast, and seaweed extract treatments recorded the highest chlorophyll a and b contents without significant differences among them in both seasons (**Figs. 3 and 4**). The lowest chlorophyll contents obtained from control treatments in both seasons. All applied treatments gave higher chlorophyll content compared to the negative control with superiority to ascorbic acid in case of Chl. a, whereas active yeast in case of Chl. b.

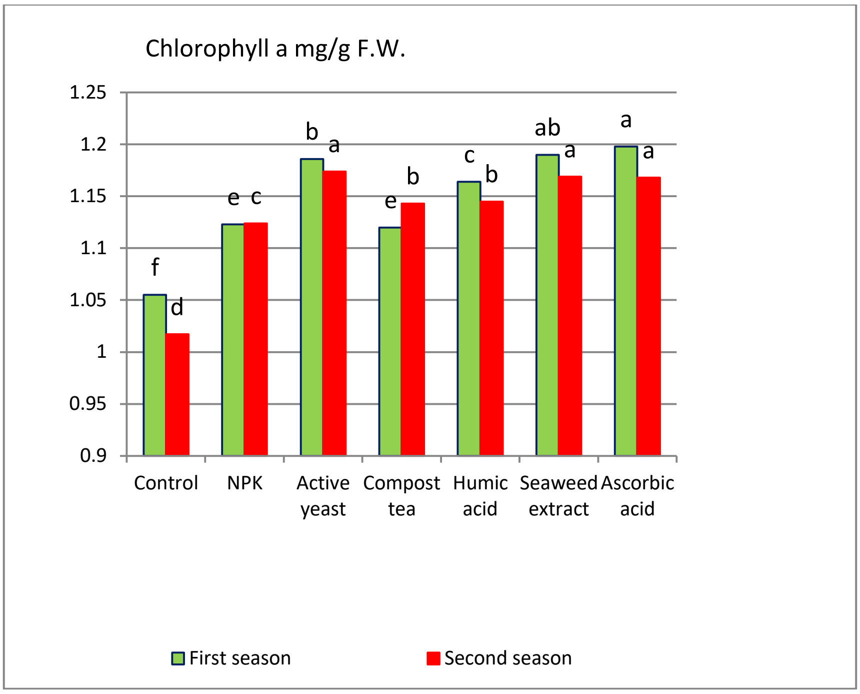


**Fig. 3. Impact of applied treatments on chlorophyll a of fennel plants during season one (S1) and season two (S2). Means in the same column followed by the same letter are not significantly different according to DMRT at (P > 0.05).**

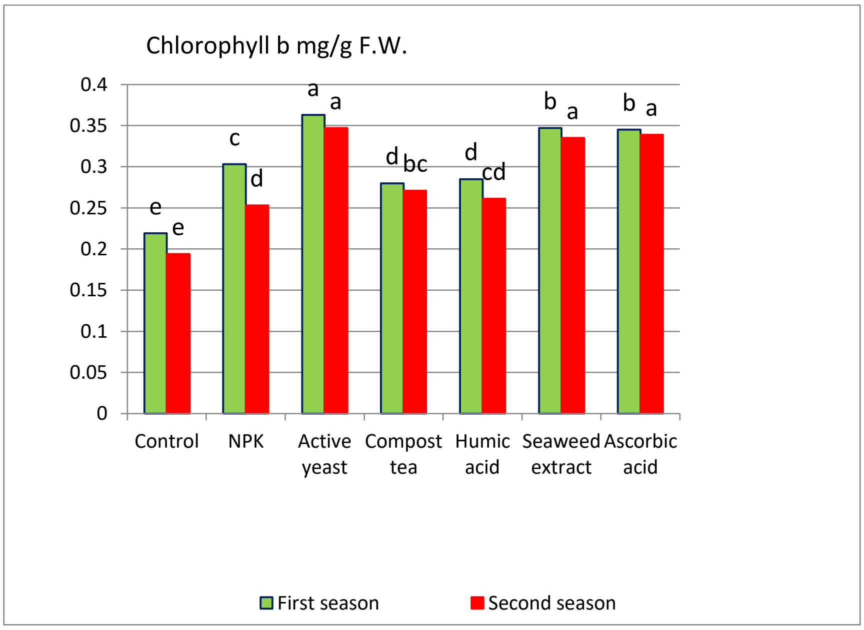


**Fig. 4. Impact of applied treatments on chlorophyll b of fennel plants during season one (S1) and season two (S2). Means in the same column followed by the same letter are not significantly different according to DMRT at (P > 0.05).**

### 3.5.2 Nitrogen, P and K contents

There was no clear trend after applying the treatments on the NPK content in fennel plants, where active yeast, compost tea, ascorbic acid or seaweed extract treatments recorded a similar result (**Table 5**). Ascorbic acid followed by active dry yeast, and humic acid treatments recorded the highest N-content without significant differences among them in the second season. Seaweed extract in the first season and NPK and ascorbic acid treatments in the second season recorded the highest P-content. The highest K-content obtained from plants treated with compost tea and active yeast in the first season, whereas active yeast followed by compost tea in the second one.

**Table 5. Effect of applied treatments on mineral contents of fennel plants.**

| Treatments | N content (%) | | P content (%) | | K content (%) | |
|---|---|---|---|---|---|---|
| | First season | Second season | First season | Second season | First season | Second season |
| Negative control | 1.57c | 2.12d | 0.133d | 0.200c | 1.97e | 2.04h |
| Control of NPK | 2.46b | 2.80bc | 0.250abc | 0.420a | 2.71b | 2.88c |
| Active yeast | 3.08a | 3.13a | 0.260abc | 0.360ab | 2.83a | 3.21a |
| Compost tea | 2.98ab | 2.90b | 0.183cd | 0.266bc | 2.91a | 3.09b |
| Humic acids | 2.30b | 3.13a | 0.220bc | 0.260bc | 2.70b | 2.54e |
| Seaweed extract | 2.35b | 2.22d | 0.320a | 0.360ab | 2.64bc | 2.39f |
| Ascorbic acid | 2.95ab | 3.36a | 0.283ab | 0.380a | 2.23d | 2.27g |

Means in the same column followed by the same letter are not significantly different according to DMRT at (P > 0.05).

### 3.5.3 Crude protein and total carbohydrates contents

The seed content of crude protein and total carbohydrates were presented in **Figs. 5 and 6.** The highest of crude protein content was recorded by active yeast followed by compost tea and ascorbic acid treatments in the first season and ascorbic acid followed by active yeast, humic acid, and compost tea treatments in the second one without significant differences among them. Active yeast followed by seaweed extract recorded the highest total carbohydrates content in both seasons comparing with the control treatment. The negative control recorded the lowest values of crude protein and total carbohydrates comparing with other applied treatments. The increase rate in crude protein and total carbohydrates in seeds after applying active yeast were 111 and 46%; 16.2 and 11.3% in both seasons, respectively.

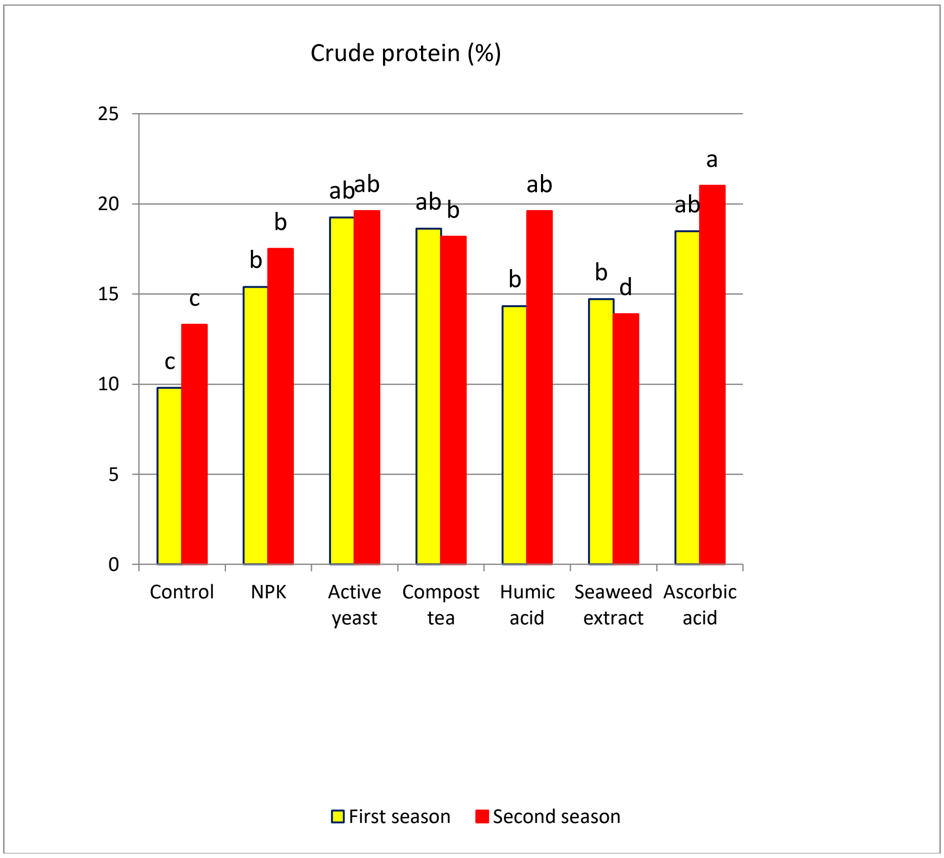


**Fig. 5. Impact of applied treatments on carbohydrates of fennel plants during season one (S1) and season two (S2). Means in the same column followed by the same letter are not significantly different according to DMRT at (P > 0.05)**

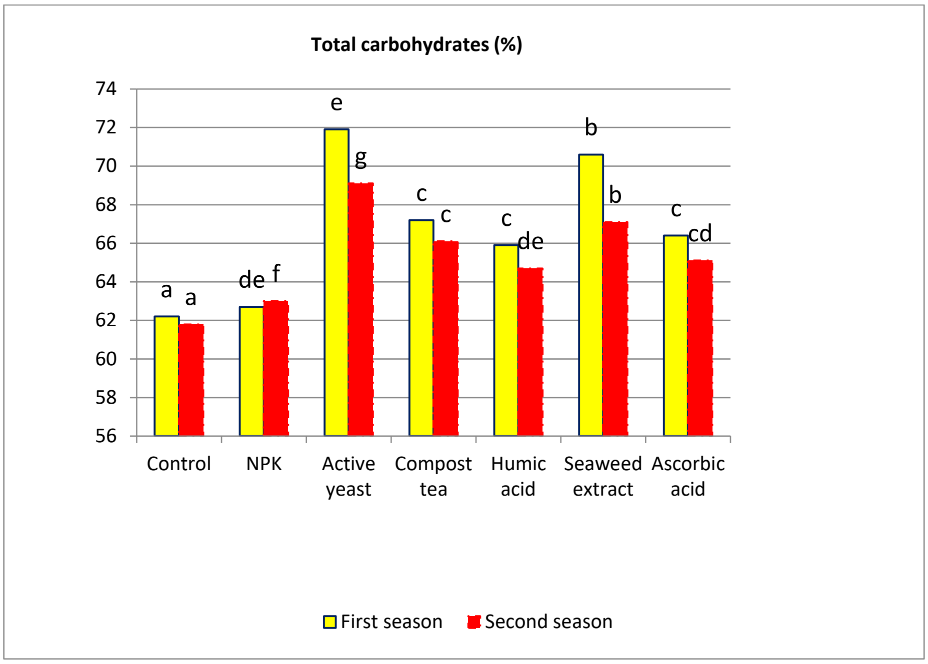


**Fig. 6. Impact of applied treatments on carbohydrates of fennel plants during season one (S1) and season two (S2). Means in the same column followed by the same letter are not significantly different according to DMRT at (P > 0.05).**

**4. Discussion**

This study was carried out to find which one of the applied treatments is the best alternative to NPK-mineral fertilizers in promoting the growth and productivity of fennel under salt-affected soil conditions. The investigated alternatives were active yeast, compost tea, humic acids, seaweed extract, and vitamin C or ascorbic acid. These alternatives to NPK-mineral fertilizers were foliar applied for producing a safe agro-product of fennel as a medical plant for human health, and for reducing our using of NPK-mineral fertilizers. Why these nutrients (NPK) are crucial for plant growth? Because they have many functions and very essential for plant growth due to their required N for leaf growth, P for development of roots and shoots, and K for the mobility of water throughout the plant (Roy et al. 2022).

The impact of applied alternatives on fennel vegetative growth was evaluated in the current study. The foliar application of active yeast gave the highest values of almost studied parameters including the number of branches per plant, dry weight of plant, seed oil yield, crude and total carbohydrates comparing with the other applied treatments and control. Yeast treatment was suggested to improve the growth and fruiting of fennel plants by promoting growth parameters, leaf pigments, nutritional content (N, P, and K), and enhancing fruit and oil productivity (El-Serafy et al. 2021). The current results were confirmed by previous studies on fennel by applying active yeast through enhancing the ratio of both essential oil and oil yield of fennel plant (Hegazi et al. 2009;Eisa 2016) or improving essential oil production of *Ocimum basilicum* by applying yeast at 4 g $L^{-1}$ (Nassar et al. 2015).The suggested mechanism of active yeast in promoting fennel productivity may back to its role as a growth promoter, because of its higher content of amino acids, which increase the production of essential oil with higher anethole and lower estragole proportions (El-Serafy et al. 2021).

For producing safe and healthy products from medicinal plants, the using of alternatives to NPK mineral fertilizers is a crucial issue especially for fennel plants as the top of the herbs and spices for the Egyptian exportation (El-Serafy et al. 2021). In the current study some selected alternatives were investigated and all candidates were carrying the same benefit as a safe alternative to NPK-mineral fertilizers can produce a healthy product. The difference between the used biostimulants may depend on the kind of these stimulants, applied dose and cultivation conditions (i.e., salinity stress). Active yeast was the most active applied biostimulants which improved cultivated plants under soil salinity conditions by improving the tolerance of fennel plants to salinity stress through different mechanisms. The main mechanism may involve preventing the decline in plant growth under such soil salinity stress through reducing the uptake of harmful ions (mainly $Na^+$ and $Cl^-$), increasing the uptake of essential ions (mainly $K^+$, $Mg^{++}$, and $Ca^{++}$), regulating osmotic status in plant, and protecting photosynthesis apparatus and its performance by maintaining photosynthetic pigments (Mohammadi et al. 2023).The production of fennel under saline soil conditions was confirmed by many studies by applying soil organic and biostimulants such as native phosphate solubilizing rhizobacterial isolates (Mishra et al. 2016),compost tea (Shawky et al. 2023), or due to the tolerance of different genotypes (Shafeiee and Ehsanzadeh 2019; Mohammadi et al. 2023).

What is the relationship between arid-saline soil stress and producing bioactive compounds in fennel seeds? It is thought that an increase in plant metabolites (mainly are well-known as bioactives) under such stresses (Castillo et al. 2022). The chromatography analysis of studied fennel in the current study showed that α-pinene, followed by sabinene, then β-pinene the main compounds found in this essential oil under such saline conditions. The main components in essential oil of fennel depend on the plant species, a wild or cultivated fennel, and cultivation conditions. it is found that essential oil from cultivated fennel plants contained higher amounts of estragole, whereas the anethole was dominant in the wild fennel (Abdellaoui et al. 2020). In the present study, several questions are still should be answered in our next studies such as to what extend can soil salinity impact the essential oil of fennel? Is soil salinity enhancer or antagonistic factor for producing high quality of fennel oil? Which biostimulant is the best in promoting the high-quality seeds of fennel under arid saline soil? Which approaches (organic, biostimulants, or genetic or nano-strategies) are most effective in producing the high-quality oil of fennel under arid saline soil? To what extend can the environmental stresses (mainly salinity and drought) control the production of plant bioactive compounds?

## 5. Conclusions

Cultivation of salt-tolerant medicinal/ aromatic fennel plants is a vital strategy for reducing the harmful effects of salinity under such arid saline soil conditions. Salt-tolerant plants can be a natural approach or by applying artificial bio- and/or organic-stimulants. According to the findings of this study, it is preferable to foliar spray active yeast or seaweed extract beside compost tea as safe alternatives to NPK-fertilizers without any defect in its productivity and/or essential oil quality. The suggested mechanism of this result may back to ameliorative effect of applied biostimulants under arid-saline soil stress. This stress induces or “enforces” cultivated plants with positive support from these biostimulants (with superiority to active yeast) to produce higher amounts of plant metabolites (mainly α-pinene, sabinene, and β-pinene in this study). These plant bioactives can play a pivotal role in protecting cultivated plants against environmental stresses (e.g., drought or salinity) and at the same time offering a great potential for the exploitation of nutraceutical and pharmaceutical compounds. This topic has several further needed investigations, which are still open questions.

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