



Growth, Productivity, and Essential Oil Content of Fennel Plants Treated with *Spirulina Platensis* Extract and Compost Tea Under Low Nitrogen Doses

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Abstract

The aim of this study was to find alternatives (even partial) to mineral nitrogen fertilization to reduce its harmful accumulation in the edible parts of fennel. Fennel (*Foeniculum vulgare*) is a perennial plant of the Apiaceae family grown for its edible shoots, leaves, and seeds. The present work was conducted in two successive seasons, in 2018/2019 and 2019/2020, at the farm of the Agricultural Botany Department, Faculty of Agriculture, Ain Shams University, Cairo, Egypt, to investigate the efficiency of application of two biostimulants—*Spirulina platensis* algae extract (SP) at 10% and compost tea (CT) at 6.72 ml L⁻¹—with partial doses (75 and 50%) of the recommended mineral nitrogen fertilizer dose on growth, photosynthetic pigments, fruit yield, and essential oil productivity. The results indicated that vegetative parameters, leaf number, branch number, shoot and bulb fresh weight, and shoot dry weight, as well as yield components such as 100-fruit weight and number of umbels per plant were significantly enhanced with application of SP as a foliar spray coupled with 75% of the recommended dose of nitrogen fertilizer (SP+75% N) as compared to other treatments. Photosynthetic pigments and total soluble carbohydrate were improved significantly when CT was applied as soil drenching coupled with 75% of the recommended N dose (CT+75% N). In this regard, a clear effect was noticed in terms of oil yield and fruit yield using SP and CT with a 75% N dose. It is concluded that using *Spirulina platensis* algae extract and compost tea as biostimulants coupled with only 75% of the recommended nitrogen fertilizer dose can be recommended for economical fennel production.

Keywords *Foeniculum vulgare* · Nitrogen fertilizer · Algae extract · Compost water extract · Oil yield

During recent decades, adding nitrogen fertilizer to boost agricultural production has been a common practice around the world. However, mineral nitrogen produces high levels of greenhouse gas emissions, which exacerbates climate change and global warming (Guo et al. 2022). Nitrogen-based fertilizers in agriculture have contributed substantially to N₂O emissions globally, with ~2% of fertilizer N returned to the atmosphere as N₂O, which has a global warming potential that is 300 times greater than that of carbon dioxide (Park et al. 2012; Coskun et al. 2017; Thompson et al. 2019).

Biostimulants are defined as organic substances or microorganisms that increase nutrient uptake, promote growth, improve crop quality, and enhance plant tolerance to biotic and abiotic stress. They directly affect plant physiological and metabolic processes (El-Serafy 2015, 2019; Caradonia et al. 2018; Rezaei-Chiyaneh et al. 2019).

Fennel, *Foeniculum vulgare*, is one of the most important medicinal and aromatic plants of the Apiaceae family, grown for its edible bulblike stem base and the blanched shoots, and is also used in flavoring. The seeds and extracted oil are used in the medical, pharmaceutical, chemical, food, and agricultural industries (Basem 2012; Shabbara et al. 2018). The FAO (Food and Agriculture Organization of the United Nations) estimated the production of anises, star anise, fennel, and coriander at almost 2,274,700 billion tones in 2020 (Schurr et al. 2022). Fennel's ripe and dry green-brown fruits, also known as seeds, are used alone or in preparations to cure a variety of ailments in folk reme-

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dies. They are also used to treat digestive and respiratory problems and have stimulant, sedative, lactagogue, and diuretic effects (Lucinewton et al. 2005; Ebeed et al. 2010; Mohamad et al. 2011; Figueredo et al. 2016).

Biostimulants can reduce the dependency on chemical fertilizers in the agricultural sector. They potentially mitigate climate change-induced stress and limit eutrophication (Hunter et al. 2017). Biostimulants can promote plant physiological processes (enhancement of crop nutrition, stress tolerance, yield quantity or quality) without harming the surrounding environment (Barone et al. 2018). One biostimulant is the water extract of compost, termed “compost tea” (CT). CT retains all the beneficial soluble bioactive components of compost, making it a potent source of plant-stimulatory and defensive compounds. CTs contain a significant quantity of total nutrients, with the majority being primary macronutrients. CTs have higher levels of humic substances and mineral nutrients than the composts from which they are formed (Ingham 1999; Eudoxie and Martin 2019). CT is used as a plant stimulant for improving growth, productivity, and phytopathogen control.

Spirulina platensis algae (SP) has also been suggested as an effective alternative to synthetic agricultural fertilizers. The extract of *Spirulina platensis* is a common commercial biostimulant. It has a high capacity to enhance plant growth

and development, which consequently improves crop development and productivity (Dias et al. 2016).

This study aimed to investigate the behavior of fennel plant's growth and yield as a consequence of reducing mineral nitrogen doses with SP algae and CT extracts.

Materials and Methods

Plant Material and Agricultural Practices

This research was carried out in the 2018/2019 and 2019/2020 seasons, at the experimental farm of the Agricultural Botany Department, Faculty of Agriculture, Ain Shams University, Cairo, Egypt (30° 06' 42" N 31° 14' 46" E). Seeds of fennel (*Foeniculum vulgare*) sp. dulce Mill were obtained from SEKEM company, Egypt. Seeds were planted September 15 and 19 in foam trays filled with a mixture of peat moss:vermiculite (1:1 v:v) in both the first and the second seasons. Thirty days after planting, seedlings were transplanted into the open field and planted on hills at a distance of 35 cm between hills and 60 cm within rows (soil and water analysis is shown in Tables 1, 2 and 3). After 5 weeks, seedlings were thinned to one plant per hill. Soil received 21,428 kg ha⁻¹ compost (Table 4) before plantation and the surface layer of all plots was mixed with calcium superphosphate (15.5% P₂O₅) at the rate of 142.85 kg ha⁻¹ (Wafaa et al. 2017). The experimental plot was divided into plots of 12 m² (3.0 × 4.0 m) to include four rows each. The experimental design was a simple system in randomized complete blocks with three replicates.

Table 1 Mechanical analysis of the experimental soil

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil texture
0–30	17	30	53	Loamy

Table 2 Chemical properties of the experimental soil

pH	Particle density (g cm ⁻³)	EC (ds/m)	Organic matter (%)	N (g/100 g) P (g/100 g)		Soluble cations (meq/l)				Soluble anions (meq/l)			
						Ca ⁺²	Mg ⁺²	Na ⁺	K ⁺	Cl ⁻	Co ₃ ⁻²	HCO ₃ ⁻	So ₄ ⁻
7.32	2.45	0.94	2.34	0.31	0.08	6.00	3.50	2.53	1.26	3.50	0.39	3.35	5.55

EC electrical conductivity

Table 3 Chemical properties of the irrigation water

pH	EC (ds/m)	Soluble cations (meq/l)				Soluble anions (meq/l)			
		Ca ⁺²	Mg ⁺²	Na ⁺	K ⁺	Cl ⁻	Co ₃ ⁻	HCO ₃ ⁻	So ₄ ⁻
6.95	0.39	1.00	1.20	1.43	0.23	1.20	0.00	0.64	2.02

EC electrical conductivity

Table 4 Chemical analysis of the used compost

pH	EC (ds/m)	Organic matter (%)	Organic carbon (%)	Macronutrients (%)			Micronutrients (mg/kg)			
				N	P	K	Fe	Mn	Zn	Cu
7	2.18	33.93	19.73	1.450	0.383	1.500	0.151	0.015	0.085	0.004

EC electrical conductivity

The levels of nitrogen were applied in plots at the rate of 385.5 kg ha^{-1} . Ammonia nitrate ($33.5\% \text{ NH}_4\text{NO}_3$) was used as nitrogen fertilizer, with the full recommended dose of nitrogen fertilizer as a control (Ctr). Treatments were performed for a total period of 7 weeks (three times per season, after 21, 45, and 65 days of transplanting). All treatments received a dose of potassium sulfate ($48\% \text{ K}_2\text{O}$) as a source of potassium at the rate of $95.23 \text{ K}_2\text{O kg ha}^{-1}$ split into two equal doses 36 and 57 days after transplanting and applied beside the plants.

Biostimulant Application

Compost Tea Extract

The compost used in preparing the CT was produced by the Saline Agriculture Unit of the Faculty of Agriculture, Ain Shams University, Egypt, by adopting routine standard methods. The obtained chemical analysis of the used compost is recorded in Table 5. CT was prepared by soaking 12 kg of fresh mature compost in 30 L of water at room temperature ($25 \pm 2^\circ \text{C}$) for 4 days with aeration to ensure plenty of oxygen in the mixture as it composes. Thereafter, 50 ml sugarcane molasses was added according to the method of Ingham (2005), with modifications described by Hegazy et al. (2015). After CT had been filtered through muslin cloth, representative samples were taken before each treatment and analyzed for determination of various chemical characteristics (Table 4). CT was applied as soil drenching at a concentration of 6.7 ml L^{-1} for each treated plot. Fennel plants received CT application three times per season, after 21, 45, and 65 days of transplanting.

Spirulina Platensis Algae Extract

Spirulina platensis (SP) algae extract was obtained from the Center of Genetic Engineering and Biotechnology (ACGEB), Ain Shams Univ, Egypt, with a concentration of 10%. Before treatment, representative samples of the SP algae extract were taken for chemical characteristic determination (Table 6). Fennel plants were foliar sprayed

three times per season after 21, 45, and 65 days from transplanting, with a concentration of 10 ml/L for each treated plot.

Treatments and Experimental Design

The experimental design was arranged in simple design in randomized complete blocks of five treatments with three replicates each. The treatments were arranged in plots as follows:

- CT + 75% of recommended dose of N (CT + 75% N)
- CT + 50% of recommended dose of N (CT + 50% N)
- SP + 75% of recommended dose of N (SP + 75% N)
- SP + 50% of recommended dose of N (SP + 50% N)

Additionally, a control plot (Ctr) received the full recommended dose of nitrogen fertilizer (100%) without any CT or SP treatment during either season.

Growth Attributes

Two successive samples were taken for both seasons, the first one at vegetative growth 90 days after transplanting, the second sample at the harvest stage (yield) 140 days after transplanting. Growth parameters of plant height (cm) and fresh and dry weight of shoot (g) were recorded at the harvest stage for both seasons.

Fruit Yield Measurements

Yield parameters studied in this experiment were 100-fruit weight (g), umbels number per plant, and fruit yield (kg ha^{-1}).

Essential Oil Determination

Fennel essential oil percentage was extracted from air-dried mature fruit by hydro distillation for 3 h using a modified Clevenger apparatus according to the British Pharmacopoeia (1963)

Table 5 Chemical analysis of the used compost tea (CT) according to time of application

Samples	Macronutrients (mg/L)			Macronutrients (mg/L)		
	N	P	K	Fe	Mn	Zn
CT1	168	3.977	24.83	0.125	0.1749	0.2894
CT2	196	3.974	24.06	0.1322	0.1825	0.2156
CT3	166	3.942	28.26	0.1558	0.1493	0.3207

Table 6 Chemical analysis of the used *Spirulina platensis* (SP) algae extract

Samples	Macronutrients (mg/L)			Micronutrients (mg/L)		
	N	P	K	Fe	Mn	Zn
SP	294	5.033	16.62	0.168	0.1235	0.2271

Essential oil percentage =

$$\left(\frac{\text{oil volume in the graduated tube}}{\text{sample dry weight}} \right) \times 100$$

Photosynthetic Pigments

Samples of fennel leaves (2–6) were randomly collected at vegetative growth of each treatment separately for chlorophyll determination, as described by Moran (1982). Fresh leaves (100 mg) were ground with 10 ml N,N-dimethyl formamide and the extractions were then incubated in a dark fridge overnight before analysis using a UV-VIS spectrophotometer (Model CT200; Randolph, NJ, USA). According to Lichtenthaler and Wellburn (1983), the data were expressed as mg/g fresh weight.

Chlorophyll a conc. = $9.784 \times A_{664} - 0.990 \times A_{647}$

Chlorophyll b conc. = $21.426 \times A_{647} - 4.650 \times A_{664}$

Carotenoids conc.(mg/g) =

$$\left[\frac{(4.695 \times A_{470}) - 0.268(\text{Chl a} + \text{b})(\text{vol. of extract})}{(\text{sample weight} \times 1000)} \right]$$

Chlorophyll a, b, and carotenoid concentrations were measured at wavelengths of 664, 647, and 470 nm, respectively, and calculated and expressed in mg g^{-1} FW using the formula of Shlyk (1971).

Amino Acids Determination

Amino acids in fennel bulbs were measured following the colorimetric method according to Jayaraman (1985) using the ninhydrin reaction. Amino acids in fennel bulbs were extracted by soaking 1 g of sample in 80% ethanol. Thereafter, 1 ml of sample extract was added to 3 ml distilled water and mixed well with 1 ml of ninhydrin reagent. The mixture was heated in a water bath for 15 min. After cooling, 50% ethanol was added to reach a volume of 10 ml and the absorbance was determined at 570 nm. Total amino acid concentration was standardized using glycine.

Total Soluble Carbohydrates Determination

Total soluble carbohydrates concentration in bulbs was assessed as recommended by Hedge and Hofreiter (1962) using the anthrone reagent method. Total soluble carbohydrates were extracted by hydrolysis of 0.1 g of dried sample with 2.5 N HCl in a water bath for 3 h, then the pH was adjusted to 7 and distilled water added to 100 ml. Taking 1 ml of sample extract with 4 mL of frozen anthrone reagent, this was heated in a water bath followed by cooling, and the developed green color was measured at 630 nm.

Statistical Analysis

Data were statistically analyzed using analysis of variance (ANOVA) with the CoStat program. Means were compared using Duncan's test at the $P \leq 0.05$ level. Results were presented as means $\pm$ standard deviation (SD).

Results

Plant Growth

In order to reduce the recommended dose of mineral nitrogen fertilizer applied to fennel plants, two biostimulants (*Spirulina platensis*, SP, and compost tea, CT) were used

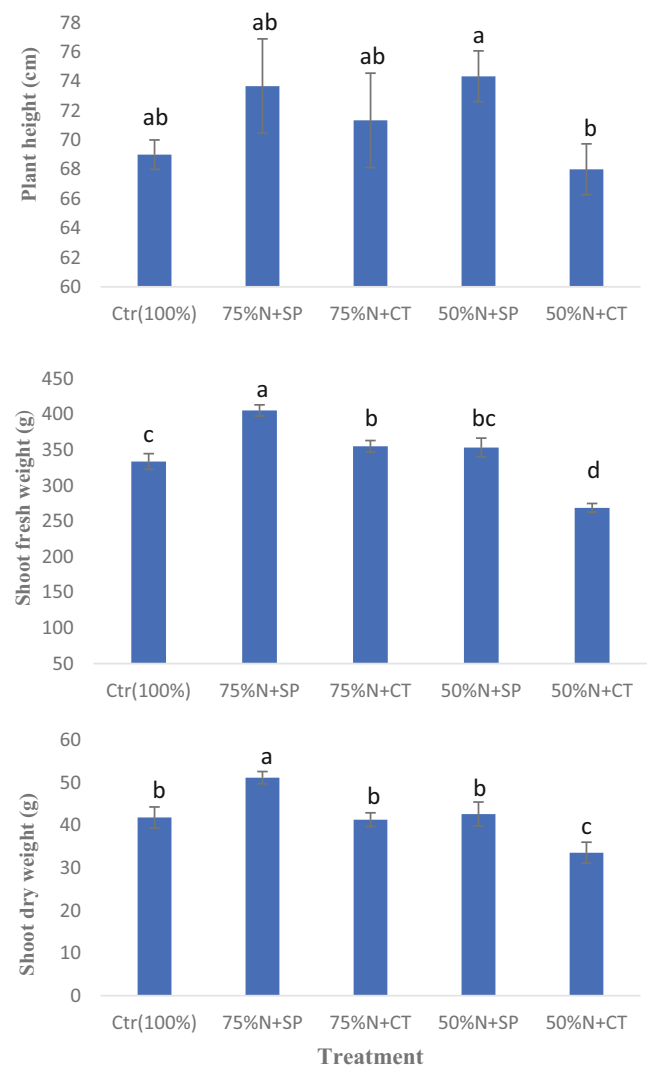


Fig. 1 Effect of different nitrogen doses with *Spirulina platensis* (SP) or compost tea (CT) on some vegetative growth characteristics of fennel plants during the first season. Ctr control. Each column represents the mean of three replicates $\pm$ SD. Significant differences ($P \leq 0.05$) between treatments are indicated by different letters

Table 7 Effect of different nitrogen doses with *Spirulina platensis* (SP) or compost tea (CT) on some vegetative growth characteristics of fennel plants during the first season

Treatment	Plant height (cm)	Leaf no./plant	Branch no./plant	Shoot FW (g)	Shoot DW (g)	Bulb FW (g)	Bulb DW (g)
Ctr (100%)	69.0 ab ± 1.0	64.0 b ± 2.6	9.0 b ± 1.0	333.6 c ± 10.9	41.8 b ± 2.4	106.5 b ± 4.1	7.5 a ± 0.4
75% N+SP	73.7 ab ± 3.2	70.0 a ± 3.5	12.0 a ± 1.0	405.3 a ± 7.8	51.2 a ± 1.4	121.8 a ± 5.6	8.3 a ± 0.9
75% N+CT	71.3 ab ± 3.2	70.7 a ± 3.4	9.0 b ± 1.0	354.9 b ± 8.1	41.3 b ± 1.6	85.7 d ± 5.3	6.8 ab ± 0.9
50% N+SP	74.3 a ± 1.7	54.7 c ± 3.0	10.0 b ± 1.0	353.3 bc ± 13.1	42.6 b ± 2.8	96.0 c ± 4.6	7.5 a ± 2.0
50% N+CT	68.0 b ± 1.7	36.0 d ± 3.6	8.3 b ± 0.5	268.6 d ± 6.1	33.5 c ± 2.4	66.1 e ± 5.1	4.8 b ± 0.2

FW fresh weight, DW dry weight, Ctr control

Significant differences ($P \leq 0.05$) between treatments are indicated by different letters**Table 8** Effect of different nitrogen doses with *Spirulina platensis* (SP) or compost tea (CT) on some vegetative growth characteristics of fennel plants during the second season

Treatment	Plant height (cm)	Leaf no./plant	Branch no./plant	Shoot FW (g)	Shoot DW (g)	Bulb FW (g)	Bulb DW (g)
Ctr (100%)	34.7 b ± 3.21	55.6 b ± 1.52	7.7 ab ± 0.57	327.4 b ± 7.05	36.8 c ± 2.40	83.4 b ± 3.62	6.3 b ± 0.52
75% N+SP	42.3 a ± 1.15	60.3 a ± 2.08	8.7 a ± 0.57	412.2 a ± 16.76	57.0 a ± 3.16	104.1 a ± 3.51	7.8 a ± 0.60
75% N+CT	34.3 b ± 2.30	59.3 ab ± 1.52	6.3 b ± 0.57	339.7 b ± 15.29	41.7 b ± 2.34	68.2 c ± 4.49	5.8 b ± 0.40
50% N+SP	30.7 c ± 1.52	47.0 c ± 3.60	6.7 b ± 0.57	278.6 c ± 12.19	30.0 d ± 2.61	54.1 d ± 6.13	4.1 c ± 0.17
50% N+CT	27.3 d ± 1.52	29.3 d ± 2.08	7.7 ab ± 1.15	232.6 d ± 15.99	25.6 e ± 1.96	45.4 e ± 2.01	3.3 d ± 0.41

FW fresh weight, DW dry weight, Ctr control

Significant differences ($P \leq 0.05$) between treatments are indicated by different letters

with different N doses (75 and 50% of the recommended dose). Growth characteristics of fennel plants treated with these biostimulants are presented in Fig. 1 and Tables 7 and 8. Generally, the data showed that plant height (cm) was not significantly affected by reducing the N dose with different treatments. Meanwhile, the number of leaves showed a significant increase in plants that received 75% N and were treated with both SP and CT as compared to control plants (100% N). The branch number in plants treated with SP+75% N was higher than the number of branches in all other treatments. The same trend was found in both fresh and dry weight of fennel shoots, as treating plants with 75%+SP increased plant weight. Although the bulb fresh weight showed significant increment in plants receiving 75% N+SP when compared with control and other treatments, the bulb dry weight was hardly affected by treatments.

Fruit Characteristics and Total Yield

Like plant growth parameters, fruit yield was also clearly changed and affected by the application of biostimulants in comparison to the control. The weight of 100 fruits and fruit yield per hectare were significantly improved with application of 75% N and SP and 75% N and CT compared to control at a rate of 28.12 and 10.41% for 100-fruit weight and 16.95 and 5.25% for fruit yield, respectively. Also, 75% N and SP significantly increased the number of umbels per plant compared with control; this increase was estimated at 21.83% (Table 9; Fig. 2).

Essential Oil

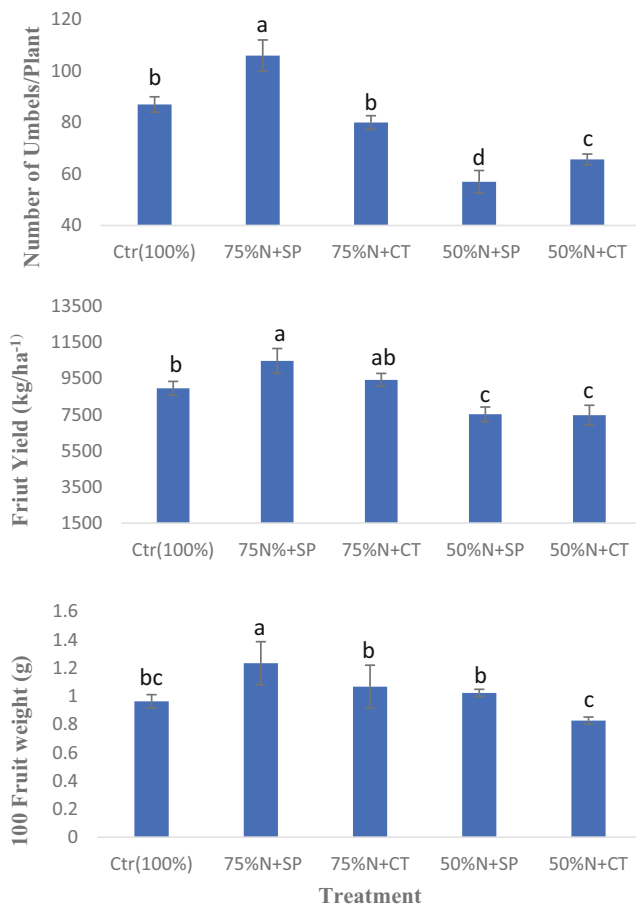
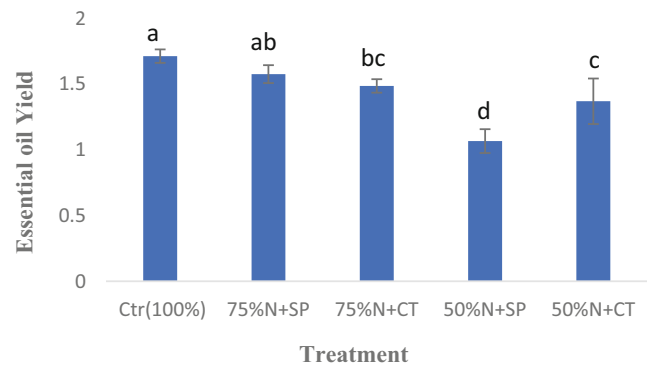
Essential oil percentage and characteristics were not improved by biostimulant application (Fig. 3). Foliar spray of SP+75% N and soil drenching with CT+75% N gave a similar total essential oil percentage to control plants.

Table 9 Effect of different nitrogen doses with *Spirulina platensis* (SP) or compost tea (CT) on number of umbels per plant and fruit yield per plant of fennel plants (first season, second season)

Treatment	Umbel no./plant Season 1	Fruit yield (kg/plant)	Umbel no./plant Season 2	Fruit yield (kg/plant)
Ctr (100%)	87 b ± 3.0	0.1884 c ± 0.0047	77.3 a ± 6.42	0.2501 b ± 0.0052
75% N+ SP	106 a ± 1.0	0.2200 a ± 0.0050	79.0 a ± 3.60	0.2869 a ± 0.0065
75% N+ TC	80 c ± 2.6	0.1980 b ± 0.0044	70.3 a ± 8.50	0.2376 b ± 0.0123
50% N+ SP	57.0 e ± 4.3	0.1586 d ± 0.0035	39.7 b ± 1.52	0.1292 d ± 0.0107
50% N+ TC	65.6 d ± 2.0	0.1566 d ± 0.0031	43.7 b ± 3.51	0.1470 c ± 0.0025

FW fresh weight, DW dry weight, Ctr control

Significant differences ($P \leq 0.05$) between treatments are indicated by different letters

**Fig. 2** Effect of different nitrogen doses with *Spirulina platensis* (SP) or compost tea (CT) on some yield parameters at the mature stage of fennel plants during the first season. Ctr control. Each column represents the mean of three replicates ± SD. Significant differences ($P \leq 0.05$) between treatments are indicated by different letters**Fig. 3** Effect of different nitrogen doses with *Spirulina platensis* (SP) or compost tea (CT) on essential oil percentage during the first season. Ctr control. Each column represents the mean of three replicates ± SD. Significant differences ($P \leq 0.05$) between treatments are indicated by different letters

Photosynthetic Pigments

The data presented in Fig. 4 indicate that the concentrations of photosynthetic pigments (chlorophyll a, b, and carotenoids) recorded their highest values when plants received 75% N+CT. However, statistically, control plants have the same photosynthetic pigment concentration values as 75%+CT. Other treatments did not elicit any significant improvements, except plants treated with 50% N+CT, which showed a significant increase in chlorophyll b concentration.

Total Soluble Carbohydrate

The results presented in Fig. 5 showed that there was a significant increase in total soluble carbohydrates percentage when plants received 75% N+CT (37.59%), while control plants showed no significant difference to plants with 50% N+CT which followed the control plants (100% N).

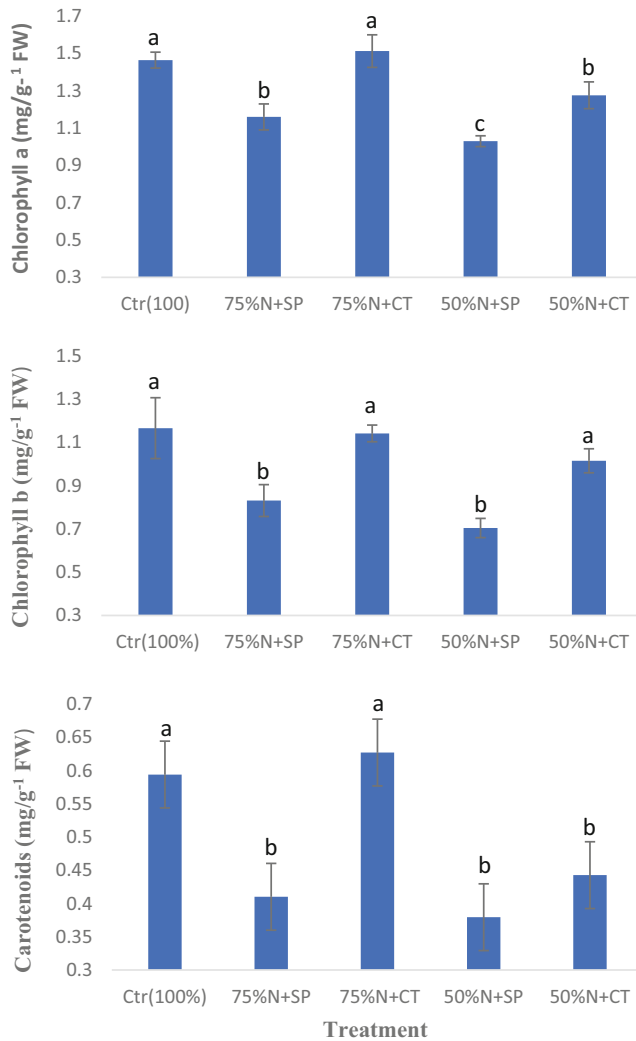


Fig. 4 Effect of different nitrogen doses with *Spirulina platensis* (SP) or compost tea (CT) on chlorophyll a, chlorophyll b, and carotenoids at the vegetative growth stage of fennel plants during the first season. Ctr control. Each column represents the mean of three replicates $\pm$ SD. Significant differences ($P \leq 0.05$) between treatments are indicated by different letters

The lowest soluble carbohydrates percentage was recorded with plants treated with SP + 50% N.

Amino Acids

Figure 6 also indicates that the highest amino acid percentage was obtained by adding 75% N + SP, while plants receiving 50% N + SP showed no significant difference to control plants and both have a higher respective percentage of amino acids than CT treatments.

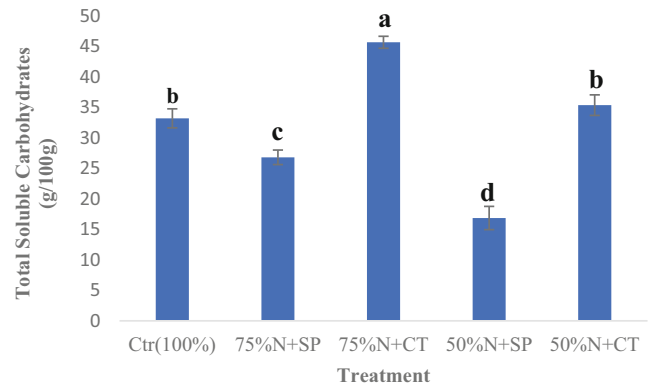


Fig. 5 Effect of different nitrogen doses with *Spirulina platensis* (SP) or compost tea (CT) on concentrations of total soluble carbohydrates at the vegetative growth stage of fennel plants during the first season. Ctr control. Each column represents the mean of three replicates $\pm$ SD. Significant differences ($P \leq 0.05$) between treatments are indicated by different letters

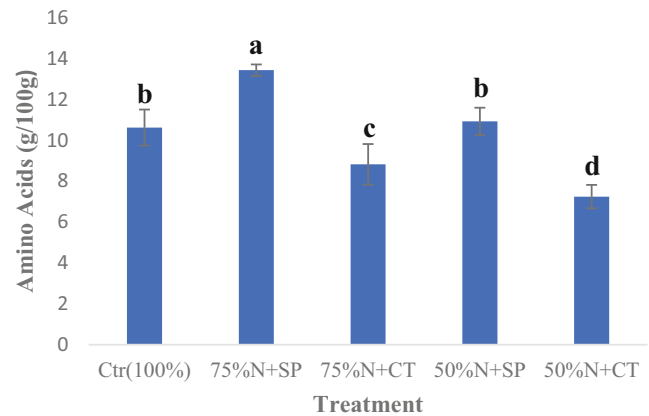


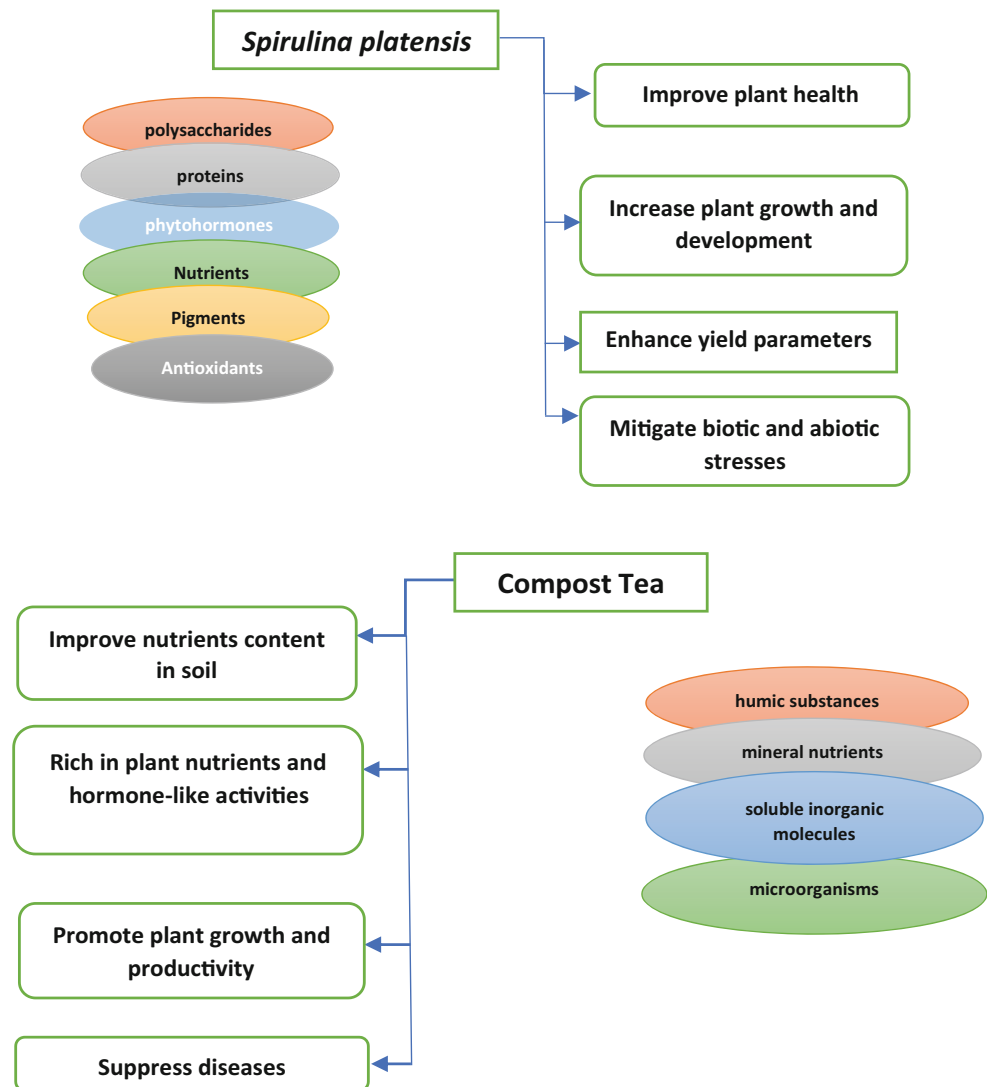
Fig. 6 Effect of different nitrogen doses with *Spirulina platensis* (SP) or compost tea (CT) on concentrations of amino acids at the vegetative growth stage of fennel plants during the first season. Ctr control. Each column represents the mean of three replicates $\pm$ SD. Significant differences ($P \leq 0.05$) between treatments are indicated by different letters

Discussion

Despite the necessity of nitrogen fertilizers, the dependency on mineral N fertilizers (annually, nearly 120 million tons of nitrogen are applied to agricultural fields) has shifted the natural balance, leading to many damaging and long-lasting environmental and ecological consequences (FAOSTAT 2017). Finding alternative natural resources, even for partial substitution of mineral nitrogen fertilizers, aims to preserve soil and atmospheric components and lead to environmental sustainability.

Blue-green algae (*Spirulina platensis*) plays a key role in improving the growth of many plants when applied as a biostimulant. This evidence was clearly shown in the growth criteria of fennel plants that received low N doses

Fig. 7 Illustration of *Spirulina platensis* and compost tea components and their impact on plant status



and treatment with biostimulants. CTs contain a significant quantity of total nutrients, with the majority being primary macronutrients. CT shows a similar trend to SP when applied to plants receiving low, partial N doses. Regardless of the purpose of CT use, its positive effects on crop growth and soil fertility, whilst controlling pest and disease, make it a contemporary sustainable tool aligned to organic agriculture (Fig. 7).

Biostimulant applications clearly enhanced the growth and yield of fennel plants under the lower-than-recommended doses of nitrogen fertilizer (75%). The potential of biostimulants as an alternative to chemical fertilizers has been reported by many scholars due to their ability to increase nutrient-use efficiency in plants without causing damage to the environment (Arnau and Richard 2016; Barone et al. 2018; Kopta et al. 2018). Results have indicated that foliar application of SP extract significantly improved fennel growth and fruit yield when applied with 75% of the recommended N dose in comparison to the con-

trol. The stimulatory effect of foliar spray of SP could be due to its high content of macro- and microelements as well as the high content of free amino acids, which can stimulate plant metabolism and thus raise the synthesis of proteins and some hormones responsible for plant growth (Mógor et al. 2018) to directly improve plant growth.

The algae extract application promoted fennel plant performance in both seasons, as represented by plant height and fresh and dry weights. SP has many beneficial effects on plants as it contains the growth-promoting hormones indole-3-acetic acid (IAA) and cytokinin, trace elements of Fe, Cu, Zn, Co, Mo, Mn, and Ni, and vitamins (Challen and Hemingway 1966).

Similarly, the number umbels per plant as well as fruit and oil percentage showed a significant increase with SP+75% N, which might be attributed to the particular molecular structure of SP extract which has an important and vital role in increasing plant production and increasing the capacity of the plant to resist various stress condi-

tions (Aly and Esawy 2008; Ogbonda et al. 2007; Anitha et al. 2016). These results were also confirmed by Wafaa et al. (2017), who found that foliar spray of SP extract on fennel plants had a significant and marked effect on growth parameters, fruit characteristics, and oil percentage as compared to untreated plants. On the other hand, CT has the capacity to stimulate plant growth and productivity via plant nutrition and hormone-like activities. The results of the current study show no significant effect on plant productivity, including number of umbels/plant, 100-fruit weight, fruit yield, and oil percentage in plants receiving CT with 75% of the recommended N dose in comparison to control plants that received the full recommended dose of N. These results may be due to the ability of water-based CT to enhance the uptake and accumulation of nutrient elements in the plant (Rodríguez-Ortíz et al. 2006) as a result of its content of organic extracts which develop the root system of plants and improve nutrient uptake (Abd El-Kader and El-Shaboury 2013; Meshref et al. 2010). Moreover, similar to compost, CT can also improve soil quality by altering the physicochemical properties, water-holding capacity, and biodiversity of soil (Scheuerell and Mahaffee 2002), which leads to improved plant productivity.

The stimulatory effect of blue-green alga extract on biochemical components of fennel could be due to its high content of macro- and microelements. However, micronutrient fertilizer only has the effect of encouraging roots to absorb more nutrients from the soil medium, as mentioned by (Shaaban and Mubarak 2000). Also, SP extract contains a high percentage of amino acids (about 62% free amino acids), essential oils, fiber, protein, and ash content in seeds (Ehsanipour et al. 2012). Blue-green algae extract contains the whole spectrum of natural mixed carotene and xanthophyll phytopigments, which are considered as the richest natural source of vitamin B12.

Eudoxie and Martin (2019) reported that CT enhanced soil quality through increased microbial diversity and nutrient availability to increase crop growth and, importantly, yield. Several mechanisms have been postulated for the altered effects associated with CT, including the increased availability and uptake of nutrients. Secondary mechanisms include increased soil organic matter and nutrient turnover via microbial activity. Stimulatory effects occur in plants through plant growth regulators, humic substances, and other biostimulatory compounds present in CTs. Further benefit is derived through the suppression of plant pathogens, which provides the best opportunity for maximum growth.

Conclusion

It can be concluded that using biostimulants (*Spirulina platensis* or compost tea) to reduce mineral nitrogen doses may improve or preserve the vegetative characteristics and yield components of fennel plant. Adding SP or CT to fennel plants not only enables reduction of nitrogen dose but also improves plant nutritional status and essential oil content. Reducing mineral N fertilizers decreases the accumulation of nitrogen derivatives in the edible parts of fennel plant and maintains the sustainability of soil and environment. These results lead to the conclusion that addition of SP or CT saved about 25% of the recommended nitrogen fertilizer dose and enhanced fennel yield quantity and quality. Therefore, farmers could reduce the agricultural cost by this means.

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Conflict of interest A.A. Shawky, G.S. Khalifa, A. Hegazi, and M. ElSherif declare that they have no competing interests.

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