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EFFECT OF ALGAE EXTRACTS ON GROWTH, YIELD, AND ESSENTIAL OIL OF FENNEL (*Foeniculum vulgare* Mill.) PLANT

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ABSTRACT: Algae are natural bioactive materials rich in protein, lipids, carbohydrates, vitamins, and elements (Fe, Mn, Zn, Cu, B, and Mo) hence; they have beneficial effects on plant growth. A field experiment was conducted to evaluate the influence of foliar spraying with different concentrations (0.5, 1.0, and 2.0 ml l^{-1}) of two algal species extracts including *Amphora coffeaeformis* (Bacillariophyta) and *Pediastrum boryanum* (Chlorophyta) on growth parameters, fruits yield, essential oil productivity, and chemical constituents of fennel plant during the two successive seasons (2019/2020 and 2020/2021). The results indicated that all treatments significantly affected all parameters compared to the control. Among the different concentrations used, the highest rate (2.0 ml l^{-1}) of *Pediastrum boryanum* caused the maximum significant increase in plant height, number of branches, number of umbels, fruits yield (g)/plant, the weight of 1000 fruits (g), essential oil percentage, yield (ml)/plant, components as well as nitrogen, phosphorus and potassium percentage in dry fruits. Therefore, using algae (*A. coffeaeformis* and *P. boryanum*) extract for enhancing yield and essential oil production is recommended.

Keywords: fennel, algal extract, essential oil, yield, *Amphora coffeaeformis*, *Pediastrum boryanum*.

INTRODUCTION

Fennel is one of the important medicinal and aromatic plants which belongs to family Apiaceae (Umbelliferae) family. Actually, it is found growing wild in many parts of the world and grown commercially in many countries like China, Russia, India, and Japan (Damjanovic *et al*., 2005). It is classified into two subspecies *vulgare* and *piperitum* which mostly include wild forms (Ferioli *et al*., 2017). Subspecies *vulgare* is the most important cultivated fennel cultivars. Fennel fruits are highly aromatic with a characteristic aniseed flavor and traditionally, the aromatic dried ripe fruits (commonly called seeds) have a long history of herbal uses in folk medicine as an analgesic, anti-inflammatory, diuretic, carminative, antispasmodic agent, stimulant and/or sedative to increase lactation in nursing mothers (Oktay *et al*., 2003 and Coşge *et al*., 2008). Fennel fruits (seeds) are used as a flavoring agent in food industries such as pastries, bread, pickles, cheese, and liqueurs as well as in cosmetic and pharmaceutical products. Mature fennel fruits contain 2-6% essential oil which has antimicrobial, antioxidant, and hepatoprotective activities (Lucinewton *et al*., 2005 and Miguel *et al*., 2010).

Recently, microalgae attracted the interest of farmers and agrochemical industries, due to their bio-stimulant and biofertilizer properties which are considered environment-friendly organic fertilizers. They are used in different applications in

agriculture such as improving crop quality and yield production, seed priming, plant growth regulators, crop protection products, and enhanced rooting. Moreover, they could be applied as partial substitution synthetic fertilizers. Further, it could be applied to tolerate drought and salinity (El-Sayed *et al.*, 2018), as well as biological control (Abdel-Maguid *et al*., 2004, Ronga, *et al*., 2019 and Abdel-Kader *et al*., 2021).

Several types of research were done on using algal extracts in the alleviation of abiotic stresses (El-Shahawy and El-Sayed, 2018), beside their uses in plant nutrition and growth enhancement (Abdel-Maguid *et al*., 2004; Shabaan, 2001; and Tarraf *et al*., 2015).

Lately, many algae have been explored for their effect on cultivation, soil, and the environment, and novel industrial processes have been developed for extensive-scale cultivation and production of algal biofertilizers. Algal are natural bioactive materials and reservoirs of nutrients as they are rich in different components (minerals, protein, lipids, carbohydrates, hormones, amino acids, vitamins, and microelements) which modify and increase plant growth, offer significant yield increment, declining costs, wasteland utilization for cultivation, and environmental improvement and protection hence achieving agricultural sustainability. Diverse species of marine algae not only provide food, but also produce extracts that are used in many foods, pharmaceutical, cosmetic, dairy, and many industrial applications. Algae also can be used to make biodiesel, biobutanol, bioethanol, and hydrogen gases (Raja *et al*., 2013).

Amphora sp. is a microalga, marine and freshwater diatom belonging to the Catenulaceae family which produces biochemical components like protein, carbohydrates, and lipids (Rajaram *et al*., 2018). Moreover, *Amphora sp.* extract is rich in chlorophyll, carotenoids such as β-carotene, proteins, polyphenols, ashes, macro and micro-elements especially phosphorous, iron, and zinc, as well as antioxidants (Chtourou *et al*., 2015 and El-Shahawy and El-Sayed, 2018). The exogenous application of *Amphora coffeaeformis* extract can alleviate the harmful effect of drought stress on lupine plants (Mogazy *et al*., 2020). *Pediastrum boryanum* is a potentially rich source of natural antioxidants and free phenolic compounds which can be applied to various fields (Corrêa da Silva *et al*., 2020).

Many forms of algae have beneficial effects on plants (Abdel-Mawgoud *et al*., 2010). Microalgae have gained much wider acceptance in different applications of agriculture, such as crop protection products, a foliar spray as plant bio-stimulants, seed treatments, and plant growth regulators, enhancing rooting, higher crop yields and quality besides increasing plant tolerance to salinity and drought (Ronga *et al*., 2019) and can also be applied in conjunction with synthetic fertilizers or as an alternative technique.

Algal as organic fertilizers can be directly applied to the soil or as a foliar spray to improve plant growth, quality as well as the chemical composition of secondary metabolites (Spinelli *et al*., 2009 and Tursun, 2022). Applying algae extract as a foliar spray on plants was recommended to increase the growth parameters of green gram (Pramanick *et al*., 2013) and garlic (Shalaby and El-Ramady, 2014) plants; Photosynthetic pigments (Latique *et al*., 2013) on bean and snap bean plants (Abo El-Yazied *et al*., 2012); total yield of cucumber (Sarhan *et al*., 2011) on garlic plants (Mohsen, 2012) and fenugreek (Tarraf *et al*., 2015). Therefore, the main objective of this work was to evaluate the role of algae in improving growth parameters, fruits yield, chemical constituents, and essential oil productivity of the fennel plant.

MATERIALS AND METHODS

Experimental design and treatments:

An experiment was set up during the two successive winter seasons of 2019/2020 and 2020/2021 at EL-Quassasin Experimental

Farm, Hort. Res. Inst. ARC, Ismailia Governorate, Egypt, to study the influence of foliar spray with different algae extract concentrations on growth, yield and essential oil productivity of fennel plants.

The experimental design was allocated in randomized complete blocks with three replicates. The plots were 4 × 2.4 meters in dimensions, with 4 rows at a distance of 60 cm between them.

This experiment included 7 treatments as follows:

1. Control (full dose of NPK)
2. *Amphora coffeaeformis* extract at 0.5 ml l^{-1}
3. *Amphora coffeaeformis* extract at 1.0 ml l^{-1}
4. *Amphora coffeaeformis* extract at 2.0 ml l^{-1}
5. *Pediastrum boryanum* extract at 0.5 ml l^{-1}
6. *Pediastrum boryanum* extract at 1.0 ml l^{-1}
7. *Pediastrum boryanum* extract at 2.0 ml l^{-1}

Plant materials:

Fennel fruits (seeds) of local variety were obtained from the Experimental Farm of Medicinal and Aromatic Plants Research Department, El-Qanater El-Khairia, El-Qalubia Governorate, Egypt and were sown on November 1st, 2019 and 2020, at a space of 25 cm. After three weeks from sowing, germinated plants were thinned to two plants/hill. Fennel plants were fertilized at the recommended doses of chemical fertilizers. All calcium superphosphate (15.5% P_2O_5) amount was added with soil preparation. Nitrogen (20.5% N), as ammonium sulfate was applied in two equal additions, the first one after plant thinning (three weeks after sowing) and the second one was added at the beginning of flowering with the full dose of potassium sulfate (48.5% K_2O). Plants received normal agricultural practices whenever they needed.

Algae extract:

The *in- situ* made extracts of *Amphora coffeaeformis* and *Pediastrum boryanum* algae extract were obtained from Algal Biotechnology Unit, National Research Centre (NRC), Egypt. Both of them were early isolated from the local irrigation water of Egypt. The preparation of algae extracts was described by El-Sayed *et al.* (2018) and they were used as a foliar spray at concentrations of 0.5, 1.0, and 2.0 ml l^{-1} for each one. The first application was after 30 days from sowing and the second one was applied one month thereafter. The composition of the original algal is listed in Tables (a and b).

Physical and chemical properties of the experimental soil analyses were done at Soils, Water and Environ. Res. Inst. Lab., ARC, Egypt and listed in Table (c) according to the methods of Sparks (1996).

Data recorded:

Fennel plant fruits were harvested at a maturity of 70% in both seasons. Samples were taken from each replicate for estimating growth parameters [plant height (cm), number of branches/plant, number of umbels/plant, fruits yield (g)/plant, and the weight of 1000 fruits (g)].

Essential oil production:

As for the essential oil percentages, the water distillation method described in British Pharmacopeia (1963) was performed. The obtained essential oil from the ripe fruits (seeds) produced in the second season was analyzed in the Laboratory of Medicinal and Aromatic Plants Research Department, Horticulture Research Institute, ARC, Egypt using Ds Chrom 6200 Gas Chromatograph equipped with a flame ionization detector for separation of volatile oil constituents. The chromatograph apparatus was fitted with capillary column BPX-5,5% phenyl (equiv.) polysillphenylene-siloxane 30 m × 0.25 mm ID × 0.25 μm film. Temperature program ramp increase with a rate of 10 ºC/min from 70 to 200 ºC. Flow rates of gases were nitrogen at 1 ml/min, hydrogen at 30 ml/min, and 330 ml/min for air. Detector and injector temperatures were 300 ºC and 250 ºC, respectively. The obtained chromatogram and report of GC analysis for each sample were analyzed to calculate the percentage of main components of volatile oil.

Table a. Proximate analysis of *Amphora* and *Pediastrum* algae.

Algae	Ingredients						
	DM %	OM %	CP %	CHO	CF %	EE %	Ash %
Amphora coffeaeformis	91.12	67.02	15.74	33.6	2.19	7.35	28.1
Pediastrum boryanum	88.1	70	31.3	43.17	1.5	18.4	18.1

DM: dry matter; CP: crude protein; CHO: total carbohydrates; CF: crude fibre and EE: ether extract (lipids).

Table b. Macro and micro-nutrients of *Amphora* and *Pediastrum* algae.

Algae	Macronutrients(%)					
	N	P	K	Ca	Mg	Na
Amphora coffeaeformis	5.41	1.32	0.63	26.9	2.29	1.51
Pediastrum boryanum	5.01	0.81	0.72	3.12	1.28	0.65
	Micronutrients (ppm)					
	Fe	**Zn**	**Mn**	**Cu**		
Amphora coffeaeformis	7.89	1.1	13.52	0.46		
Pediastrum boryanum	3.42	3.46	12.31	5.21		

Table c. Physical and chemical properties of experimental farm soil.

Physical analysis				
Clay (%)	**Silt (%)**	**Fine sand (%)**	**Coarse sand (%)**	**Soil texture**
5.63	4.27	52.83	37.15	Sandy

Chemical analysis											
pH	**E.C. (dS m^{-1})**	**Organic matter (%)**	**Soluble cations(mM)**			**Soluble anions (mM)**			**Available (ppm)**		
			Ca^{++}	**Mg^{++}**	**Na^{+}**	**Cl^{-}**	**HCO_3^{-}**	**SO_4^{--}**	**N**	**P**	**K**
7.85	0.53	0.33	3.13	1.44	3.8	3.78	2.46	2.68	6.8	18.14	0.51

***Average of two seasons**

Chemical constituents:

A sample of dry fruits was randomly taken from each treatment for chemical analysis. Total nitrogen, phosphorus, as well as potassium percentage, were determined in dry fruits according to the methods described by Chapman and Pratt (1978).

Statistical analysis:

Data were statistically analyzed and the differences between the means of the treatments were considered significant when they were more than the least significant differences (LSD) at the 5% levels using the method illustrated by Snedecor and Cochran (1980).

RESULTS AND DISCUSSION

Growth characteristics:

Initially, the used soil (Table, c) was characterized by a sandy structure, relatively low saline (0.53 dS m1^{-1}); slightly rich in coarse sand (37.15%) and poor fertile (0.33% organic matter). As shown in Table (1), algae extract application significantly affected the height of fennel plants. The major effect in both seasons was recorded with the application of *P. boryanum* alga extract at a concentration of 2.0 ml l^{-1} which increased the plant height to 170.00 and 165.50 cm of plant height in the first and second seasons, respectively. Furthermore, a positive effect on number of branches per fennel plant due to algae application over the two seasons was also found as well as the highest rate of *P. boryanum* extract (2.0 ml l^{-1}) gave the highest increases in fennel branches number. Here values of the two seasons were 12.33 and 11.67 for the first and second seasons, respectively, in comparison to control which gave 7.33 and 6.67 branches per plant for the two seasons, respectively.

In concern to the number of umbels/plant, all given doses of the algal extracts significantly increased number of umbels/plant in comparison to the control in both seasons. In the first season, *P.*

Table 1. Effect of algae extracts on some vegetative growth parameters of fennel (*Foeniculum vulgare* Mill) plant during 2019/2020 and 2020/2021.

Treatments	Plant height (cm)		Number of branches/plant		Number of umbels/plant	
	First season	Second season	First season	Second season	First season	Second season
Control	151.67	139.89	7.33	6.67	49.00	47.67
***A. coffeaeformis* (0.5 ml l^{-1})**	153.00	143.50	7.67	7.67	55.00	53.67
***A. coffeaeformis* (1.0 ml l^{-1})**	160.00	146.50	9.00	8.33	57.67	60.00
***A. coffeaeformis* (2.0 ml l^{-1})**	169.50	152.15	10.33	9.67	62.33	75.33
***P. boryanum* (0.5 ml l^{-1})**	165.00	159.33	8.33	9.00	69.00	63.67
***P. boryanum* (1.0 ml l^{-1})**	166.50	160.33	10.33	10.67	85.33	69.33
***P. boryanum* (2.0 ml l^{-1})**	170.00	165.50	12.33	11.67	93.00	74.00
L.S.D at 0.05	2.00	1.13	0.94	0.94	1.55	2.10

boryanum extract at 2.0 ml l^{-1} recorded the highest value (93 umbels/plant); whereas in the second one *A. coffeaeformis* extract at the rate of 2.0 ml l^{-1} produced the highest number (75.33 umbels/plant).

Fruits yield:

Similarly, to plant growth characteristics, fruits yield (g/plant) was also significantly improved with the application of both *A. coffeaeformis* and *P. boryanum* algae extracts at all levels in comparison with the control (Table, 2). *P. boryanum* extract at the highest rate (2.0 ml l^{-1}) recorded the highest values (114.92 and 93.90 g/plant in the first and second seasons, respectively).

Results presented in Table (2) also revealed that the weight of 1000 fruits (g) was also significantly affected with the application of all levels of both *A. coffeaeformis* and *P. boryanum* algae extracts. Moreover, the highest weight of 1000 fruits (g) was obtained with *P. boryanum* 2.0 ml l^{-1} giving 14.407 g in the first one, while in the second season, both of *A. coffeaeformis* and *P. boryanum* extracts at 2.0 ml l^{-1} for each gave the same highest value of 12.117 g.

These findings were closely confirmed by Amer *et al*. (2019) on cardoon plants who indicated that plants treated with algae extract produced higher values of morphological attributes, fruits yield, and chemical constituents than the untreated plants (control). The data also were found in harmony with those obtained by Tursun (2022) who mentioned that there were positive effects in plant height, yield, essential oil (%) and protein content of two coriander varieties at different locations as treated by seaweed as organic fertilizer. The aforementioned effect could be ascribed to the role of algae in plant nutrition and growth development as well as increasing yield, yield quality, and secondary metabolites. Different hypotheses claimed the effect of algae extract in this action of these, algae extract enhances germination, cell division, root initiation, and leaf area (Khan *et al*., 2009).

Algae are rich in protein and consequently have a marked content of amino acids. Most research in this concern revealed that the effect of algae in plant growth enhancement could ascribe to such chemical composition, as amino acids were considered as a precursor of other nitrogenous compounds, mainly nucleic acids, and acting as regulatory and signalling molecules, some enzymes activity and synthesis, redox-homeostasis conditions, and gene expression (Rai, 2002). Amino acids not only act as a nitrogen source required for different cell metabolites, peptide structure, protein formation, and chelating agents but more benefit as precursors of most growth regulators. In this concern, Maxwell and Kieber (2004) indicated that methionine is

Table 2. Effect of algae extract on fruits yield and weight of 1000 fruit of fennel (*Foeniculum vulgare* Mill) plant during 2019/2020 and 2020/2021.

Treatments	Fruits yield (g)/plant		Weight of 1000 fruits (g)	
	First season	Second season	First season	Second season
Control	37.86	37.14	9.367	8.120
***A. coffeaeformis* (0.5 ml l^{-1})**	70.58	39.47	11.557	10.480
***A. coffeaeformis* (1.0 ml l^{-1})**	85.00	50.08	12.233	10.630
***A. coffeaeformis* (2.0 ml l^{-1})**	103.43	89.14	13.080	12.117
***P. boryanum* (0.5 ml l^{-1})**	80.58	50.89	11.360	10.560
***P. boryanum* (1.0 ml l^{-1})**	102.18	71.61	11.600	10.900
***P. boryanum* (2.0 ml l^{-1})**	114.92	93.90	14.407	12.117
L.S.D at 0.05	2.68	2.12	0.27	0.28

linked to the biosynthesis of growth-regulating substances, in plants e.g., brassinosteroids, auxins, and cytokinins. Moreover, Tao *et al*. (2008) reported that tryptophan is linked to the biosynthesis of auxins, phenylpropanoids, phytoalexin camalexin, and other related natural products in plants.

Essential oil productivity:

Essential oil percentage:

It could be appreciated that certain treatments had a significant effect on the essential oil % and yield (ml)/plant (Table, 3).

Moreover, foliar application with *P. boryanum* extract (2.0 ml l^{-1}) treatment recorded the most notable, significant effect on essential oil percentage (1.983 and 1.58% in the 1st and 2nd seasons, respectively) in comparison to control.

Essential oil yield:

Regarding the essential oil yield(ml)/plant, It is evident from Table (3) that the highest values were 2.279 and 1.484 ml/plant in the 1st and 2nd seasons, respectively, which were recorded with plants that received *P. boryanum* extract at 2.0 ml l^{-1}.

Essential oil components:

The major 8 components of fennel essential oil were identified by using GC and listed as shown in Table (4). Results showed that estragole (methyl chavicol) and 1,8 cineole were the highest essential oil components.

It could be noticed that the oil extracted from control recorded the highest values of myrcene, 1,8 cineole and limonene (3.078, 26.095, and 8.784%, respectively), whereas, the major component of methyl chavicol (71.863%) was obtained from the treatment of *P. boryanum* extract at 2.0 ml l^{-1}. On the other hand, treating fennel plants with 0.5 ml l^{-1} *A. coffeaeformis* extract gave the highest total identified value (99.562%). It is worth mentioning that, Gross *et al*. (2002) reported that S-adenosyl-methionine plays a role through the methyl group as a donor to produce estragole and t-anethole in extracts of cell-free of the fennel plant.

Chemical constituents:

Data exhibited in Table (5) cleared that, during the two growing seasons, mineral constituents in fennel dry seeds were affected by foliar application with algae extracts.

Regarding nitrogen %, *P. boryanum* extract (2.0 ml l^{-1}) was the most effective treatment giving 2.654 and 2.656% DW in the 1st and 2nd seasons, respectively. For phosphorus percentage, the highest values (0.776% DW in both seasons) were recorded in plants treated with *A. coffeaeformis* extract (0.5 ml l^{-1}). On the other hand, the highest potassium percentage was produced from the treatment of *P. boryanum* extract at

Table 3. Effect of algae extract on essential oil productivity of fennel (*Foeniculum vulgare* Mill.) plant during 2019/2020 and 2020/2021.

Treatments	Essential oil (%)		Essential oil yield (ml/plant)	
	First season	Second season	First season	Second season
Control	1.200	1.230	0.454	0.457
***A. coffeaeformis* (0.5 ml l^{-1})**	1.675	1.373	1.182	0.542
***A. coffeaeformis* (1.0 ml l^{-1})**	1.700	1.453	1.445	0.728
***A. coffeaeformis* (2.0 ml l^{-1})**	1.940	1.483	2.007	1.322
***P. boryanum* (0.5 ml l^{-1})**	1.807	1.266	1.456	0.645
***P. boryanum* (1.0 ml l^{-1})**	1.930	1.336	1.972	0.957
***P. boryanum* (2.0 ml l^{-1})**	1.983	1.580	2.279	1.484
L.S.D at 0.05	0.059	0.048	0.098	0.035

Table 4. Effect of algae extract on essential oil components of fennel (*Foeniculum vulgare* Mill) plant in the second season.

Treatment	α- pinene	Myrcene	1,8 cineole	Limonene	Methyl chavicol	Anethole	Total identified (100)
Control	1.320	3.078	26.095	8.784	56.239	1.812	97.328
***A. coffeaeformis* (0.5 ml l^{-1})**	1.918	1.919	20.018	7.285	67.717	0.705	99.562
***A. coffeaeformis* (1.0 ml l^{-1})**	2.314	2.147	17.919	8.684	66.614	1.800	99.478
***A. coffeaeformis* (2.0 ml l^{-1})**	2.137	1.093	19.700	5.390	69.876	0.734	98.930
***P. boryanum* (0.5 ml l^{-1})**	2.000	1.241	20.131	8.660	65.282	1.452	98.766
***P. boryanum* (1.0 ml l^{-1})**	1.304	1.027	16.235	5.703	70.520	1.814	96.603
***P. boryanum* (2.0 ml l^{-1})**	1.810	0.864	17.308	5.517	71.863	1.718	99.080

Table 5. Effect of algae extracts on some macronutrients (% DW) of fennel (*Foeniculum vulgare* Mill) plant.

Treatments	Nitrogen %		Phosphorus %		Potassium %	
	First season	Second season	First season	Second season	First season	Second season
Control	1.327	1.106	0.677	0.678	1.610	1.638
***A. coffeaeformis* (0.5 ml l^{-1})**	1.659	2.212	0.776	0.776	1.811	1.782
***A. coffeaeformis* (1.0 ml l^{-1})**	1.99	2.433	0.705	0.707	1.868	1.696
***A. coffeaeformis* (2.0 ml l^{-1})**	1.99	1.990	0.636	0.638	1.811	1.782
***P. boryanum* (0.5 ml l^{-1})**	1.327	1.769	0.598	0.596	1.753	1.868
***P. boryanum* (1.0 ml l^{-1})**	1.548	1.990	0.622	0.623	1.839	2.758
***P. boryanum* (2.0 ml l^{-1})**	2.654	2.656	0.629	0.630	1.926	1.811

2.0 ml l^{-1} in the first season (1.926%) and 1.0 ml l^{-1} of *P. boryanum* extract in the second one (2.758%).

CONCLUSION

This study investigated the effects of algal extracts (*Amphora coffeaeformis* and *Pediastrum boryanum*) foliar application with different rates (0.5, 1.0 and 2.0 ml l^{-1}) as growth amendments on the growth parameters, yield, essential oil, and chemical constituents of fennel plants. In conclusion, the above-obtained results suggested that it is preferable to spray *Foeniculum vulgare* Mill. plants with *P. boryanum* extract (2 ml l^{-1}) to enhance the growth, fruits (seeds) yield,

essential oil yield as well as mineral elements of fennel plant under Ismailia Governorate conditions. Further studies of using *A. coffeaeformis* and *P. boryanum* extracts as biofertilizers and growth amendments should be encouraged.

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تأثير مستخلصات الطحالب على النمو، والمحصول، والزيت الطيار في نبات الشمر (*Foeniculum vulgare* Mill.)

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الطحالب عبارة عن مواد طبيعية نشطة بيولوجياً غنية بالبروتينات والدهون والكربوهيدرات والفيتامينات والعناصر (Fe، Mn، Zn، Cu، Bo، Mo) وبالتالي؛ لها تأثير مفيد على نمو النبات. أجريت تجربة حقلية لإختبار تأثير الرش الورقي بتركيزات مختلفة (٠,٥، ١,٠، ٢,٠ مل/ لتر) لنوعين من مستخلصات الطحالب هما (Bacillariophyta) *Amphora coffeaeformis* و(Chlorophyta) *Pediastrum boryanum* على النمو، محصول الثمار، محصول وجودة الزيت العطري والمكونات الكيميائية لنبات الشمر خلال الموسمين المتتاليين (٢٠١٩/٢٠٢٠ و٢٠٢٠/٢٠٢١). أشارت النتائج إلى أن جميع المعاملات أثرت معنوياً على جميع المتغيرات مقارنة بالكنترول. من بين التركيزات المختلفة المستخدمة، أدى أعلى معدل (٢,٠ مل/ لتر) من *P. boryanum* إلى زيادة كبيرة في طول النبات، عدد الأفرع، عدد النورات، محصول الثمار، وزن ١٠٠٠ ثمرة (جم)، النسبة المئوية للزيت العطري، محصول الزيت العطري (مل/نبات)، مكونات الزيت العطري وكذلك نسبة النيتروجين، الفوسفور والبوتاسيوم في الثمار الجافة. لذلك، يوصى باستخدام مستخلص الطحالب (*A. coffeaeformis* و*P. boryanum*) لتحسين المحصول وإنتاجية الزيت الطيار في نبات الشمر.