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Research Article

Effect of *Ascophyllum nodosum* extract and chemical fertilizers on the growth, yield and composition of *Satureja hortensis* L. essential oil[1]

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ABSTRACT

Nutrition is essential to optimize the quantitative and qualitative performance of medicinal plants, as well as prevent biotic and abiotic stresses. This study aimed to evaluate the effect of seaweed extract [*Ascophyllum nodosum*; non-application, soil application (SA), foliar application (FA) and SA + FA] and chemical fertilizers (application and non-application) on yield, essential oil content and compounds of savory, in a factorial experiment based on a randomized complete block design. A significant increase was observed in the savory dry weight and essential oil yield under chemical fertilizer and SA + FA, being the highest dry matter yield obtained with (SA + FA) + chemical fertilizer. There was a significant correlation between essential oil yield and dry weight, dry matter yield and essential oil percentage. The carvacrol content increased under the application of seaweed extract. The use of seaweed extract as an organic fertilizer has the potential to increase the quantitative and qualitative yield of savory.

KEYWORDS: Savory, medicinal plants, seaweed extract.

RESUMO

Efeito do extrato de *Ascophyllum nodosum* e fertilizantes químicos no crescimento, rendimento e composição de óleo essencial de *Satureja hortensis* L.

A nutrição é essencial para otimizar o desempenho quantitativo e qualitativo de plantas medicinais, bem como prevenir o estresse biótico e abiótico. Objetivou-se avaliar o efeito de extrato de algas marinhas [*Ascophyllum nodosum*; não aplicação, aplicação no solo (AS), aplicação foliar (AF) e AS + AF] e de fertilizantes químicos (aplicação e não aplicação) sobre o rendimento, teor de óleo essencial e compostos de segurelha, em experimento fatorial baseado em delineamento de blocos casualizados. Um aumento significativo foi observado na massa seca de segurelha e no rendimento de óleo essencial sob fertilizante químico e AS + AF, sendo o maior rendimento de matéria seca obtido utilizando-se (AS + AF) + fertilizante químico. Houve correlação significativa entre o rendimento de óleo essencial e a massa seca, rendimento de matéria seca e porcentagem de óleo essencial. O conteúdo de carvacrol aumentou sob a aplicação de extrato de algas marinhas. O uso de extrato de algas marinhas como fertilizante orgânico tem o potencial de aumentar o rendimento quantitativo e qualitativo de segurelha.

PALAVRAS-CHAVE: Segurelha, plantas medicinais, extrato de algas marinhas.

INTRODUCTION

Plant growth, development and synthesis of bioactive chemicals all depend on nutrients. Deficiencies in some nutrients may have a significant impact on plant health, and proper plant nutrition can play an important role in improving plant health and performance.

Biostimulants are organic substances that are used to stimulate plant growth, improve nutrient absorption and support plants against various types of environmental stress (Jardin 2015, Ghatas et al. 2021). Recently, the use of plant biostimulants has been promoted as non-chemical and environmentally friendly alternatives to chemicals in crop production.

Seaweed extract, as a biostimulant, is a mixture of micro and macronutrients, vitamins, hormones, amino acids, humic substances, phenolic compounds, etc., and it can affect the growth and performance of plants (Hernández-Herrera et al. 2014, Medi & Manea 2020). Extracts of the brown seaweed *Ascophyllum nodosum* (L.) Le Jolis are well-known and commercially used in agriculture due to their ability to be used in organic agriculture and food production. This seaweed is one of the main types of marine seaweed, which can be a suitable

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alternative to reduce the use of chemical inputs and, consequently, reduce environmental pollution and health problems caused by the consumption of such fertilizers (Frioni et al. 2021, Ali et al. 2022). In parsley (*Petroselinum sativum*, Hoffm) plants, it has been reported that the highest chlorophyll content, grain yield and essential oil content were observed with seaweed extract foliar application (Aly et al. 2021). The use of seaweed extract (Gifert liquid) in the soil and foliar spraying on the plant has caused a significant increase in the yield, yield components and essential oil content of the fennel (*Foeniculum vulgare* Mill) plant (Mostafa 2015).

Savory (*Satureja hortensis* L.; Lamiaceae family) is an annual herb that is currently cultivated throughout the world. Its flowers and leaves contain essential oil, and carvacrol, thymol, paracimen and γ-terpinene are the main components of its essential oil (Chambre et al. 2020, Nasiri et al. 2025). Savory essential oil is used in various food and pharmaceutical industries (Skubij & Dzida 2019). Antibacterial, antifungal, antioxidant and anti-inflammatory properties have been reported for savory essential oils (Ejaz et al. 2023). Summer savory (*Satureja hortensis* L.) is an important medicinal and aromatic plant that is widely cultivated in Iran. The recent species of the savory plant, along with winter savory (*Satureja montana*), are the only species of this genus that are cultivated as vegetables, spices or herbal medicines (Ghannadi 2002, Gulluce et al. 2003).

The secondary metabolites (active substances) of medicinal plants are significantly influenced by the genetic characteristics of the plant, agronomic management and climatic conditions where the plants grow. It has been reported that the application of chemical and organic fertilizers has an important role in the production of medicinal and aromatic plants (Emami Bistgani et al. 2018, Ozyazici 2021, Nasiri 2021, Tursun 2022). As an organic and environmentally friendly product, seaweed extract is a suitable input for organic agriculture, and its use in an integrated management system can be a new way to achieve sustainable agricultural goals (Ashour et al. 2021).

Nowadays, global approaches in agricultural production, including medicinal plants, are aimed to improve the quality and quantity of their active ingredients and pay attention to environmental problems. Therefore, the use of organic fertilizers containing growth regulators such as seaweed extract becomes more important.

This research was conducted with the assumption that the use of seaweed extract can improve the growth and increase the quantitative and qualitative yield of savory, and has a significant effect on essential oil compounds. Therefore, this study focused on investigating the response of savory, in terms of growth, essential oil production and changes in essential oil compounds, to the application of seaweed extract and chemical fertilizers.

MATERIAL AND METHODS

This experiment was performed at the research farm of the University of Maragheh (37º23′N and 46º16′E), East Azerbaijan, Iran, during the 2021 growing season. The climate of this region is cold and semi-arid, and the maximum temperature in the summer is about 35 ºC and the minimum temperature in the winter is about -20 ºC. The region receives an average of 330 mm of rain annually. The soil analysis (depth of 0-30 cm) showed that the soil type is sandy-clay loam (pH: 7.75; EC: 0.49 dS m^{-1}; organic carbon: 0.22 %; total N: 0.02 %; available P: 5.65 mg kg^{-1}; exchangeable K_2O: 345 mg kg^{-1}).

After the initial soil preparation (including plowing and disking) on April 5, 2021, the field was divided into 24 experimental plots. The dimensions of each plot were 3 × 2 m and included 6 planting rows, with a distance of 30 cm between them. The plant spacing and planting depth were considered to be 25 and 0.5 cm, respectively. Local savory seeds were used for planting, which was done manually on April 25. After the planting operation, to facilitate the germination of the seeds and the seedling emergence, sandy soil was spread on the plots, and then the plots were irrigated with the strip drip irrigation method. Based on the soil analysis and fertilizer recommendations (Alizadeh Sahzabi et al. 2019), phosphorus fertilizer (triple superphosphate; 50 kg ha^{-1}) was used before planting, and nitrogen fertilizer (urea; 200 kg ha^{-1}) was used three times (before sowing, vegetative stage and beginning of flowering). Weed management was done manually when needed. The field was irrigated once a week, according to the irrigation routine in the region.

The experiment was performed as a factorial based on the randomized complete block design, with three replications. The first and second factors consisted of chemical and seaweed extract fertilizers, respectively. The chemical fertilizer included two application and non-application levels, whereas the seaweed extract fertilizer consisted of non-application (control), soil application (SA), foliar application (FA) and SA + FA. The seaweed extract was applied two times (at the beginning of the stem elongation period and the beginning of flowering) with two application methods: fertigation with 1,000 g ha^{-1} and foliar application with 2 g L^{-1} (according to the instructions of the product manufacturer). The seaweed fertilizer (in powder form) was called Acadian and contained the extract of a species of seaweed called *Ascophyllum nodosum* (L.) Le Jolis, a product from Canada. The seaweed extract contained NPK and minerals (ash; 45-55 %), alginic acid (10 %), mannitol (4 %), amino acids (4 %) and other organic matter naturally occurring plant growth substances (20 %).

The savory plants were harvested at the flowering stage of 50 %, on August 14, 2021. The characteristics of plant height (cm), number of lateral branches (per plant), plant dry weight (g), dry matter yield (g m^{-2}), essential oil content (%), essential oil yields (g m^{-2}) and chemical composition of essential oil were evaluated. To determine the dry matter yield (g m^{-2}), two middle rows per plot (1 m^{-2}) were harvested.

The essential oil was extracted using a Clevenger distillation apparatus. A total of 40 g of dried savory shoots were distilled with distilled water (450 mL) for 2.5 h. The extracted essential oil was weighed and the essential oil percentage calculated based on the weight of the dry matter (40 g) and the extracted essential oil. The essential oil yield (g m^{-2}) was calculated by multiplying the essential oil percentage in the dry matter yield. The extracted essential oil was dried with anhydrous sodium sulfate and stored in dark glass containers at a temperature of 4 ºC until analysis. The essential oils were analyzed by GC-FID and GC-MS (Nasiri 2021). The analysis was performed using an Agilent 7990 B gas chromatograph equipped with a 5988A mass spectrometer and an HP-5MS. The GC-FID analysis was conducted using a gas chromatograph equipped with a flame ionization detector (FID).

Analysis of variance (Anova) was performed using the Statistical Analysis System (SAS) software package, version 9.3. The significance of the effect of the treatments was determined based on p values ($p < 0.05$). Means were compared by the least significant difference (LSD) method. The Pearson's correlation analysis (heatmap) was drawn using the Rstudio 14.2.1 software.

RESULTS AND DISCUSSION

According to the Anova (Table 1), the effect of the chemical fertilizers' treatment on the plant dry weight ($p < 0.05$), dry matter yield ($p < 0.01$) and essential oil yield ($p < 0.01$) was significant. The means comparison showed that the plants that were treated with chemical fertilizers had a higher plant dry weight, dry matter yield and essential oil yield, when compared to control plants. However, there was no significant difference for plant height, number of lateral branches and essential oil percentage between the plants that received chemical fertilizers and those that received no fertilizers.

The response of the savory to the seaweed application was significant, regarding plant height, number of lateral branches, plant dry weight, dry matter yield, essential oil percentage and essential oil yield (Table 1). Also, the results revealed that the interaction between the chemical and the seaweed fertilizers on the dry matter yield and the essential oil percentage was significant ($p < 0.01$). According to the means comparison, the plants that were treated with seaweed (SA and FA + SA) had higher height and essential oil yield than those sprayed with distilled water. These treatments increased the plant height and the essential oil yield by 6.9 and 31.2 %, on average, respectively, if compared to the control plants. The application of seaweed significantly increased the number of lateral branches and plant dry weight of the savory plants, as compared to the control plants.

Regarding the dry matter yield and essential oil, the means compassion showed that the highest dry matter yield (903.7 g m^{-2}) was obtained with SA + FA of the seaweed extract + chemical fertilizer, which was 39.5 % higher than for the control (without chemical and seaweed extract fertilizers) (Figure 1A). The treatments of SA and SA + FA of the seaweed extract without the use of chemical fertilizers and SA + FA with the application of chemical fertilizers had the highest essential oil percentages, reaching an average increase of 13 %, when compared to the control (Figure 1B).

The results of the essential oil analysis (Table 2) showed that 27 compounds were

Table 1. Effects of chemical and seaweed extract application on traits of savory (± standard error).

Treatments	Plant height (cm)	Sub stem (number)	Plant dry weight (g)	Dry matter yield (g m^{-2})	Essential oil (%)	Essential oil yield (g m^{-2})
Chemical fertilizer (CF)						
Non-application	51.07 ± 1.60	21.27 ± 1.03	45.3 ± 5.37	720.5 ± 39.5	1.48 ± 0.07	10.68 ± 0.98
Application	50.26 ± 1.20	21.77 ± 0.71	50.0 ± 4.08	791.8 ± 31.0	1.47 ± 0.08	11.66 ± 0.86
LSD	1.67	1.04	4.58	20.6	0.06	0.63
Seaweed extract (SE)						
Non-application	48.45 ± 1.83	19.97 ± 1.10	35.83 ± 2.67	681.5 ± 27.19	1.37 ± 0.03	9.36 ± 0.51
Foliar application (FA)	50.57 ± 0.63	22.00 ± 0.21	48.67 ± 3.15	7,745.7 ± 16.93	1.44 ± 0.61	10.77 ± 0.67
Soil application (SA)	52.13 ± 0.99	22.30 ± 0.67	52.00 ± 2.95	740.7 ± 37.7	1.51 ± 0.7	11.14 ± 0.51
FA + SA	51.47 ± 0.71	21.80 ± 0.56	54.17 ± 3.94	856.7 ± 32.19	1.57 ± 0.4	13.42 ± 0.64
LSD	2.37	1.47	6.45	29.13	0.08	0.89
Statistical significance (*F ratio*)						
CF	1.21^{ns}	1.06^{ns}	7.78*	55.05**	0.13^{ns}	11.14**
SE	4.23*	4.71*	14.77**	57.92**	8.75**	32.57**
CF × SE	0.15^{ns}	1.81^{ns}	1.14^{ns}	3.93*	4.89*	0.56^{ns}

Values are mean ± SD. Mean separation by the LSD test ($p < 0.05$). ^{ns}, ** and *: non-significant, significant at 1%, and significant at 5 % of probability, respectively. Each value is the average of nine replicates for CF ± standard error, six replicates for SE ± standard error, and three replicates for (CF + SE) + standard error.

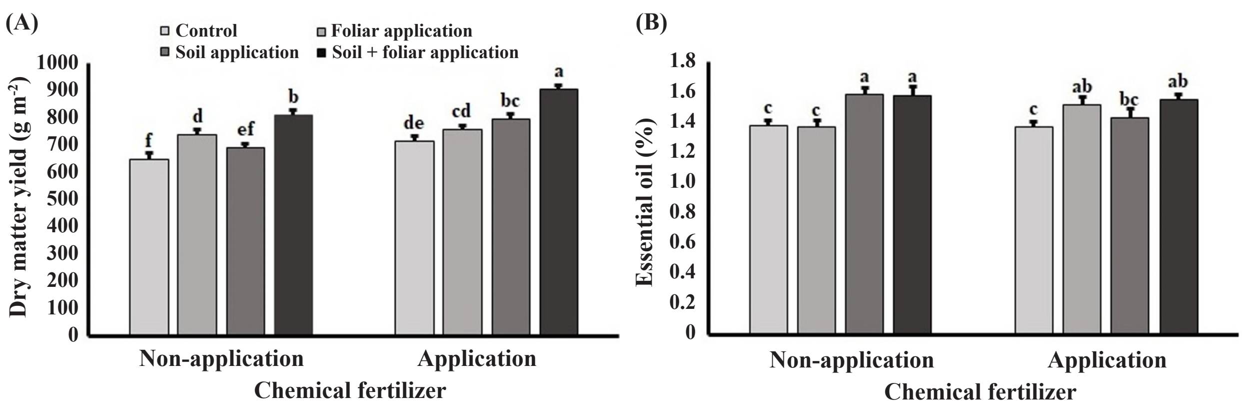

Figure 1. Savory dry matter yield (A) and essential oil (B) under chemical and seaweed extract fertilizers. Vertical bars represent the standard error, and different combinations of lowercase letters indicate significantly different means (n = 3) according to the LSD test ($p < 0.05$).

identified in the savory essential oil, representing 99.15 % of the entire essential oil composition. In all the evaluated treatments, carvacrol, γ-terpinene, *p*-cymene, *a*-terpinene and myrcene were the most abundant compounds in the essential oil. The presence of 59.80 % of carvacrol and 25.23 % of γ-terpinene as the main components of the savory essential oil dominated 85.03 % of the total components of the essential oil. According to the data for essential oil contents, the savory plants cultivated at different treatments had different amounts of essential oil compounds. Carvacrol, as an important compound in the essential oil, was obtained in the highest amounts for the treatments of SA and SA + FA of seaweed extract without the use of chemical fertilizers (63.18 and 63.49 %, respectively). The lowest amount of carvacrol was obtained without the use of seaweed extract and chemical fertilizer. Depending on the treatment, the γ-terpinene ratio was 23.15-28.05 %, paracymenene 3.03-3.58 %, *a*-terpinene 2.14-2.65 % and myrsene 1.24-1.60 %.

According to the correlation analysis (heatmap) (Figure 2), there were positive correlations between essential oil yield and essential oil percentage (r = 0.979**), dry matter yield (r = 0.909**) and plant dry weight (0.702**). The correlations between essential oil percentage and dry matter yield (r = 0.474*), plant dry weight (r = 0.601**) and plant height (r = 0.415*) were also significant and positive.

Table 2. Essential oil compositions ratio of the savory under chemical fertilizers and seaweed.

Nº	Chemical fertilizer		Non-application				Application			
	Seaweed Compound (%)	RI*	NA	FA	SA	FA + SA	NA	FA	SA	FA + SA
1	*a*-Thujene	924	0.54	0.35	0.49	0.65	0.35	0.59	0.60	0.64
2	*a*-Pinene	932	0.61	0.62	0.46	0.58	0.62	0.69	0.59	0.76
3	Camphene	946	0.12	0.14	0.16	0.15	0.14	0.16	0.13	0.16
4	*β*-Pinene	974	0.33	0.39	0.29	0.32	0.39	0.38	0.36	0.45
5	Myrcene	988	1.49	1.24	1.28	1.40	1.24	1.57	1.47	1.60
6	*n*-Decane	1,000	0.43	0.42	0.43	0.51	0.42	0.44	0.49	0.11
7	*a*-Phellandrene	1,002	0.25	0.18	0.17	0.20	0.18	0.24	0.09	0.42
8	*δ-3*-Carene	1,008	0.28	0.30	0.23	0.15	0.30	0.12	0.20	0.28
9	*a*-Terpinene	1,014	2.61	2.14	2.16	2.32	2.14	2.64	2.45	2.65
10	*p*-Cymene	1,020	3.30	3.57	3.03	3.10	3.57	3.58	3.28	3.37
11	*β* -Phellandrene	1,025	0.24	0.27	0.17	0.25	0.27	0.29	0.25	0.27
12	*(E)-β*-Ocimene	1,044	0.17	0.20	0.12	0.18	0.20	0.20	0.19	0.28
13	γ-Terpinene	1,054	27.34	23.66	23.45	23.15	23.66	28.05	25.78	26.74
14	*Cis*-Sabinene hydrate	1,065	0.19	0.18	0.16	0.16	0.18	0.15	0.22	0.16
15	*Trans*-Sabinene hydrate	1,098	0.13	0.20	0.07	0.19	0.20	0.09	0.32	0.19
16	Menthofuran	1,159	0.21	0.32	0.15	0.14	0.32	0.21	0.12	0.15
17	Menthol	1,167	0.20	0.73	0.14	0.15	0.73	0.10	0.11	0.20
18	Terpinen-4-ol	1,174	0.21	0.26	0.22	0.23	0.26	0.21	0.19	0.14
19	*n*-Dodecane	1,200	0.46	0.14	0.12	0.15	0.14	0.16	0.17	0.08
20	Thymol methyl ether	1,232	0.30	0.16	0.19	0.11	0.16	0.21	0.19	0.16
21	Thymol	1,289	0.27	0.17	0.14	0.12	0.17	0.13	0.10	0.15
22	Carvacrol	1,298	54.57	61.09	63.18	63.49	61.09	56.90	59.90	58.21
23	Thymol acetate	1,349	1.21	0.30	0.24	0.71	0.30	0.09	0.72	0.20
24	(*E*)-Caryophyllene	1,417	1.46	0.31	0.17	0.15	0.31	0.17	0.14	0.89
25	Aromadendrene	1,439	1.12	1.08	1.14	0.10	1.08	1.01	0.93	0.26
26	Viridiflorene	1,496	0.60	0.31	0.28	0.24	0.31	0.19	0.25	0.24
27	*β*-Bisabolene	1,505	0.75	0.61	0.14	0.33	0.61	0.11	0.13	0.50
Total compounds		-	99.37	99.32	98.76	99.21	99.32	98.67	99.35	99.23

* RI: retention indices measured on HP-5MS capillary column, experimentally determined using a homologue series of n-alkanes. NA: non-application; FA: foliar application; SA: soil application.

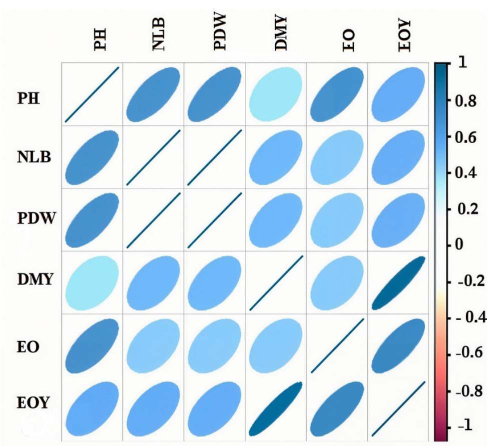

Figure 2. Heat map of the Pearson's correlation analysis for morphological and yield traits of the savory plant in response to seaweed extracts foliar application along with chemical fertilizers. PH: plant height; NLB: number of lateral branches; PDW: plant dry weight; DMY: dry matter yield; EO: essential oil (EO); EOY: essential oil yield.

In this study, the results showed that the application of chemical fertilizer led to an increase in the plant dry weight, plant dry matter yield and essential oil yield. In line with these results, several studies indicated that the use of chemical fertilizers increases the plant's access to nutrients, including nitrogen, and, as a result, it leads to an increase in the content of chlorophylls and carotenoids, which is followed by more plant greenness, high-efficiency solar absorption and more production of photosynthetic materials, and, finally, plant weight increases (Mafakheri & Asghari 2018, Yamashita et al. 2020, Keçe et al. 2024). Any increase in the plant dry weight can ultimately lead to an increase in the dry matter yield and essential oil yield. Emami Bistgani et al. (2018) have also reported that the biological yield and the essential oil yield of the thyme plant (*Thymus daenensis* Celak) significantly increased under the application of chemical fertilizers (NPK), when compared to control plants.

According to the results of the present study, the evaluated traits had a significant response to the application of seaweed extract. These results are consistent with those of Rezaei et al. (2020) and Heydari et al. (2017), who reported an increase in the height of savory and marigold (*Calendula officinalis* L.) plants with the application of seaweed extract. In addition to having nitrogen and high levels of mineral elements, the seaweed extract contains hormonal compounds such as auxin, gibberellin and cytokinin (Holdt & Kraan 2011), so the presence of these hormones in seaweed extract can increase the height, number of lateral branches and dry weight of the savory plant. It seems that the seaweed extract with compounds such as betaine and cytokinin enhances cell division in the plant and, as a result, its use can increase the number of lateral branches in the plant. Rahghoshahi et al. (2022) observed a significant increase in the number of branches of cumin (*Cuminum cyminum* L.) with the use of seaweed extract. Rathore et al. (2009) reported that the plant height and number of branches per plant in soybean (*Glycine max*) were significantly affected by seaweed foliar application. Shehata et al. (2011) reported that the plant weight of celery (*Apium graveolens* L.) increased under the exogenous application of the seaweed extract. They attributed this increase to the presence of macro-micronutrients and some growth-promoting substances in the seaweed extract. The results of this research, regarding the positive effect of seaweed extract fertilizer in increasing the essential oil content, are consistent with those from Pirani et al. (2020) in hyssop (*Hyssopus officinalis* L.), and Elansary et al. (2016) in mint (*Mentha × piperita* L.) and basil (*Ocimum basilicum* L.). One of the reasons for this phenomenon is the presence of nutrients such as nitrogen and phosphorus in the seaweed extract. These two elements are necessary for the biosynthesis of isoprenoids as precursors of terpenoid compounds (essential oils), and the use of seaweed extract can provide the nitrogen and phosphorus needed for their biosynthesis (Pandey et al. 2016, Kapoor et al. 2017). It has also been reported that the use of seaweed extract as a source of amino acids plays an important role in the production of secondary metabolites (Ardebili et al. 2012, El-Sharabasy et al. 2012).

Our results showed that the dry matter yield and essential oil percentage were enhanced by the interaction of seaweed extract and chemical fertilizer. Various researchers have proven that seaweed extracts are rich in macronutrients, micronutrients, phytohormones, plant growth-promoting molecules and secondary metabolites, and, with these characteristics, they contribute to plant growth promotion, increase the absorption of nutrients from the soil, and can increase the vegetative growth and quantitative and qualitative performance of plants (Ali et al. 2021, Deolu-Ajayi et al. 2022, Hamouda et al. 2022). Rathore et al. (2009) observed that the absorption of some nutrients (N, P, K and S) was improved by the application of seaweed extract. Mafakheri & Asghari (2018) have also reported that the application of seaweed extract increased the fresh and dry weight of fenugreek. Since the essential oil yield is obtained by multiplying the essential oil percentage and dry matter yield, any increase in these two parameters through seaweed extract will lead to an increase in essential oil yield. The positive and significant correlation of essential oil parentage and dry matter yield with essential oil yield (Figure 2) also confirms this issue. The results of other research also indicate the positive effect of seaweed extract on the essential oil yield of marigold (Heydari et al. 2017) and fennel (Mostafa 2015).

The positive correlation between essential oil yield and essential oil percentage, dry matter yield and plant dry weight indicates that the factors involved in increasing the plant dry weight, dry matter yield and essential oil percentage can also be effective in increasing the essential oil yield (Rezaei et al. 2020, Rahghoshahi et al. 2022). In line with the results of this research, Rezaei et al. (2020) also showed a positive correlation between essential oil percentage and plant height and essential oil yield.

The results of the essential oil analysis showed that the compounds of the savory essential oil were affected by the application of seaweed extract and chemical fertilizers. Consistent with these results, in various studies on savory plants (*Satureja hortensis* L.), carvacrol and γ-terpinene have been identified as the two main compounds of the essential oil, and their ratio ranges have been reported as 49.7-65.1 and 18.9-30.8 % (Skubij & Dzida 2019), 32.8-91.4 and 12.9-42.4 % (Chambre et al. 2020) and 35.9-42.0 and 18.5-20.0 % (Naderi et al. 2023), respectively for carvacrol and γ-terpinene. Mansori et al. (2022) reported that the application of seaweed extract affected the qualitative and quantitative composition of sage essential oil. Elansary et al. (2016) have also reported the same effects of *Ascophyllum nodosum* (a liquid extract) on the essential oil content and compositions of mint and basil plants. It seems that the effectiveness of seaweed extract is due to the presence of secondary metabolites in the seaweed extract, which play a role in stimulating the plant's defense mechanisms and thus cause the production of essential oil and changes in essential oil compounds. According to Chrysargyris et al. (2016), the presence of nitrogen and boron in seaweed extract can help to produce essential oil and improve the quality of essential oil compounds.

CONCLUSIONS

1. The application of chemical fertilizers and seaweed extract has positive and significant effects on the growth characteristics of the savory plant;
2. The essential oil percentage and essential oil yield were increased under seaweed extract application, especially with a combination of foliar and soil application;
3. The combined foliar application of seaweed extract and chemical fertilizers resulted in a further increase in the dry matter yield;
4. The application of seaweed extract is more effective in the absence of chemical fertilizer to increase the essential oil percentage and carvacrol content;
5. The soil or foliar application of seaweed has significant effects on increasing the quantitative and qualitative yield of savory, and can be used as an eco-friendly fertilizer in sustainable agricultural systems.

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