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Effect of foliar organic fertilization and some biostimulants on growth and productivity of chia (*Salvia hispanica* l.) plant.

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ABSTRACT:
Chia (*Salvia hispanica* L) is very appreciated for its oleaginous seeds in the agri-food field. Chia seeds are natural sources of many bioactive compounds which provide benefits to human health. Chia seeds are a promising source of antioxidants owing to their content of omega-3 and the presence of polyphenols, chlorogenic acid, caffeic acids, myricetin, quercetin, and kaempferol. The study was conducted on chia (*Salvia hispanica* L.) plants at a private farm of Sekem Company, located in El-Sharkia Governorate, Egypt, throughout the two consecutive seasons of (2022/2023) and (2023/2024). In this study, to improve vegetative growth, seed yield, chemical constituents, fixed oil productivity, and fixed oil composition of chia (*Salvia hispanica* L.) plants, some biostimulants and organic fertilizer were applied exogenously to chia plants. After 45 days from sowing, plants were sprayed with different doses of Karni as an organic fertilizer and Daltons NZ as a biostimulant in addition to the interaction treatments. The results showed that different doses of biostimulant and/or organic fertilizer significantly increased the vegetative growth and yield of chia plants. The results also indicated that the highest values of plant height (125cm), number of inflorescences (27 inflorescences/plant), seed yield (12.32 g/plant, 591.4 kg/fed.), and fixed oil yield (49.74 L/fed.) of *S. hispanica* were recorded with Karni 1.4 mL/L and Daltons NZ 0.4 ml/L. The major components were α-linolenic acid (59.33 to 62.70%), linoleic acid (16.03 to 18.45%), palmitic acid (6.99 to 8.63%), oleic acid (5.03 to 6.44%), and stearic acid (2.41 to 3.71%).It is concluded that Karni 1.4 mL/L and Daltons NZ 0.4 mL/L can be used to improve vegetative growth and fixed oil productivity of chia plants.
Keywords:Chia; Karni; Daltons NZ; Fixed oil; α-linolenic acid; Linoleic acid; Oleic acid.

1. Introduction

Chia (*Salvia hispanica* L.), a member of the Lamiaceae family, is primarily found in northern Guatemala and Mexico. This annual, summer-growing, and oleaginous plant, as highlighted by Ayerza and Coates [1], holds significance as a fundamental food source in Central American civilizations during pre-Columbian times [2]. Notably, chia is abundant in α-linolenic acid (omega-3), renowned botanical oil [3]. It is recognized as an oilseed crop with potential for human consumption [4], its ability to thrive in arid environments makes it a favorable alternative to major crop industries [5].

Due to its health benefits, chia plant has gained popularity in African countries, where its cultivation has expanded, offering a valuable source of essential and beneficial nutrients for the human body [6].

The Chia plant attains a height of 1 meter, featuring leaves arranged in a reverse pattern and small flowers (3-4 mm) with compact corollas. The fused flower parts contribute to a higher self-pollination rate. *Salvia hispanica* seeds are notably rich in essential compounds, boasting high protein content (15-25%), fats (30-33%), carbohydrates (26-41%), high dietary fiber (18-30%), ash (4-5%) and oils ranging from 25 to 40%. Approximately 60-68% of the oil consists of omega-3 α-linolenic acid, with an additional 20% comprising omega-6 linoleic acid. Furthermore, they contain minerals, vitamins, and dry matter ranging from 90 to 93%. Numerous studies have indicated the presence of a substantial amount of antioxidants in Chia seeds [7]. The seeds,

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varying in color from black, gray, black-spotted, to white, are oval-shaped and measured between 1 and 2 mm [3, 8].

During plant growth, there are continuous processes of building up complex compounds of carbon and nitrogen and their breakdown into simple substances, in which water and oxygen are intimately concerned. The chief processes involved in plant metabolism, viz., absorption, C assimilation, photosynthesis, formation of protoplasts, transpiration, respiration, translocation, storage, etc., are regulated by micro- and macro-elements readily available in different forms in soil. Supplementing the nutrient requirements of medicinal and aromatic plants through organic fertilizers plays a key role in sustaining soil fertility and crop productivity.

Because of bio stimulants contain hormones such as gibberellins, cytokinins, and auxins, they are safe substitutes for some chemical fertilizers [9]. They reduce the requirement for fertilizers by improving the absorption of both macro- and micronutrients from the environment [10].

There has been a significant 33-66% growth in the agriculture industry as a result of chemical fertilizer consumption [11]. Nevertheless, the extensive application of mineral fertilizers has resulted in a significant reduction in soil fertility and overall production, which has been attributed to their mismanagement and overuse [12]. Furthermore, the widespread use of chemical fertilizers has resulted in a number of problems, such as heavy metal poisoning and salinity of the soil [13]. On the other hand, biostimulants positively impact a number of soil qualities, including microbial activity, soil structure, and the ability of the soil to hold moisture [14].

Due to its important minerals and growth-stimulating hormones, seaweed became more important as a foliar spray later on. This application covers a wide range of crops, including cereals, flowers, herbs, as well as aromatic and medicinal plants [15, 16]). Seaweed extracts have a broad range of applications worldwide as biostimulants [9]. Based on expectations, the biostimulant industry is anticipated to reach a valuation of 894 million euros by 2022 [17]. Numerous scientific studies have shown interest in the field of research on marine seaweed extracts. Mohamed et al. [18], for example, studied the effects of marine seaweed extracts, particularly with relation to basil (*Ocimum basilicum*L.). Furthermore, Ghatas et al. [19] investigated marine seaweed extracts, specifically with regard to Artemisia annua. The aforementioned studies provide significant perspectives on the possible uses and advantages of marine seaweed extracts concerning the growth and development of plants.

Therefore, the primary objective of this study was to explore the impact of employing organic fertilization and specific biostimulant treatments on the growth and yield of the chia (*Salvia hispanica* L.) plant.

2. Materials and methods:

The field experiments were conducted at Al-Adlya Farm, El-Sharkia Governorate, Sekem Company, during two successive seasons (2022/2023 and 2023/2024). The experiment was laid out in a random block design (RBD) with three replications. Chia seeds were planted with an inter-row spacing of 20 cm and an intra-row spacing of 10 cm in the field on September 25. After 45 days of sowing, the plants were sprayed with the following treatments:

- Control (Foliar application with water)
- Karni at 0.7 ml/L.
- Karni at 1.4 ml/L.
- Daltons NZ at 0.1 ml/L.
- Daltons NZ at 0.2 ml/L.
- Daltons NZ at 0.4 ml/L.
- Karni at 0.7 ml / l + Daltons NZ at 0.1 ml/L.
- Karni at 0.7 ml / l + Daltons NZ at 0.2 ml/L
- Karni at 0.7 ml / l + Daltons NZ at 0.4 ml/L.
- Karni at 1.4 ml / l + Daltons NZ at 0.1 ml/L.
- Karni at 1.4 ml / l + Daltons NZ at 0.2ml/L.
- Karni at 1.4 ml / l + Daltons NZ at 0.4ml/L.

Karni as organic fertilizer was obtained from Modern Agricid Co. (MAG), having the following composition: nitrogen as amide (70 g/L), phosphorus as P2O5 (3g/L), potassium as K2O (100 g/L), potassium as humat (400 g/L), organic acid (4 g/L), fulvic acid (4g/L), boron (10ppm), copper (12 ppm), and zinc (227 ppm).

Daltons NZ Natural Liquid Seaweed use as a rooting solution for cuttings or soak seeds for improved germination. Apply to flowers 2-3 days before cutting to lengthen their lives. Folloing Composition: *Undaria pinnatifida* (brown algae seaweed) 60 % , Ammonium nitrate 15% , Potassium nitrate 15%, Potassium sulphate 10%.

Compost and calcium superphosphate were added to the soil during the preparation process and well mixed. For each season, the application rates were 20 m3 of compost per fed and 200 kg of calcium superphosphate (15.5% P2O5) per fed.The soil physical and chemical analysis in this experiment was assessed according to the methods established by Jackson [20] and Black et al. [21]. The results obtained from the soil analysis are presented in Table (1).

2.1. **Growth and yield Characters**

Plants were hand-harvested in February during both seasons (after reaching full maturity).

The vegetative and yield parameters were measured and recorded at harvesting time on February as follows:

1. Vegetative characteristics: plant height (cm)
2. Flowering parameters: number of inflorescences/plant
3. Seed yield parameters: seed yield/plant (g) & Seed yield/fed (Kg).

2.2. Chemical constituents:

Nitrogen, crude protein, and total carbohydrates in dried chia leaves were analyzed using the methods described by Horneck and Miller [22], James [23] and Chaplin and Kennedy [24], respectively.

2.3. Fixed oil extraction:

Chia oil was extracted from milled seeds using petroleum ether (40–60C) with an ultrasonic assessed method (Ultrasonic UP650, Acculab Inc., the USA) without raising the heat over 35 ◦C. The collected extract was evaporated by rotary evaporator (Heidolph, Germany) at 40 ◦C. The resultant oil was filtered, packed in dark brown bottle and stored at 20 ◦C until use [25]. The percentage of fixed oil was calculated as weight/weight using the following equation:

Fixed oil percentage = (Extracted fixed oil weight / Seeds sample weight) × 100

The fixed oil content per plant and the yield per fed were calculated.

2.3.1. Preparation of fatty acid methyl esters

Aliquot (20mg) of chia oil into screw-capped tube and 1 ml of 1 % sodium methoxide in methanol was added. Tubes were homogenized in a vortex for 20 s. Then, 1 mL of hexane was added, which led to separation two layer; the organic layer was collected, dried over anhydrous Na2SO4, and injected in GC-MS. 2.8.2.

2.3.2. Gas chromatography–mass spectrometry analysis (GC-MS) for FAME

The GC-MS system (Agilent Technologies) equipped with gas chromatograph (7890B), mass spectrometer detector (5977A) and HP-5MS column (30 m × 0.25 mm internal diameter and 0.25μm film thickness) was used. Analyses were carried out using helium as the carrier gas at a flow rate of 1.0 ml/min, injection volume of 1μl and the following temperature program: 50 ◦C for 1 min; rising at 20 ◦C/min to 200 ◦C and held for 5 min; rising at 3 ◦C/min to 230 ◦C and held for 23 min. The injector and detector were held at 250 ◦C. Mass spectra were obtained by electron ionization (EI) at 70 eV and using a spectral range of m/z 20–550 and solvent delay 1.8 min. Identification of different constituents was determined by comparing the spectrum fragmentation pattern with those stored in Wiley and NIST Mass Spectral Library data

2.4. Statistical analysis:

Data were statistically analyzed using Co-Stat 6.303 software Computer Program (2004) including one-way analysis of variance (ANOVA) using Duncan test. Correlation (r) and regression were estimated among different variables according to Steel and Tome [26].

3. RESULTS

In this section, we will show the effect of foliar organic fertilization and some biostimulants and their combination treatments on:

3.1. Growth and Yield Characters:

The datapresented in Tables (2, 3, and 4) clear that Karni and / or Daltons NZ had a significant effect on growth and yield characters of chia plants.

3.1.1. Effect of Karni treatments:

It is clear that all growth and yield characteristics increased as levels of Karni increased. The maximum mean values of plant height (125cm), number of inflorescences per plant (25.50), and seed yield (11.12 g/plant and 533.7 kg/fed.) were obtained from plants treated with Karni at 1.4mL/L.

Table 1. Mechanical and chemical analysis of the experimental soil (average of the two seasons).

Mechanical properties		Chemical analysis	
Parameters	Values	Parameters	Values
fine sand	40.57%	organic matter	1.69%
coarse sand	24.6 %	Caco3	0.94%
clay	18.52%	nitrogen availability	0.71%
silt	15.31%	phosphorus availability	0.39%
textural class	Sandy loam	potassium availability	137%
		pH	7.5%
		EC (dS/m)	0.88

Table 2. Effect of Karni on vegetative growth and yield characters of chia plant, average of the two seasons

Karni ml/L	Plant height (cm)	Number of inflorescences	Seed Yield g/plant	Seed yield (Kg/ Fed.)
0	124.03^{c}	15.50^{c}	6.35^{c}	304.8^{c}
0.7	136.23^{b}	17.75^{b}	8.25^{b}	396.95^{b}
1.4	147.2^{a}	25.50^{a}	11.12^{a}	533.7^{a}

Means that are followed by the same letter(s) are not significantly ($P < 0.05$) different.

Table 3. Effect of Daltons NZon vegetative growth and yield characters of chia plant, average of the two seasons

Daltons NZml/L	Plant height (cm)	Number of inflorescences	Seed Yield g/plant	Seed yield (kg/ fed.)
0	130.67^{d}	17^{c}	7.71^{b}	370.07^{d}
0.1	133.98^{c}	20^{b}	8.61^{ab}	413.13^{c}
0.2	137.22^{b}	20.7^{ab}	8.77^{ab}	420.73^{b}
0.4	141.4^{a}	21^{a}	9.21^{a}	441.93^{a}

Means that are followed by the same letter(s) are not significantly ($P < 0.05$) different.

Table 4. Effect of combination treatments between Karni and Daltons NZon some vegetative growth and yield parameters of chia plants, average of the two seasons

Karni ml/L	Daltons NZml/L	Plant height cm	No. of inflorescences/plant	Seed yield g/plant	Seed yield (Kg/ Fed.)
0	0	84^{j}	13^{g}	6^{e}	288^{h}
	0.1	101^{h}	16^{ef}	6.5^{de}	312^{g}
	0.2	105^{g}	16^{ef}	6.4^{de}	307.2^{i}
	0.4	108^{e}	17^{de}	6.5^{de}	312^{g}
0.7	0	96^{i}	15^{f}	7.0^{de}	336^{f}
	0.1	106^{fg}	18^{cd}	8.3^{cde}	398.4^{e}
	0.2	107^{ef}	19^{c}	8.9^{bcd}	427.2^{d}
	0.4	110^{d}	19^{c}	8.8^{bcd}	422.4^{d}
1.4	0	112^{c}	23^{b}	10.13^{bc}	486.2^{c}
	0.1	113^{c}	26^{a}	11.02^{ab}	529^{b}
	0.2	118^{b}	27^{a}	11.00^{ab}	528^{b}
	0.4	125^{a}	27^{a}	12.32^{a}	591.4^{a}

Means that are followed by the same letter(s) are not significantly ($P < 0.05$) different.

The lowest values of these traits were obtained from control plants.
From the data tabulated in Table 3, it can be concluded that Daltons NZ, as a biostimulant, promoted the growth and yield characteristics of chia plants. Plants treated with Daltons NZ at 0.4 ml/L gave the highest mean values of plant height (125cm), number of inflorescences per plant (21) and seed yield (9.21 g/plant and 441.93 kg/ fed.).
The growth and yield characteristics of chia plants varied significantly due to different combination treatments (Table 4). Significantly higher plant height (125cm), number of inflorescences per plant (27) and seed yield (12.32 g/plant and 591.4 kg/fed) as the result of combination treatment between Karni at 1.4 ml/L and Daltons NZ at 0.4 ml/L.

3.2. Chemical composition determinations:

The information provided in Table 5 demonstrates that all treatments involving organic fertilization and biostimulants resulted in a statistically significant increase in leaf nitrogen, crude protein, and total carbohydrate contents (%) of *Salvia hispanica* L. compared to the control. Notably, the combination treatment with Karni at 1.4 ml/L and Daltons NZ at 0.4 ml/L exhibited the highest values in these parameters, while the control recorded the minimum values.

Table 5. Effect of combination treatments between Karni and Daltons NZ on Nitrogrn, crude protein and carbohydrate % of chia plants, average of the two seasons.

Karni ml/L	Daltons NZml/L	Nitrogen%	Crude Protein%	Total Carbohydrate %
0	0	3.99^{d}	24.94^{e}	40.01^{f}
	0.1	4.01^{c}	25.06^{d}	42.11^{ef}
	0.2	4.01^{c}	25.06^{d}	44.27^{e}
	0.4	4.11^{c}	25.69^{d}	44.37^{e}
0.7	0	4.00^{c}	25.00^{d}	40.30^{f}
	0.1	4.32^{b}	27.00^{bc}	44.25^{e}
	0.2	4.31^{b}	26.94^{c}	47.01^{d}
	0.4	4.35^{b}	27.19^{bc}	47.44^{d}
1.4	0	4.22^{b}	26.38^{c}	49.02^{c}
	0.1	4.69^{ab}	29.31^{b}	50.01^{b}
	0.2	5.01^{a}	31.31^{a}	51.33^{a}
	0.4	5.22^{a}	32.63^{a}	51.40^{a}

Means that are followed by the same letter(s) are not significantly ($P < 0.05$) different

3.2.2. Fixed oil content (%) and yield

Data tabulated in Table 6 show that Karni at 1.4 ml/L had a significant effect on the fixed oil percentage compared with other treatments. The highest mean value of fixed oil (7.44%) was obtained by using Karni at 1.4 ml/L followed by 0.7 ml/L which recorded 6.79 %. Fixed oil yield increased gradually by increasing the concentration of Karni. So, the maximum values of fixed oil yield (0.84 ml/plant and 39.93 /fed.) were obtained from plants treated with Karni at 1.4 ml/L.
Concerning the effect of Daltons NZ treatments, the data presented in Table 7 show that these treatments had no significant effect on the fixed oil percentage.

On the other hand, Daltons NZ treatments had a pronounced effect on fixed oil yield, where Daltons NZ at 0.40 ml/L caused the highest values of fixed oil yield (0.69 ml/plant and 33.06 L/fed) followed by Daltons NZ at 0.2, which recorded 0.60 ml/plant and 28.85 L/fed. Results in Table 8 illustrate the effect of the combination treatments between Karni and Daltons NZ on fixed oil percentage and yield. It is clear that the fixed oil percentage reached its maximum value (8.41%) as the result of the combination treatment between Karni at 1.4 ml/L and Daltons NZ at 0.4 ml/L. The same treatment resulted in the maximum values of fixed oil yield (1, 04 ml/plant and 49.74 L/fed.).

Table 6. Effect of karni on fixed oil content (%) and yield of chia plant. average of the two seasons

Karni ml/L	Fixed Oil percentage	Fixed Oil yield Ml/Plant	Fixed Oil yield L/fed.
0	6.35[b]	0.41[c]	19.40[c]
0.7	6.79[b]	0.56[b]	26.91[b]
1.4	7.44[a]	0.84[a]	39.93[a]

Means that are followed by the same letter(s) are not significantly (P < 0.05) different.

Table 7. Effect of Daltons NZ on fixed oil content (%) and yield of chia plant, average of the two seasons

Daltons NZ ml/L	Fixed Oil percentage	Fixed Oil yield Ml / Plant	Fixed Oil yield L/fed.
0	6.66[a]	0.53[c]	24.81[c]
0.1	6.75[a]	0.59[b]	28.26[b]
0.2	6.78[a]	0.60[b]	28.85[b]

Means that are followed by the same letter(s) are not significantly (P < 0.05) different.

Table 8. Effect of combination treatments between Karni and Daltons NZ on fixed oil of chia plants, average of the two seasons

Karni ml/L	Daltons NZ ml/L	Fixed Oil %`	Fixed Oil yield ml/ Plant	Fixed Oil yield L/fed.
0	0	6.35d	0.41e	18.29f
	0.1	6.30d	0.41e	19.81f
	0.2	6.40d	0.41e	19.66f
	0.4	6.36d	0.41e	19.84f
0.7	0	6.71c	0.47e	22.55e
	0.1	6.73c	0.56d	26.78d
	0.2	6.72c	0.60d	28.71d
	0.4	7.01b	0.62d	29.61d
1.4	0	6.91b	0.70c	33.60c
	0.1	7.22b	0.80b	38.19b
	0.2	7.23 b	0.80b	38.17b
	0.4	8.41a	1.04a	49.74a

Means that are followed by the same letter(s) are not significantly (P < 0.05) different.

3.3. Fatty acids:

Table 9 showed the data belonging to the effect of combination treatments between Karni as an organic fertilizer and Daltons NZ as a biostimulant on the qualitative aspects of the fixed oil compositions of chia (*Salvia hispanica* L.) seeds. The fixed oil composition analysis identified five major components, namely Palmitic acid, Stearic acid, oleic acid, linoleic acid, and α-linolenic acid. The major components were α-linolenic acid (59.33 to 62.70%), linoleic acid (16.03 to 18.45%), palmitic acid (6.99 to 8.63%), oleic acid (5.03 to 6.44%) and stearic acid (2.41 to 3.71%).

4. DISCUSSION

Organic fertilizer and biostimulants have been shown to improve plant growth, as evidenced by increased plant height and a greater number of inflorescences across all fertilization treatments compared to the untreated control. The beneficial effects of both organic and mineral fertilization on crop yield are consistent with findings from other studies [27]. The obtained results in terms of vegetative development with chemical fertilization are consistent with those reported by Said-Al Ahl et al. [28], Ghatas [29] and Abou El-Ghait et al. [30] for *Anethum graveolens*, *Coriandrum sativum* L. and chia plants, respectively.

Table 9. Effect of combination treatments between Karni and Daltons NZ on Fatty acids % of chia Seeds, average of the two seasons

Karni ml/L	Daltons NZ ml/L	Palmetic acid	Stearic acid	Oleic acid	Linoleic acid	α-linolenic acid	Total saturated fatty acids	Total unsaturated fatty acids	Total fatty acids
0	0	6.99	2.41	5.03	16.03	59.33	9.40	80.39	90.79
	0.1	7.01	2.60	5.31	16.31	60.05	9.61	81.67	91.28
	0.2	7.02	2.64	5.33	16.52	60.45	9.66	82.30	91.96
	0.4	7.33	2.63	5.61	16.51	60.78	9.96	82.90	93.86
0.7	0	7.01	2.53	5.11	16.09	60.01	9.54	81.21	90.75
	0.1	7.42	2.67	5.51	17.01	61.39	10.09	83.91	94.00
	0.2	7.49	2.71	5.63	17.11	61.66	10.2	84.4	94.6
	0.4	7.69	2.70	5.77	17.54	61.66	10.39	84.97	97.36
1.4	0	7.19	3.01	5.87	17.73	62.09	10.20	85.69	95.89
	0.1	8.09	3.23	6.05	17.04	62.05	11.32	85.14	96.46
	0.2	8.55	3.34	6.34	18.13	62.35	10.89	86.82	97.68
	0.4	8.63	3.71	6.44	18.45	62.70	12.34	87.59	99.93

The application of Karni substance, serving as a foliar organic fertilizer with a composition containing 400g/L of humic acid and 227ppm of zinc, has demonstrated a significant enhancement in plant growth and development. Humic acid (HA) stands out as a natural growth biostimulant and is recognized as a crucial component of organic substances in aquatic systems. Its significance extends to the soil, where it contributes to increasing soil content and enhancing microbial activity by acting as a chelating agent that facilitates the absorption of various nutrients. Additionally, HA plays a role in activating soil microorganisms and increasing organic matter, particularly in alkaline soils with limited organic content. Humic materials, including humic acid, are known to boost root growth activity, akin to auxins, resulting in overall increased plant growth across various stages. This effect also extends to influencing leaf pigments [31, 32, 33].

The recommendations of other researchers are consistent with the previous exploration of the elements under study. Similar results were reported in Salvia officinalis by El-Shayeb et al. [34]; *Pelargonium graveolens* plant by Nasiri et al. [35], Mentha piperita var. citrata plants by Hendawy et al. [36], and *Carum carvi* plant by Awad [37] and El-Khateeb et al. [38] studied *Majorana hortensis* plants. While, Ibrahim and Helaly [39] showed that humic acid at a rate of 2 L/fed. on fertilized fenugreek plants with NK at 75% of the recommended rate could be used to achieve fixed oil productivity, seed chemical components, and trigonelline content in seeds. Mohamed and Ghatas (2020) [40] also reported similar outcomes in their research on chia (*Salvia hispanica* L.) plants.

It has been discovered that humic substances (HS) have favorable impacts on a number of plant growth processes, such as nutrient intake, root growth, yield, and photosynthesis, which in turn affects the production of oil [41]. The observed increase in essential oil productivity due to humic acid treatments is consistent with findings from other investigations. Similar findings in *Mentha piperita* var. citrata were reported by Hendawy et al. [36], in *Guizotia abyssinica* by Tadayyon [42], and in basil plants by Jamali et al. [43]. The constant positive results highlight the potential of humic acid as a favorable component in increasing essential oil production across a wide range of plant species.

Furthermore, it is acknowledged that zinc is one of the key microelements required for plants to develop vegetative and flowering processes [44]. This micronutrient stimulates the synthesis of proteins, carbohydrates, and DNA by regulating the production of RNA and ribosome content, which is essential to the metabolism of plant cells. Moreover, tryptophan, a building block of indole-3-acetic acid (IAA), which is thought to stimulate plant growth, requires zinc for production.
Amberger [45] identified three main roles for zinc in plants: catalytic, cocatalytic (coactive), and structural. Accordingly, maintaining a sufficient supply of these nutrients in plants is necessary for healthy growth and yields that are desirable [46]. Numerous studies have emphasized the importance of using micronutrients as foliar sprays and their positive impact on stimulating and strengthening the development and output of medicinal and aromatic plant species. Several studies have been demonstrated how zinc applied topically might affect vegetative development and lessen the negative consequences of shortages of water on various plant species, on various plant species, such as moringa plan [47]t*;lemon* grass [48], and cumin [49].

When compared to untreated plants in both seasons, applying seaweeds (Daltons NZ) at 0.4 ml/L in combination with organic fertilizer (Karni) at 1.4 ml/L proved to be the most effective treatment for increasing plant height (cm), inflorescence number, seeds yield (g/plant), (Kg/ Fed.), and fixed oil yield. Additionally, the percentages of leaf nitrogen, total carbohydrates, and crude protein were significantly raised by biostimulant treatments. According to Ghatas et al. [19], using seaweed extract greatly enhanced the concentration of artemisinin and all other growth parameters. Abou El-Ghait et al. [30] observed that treatment T3, consisting of 75% recommended dose (R.D.) of mineral NPK fertilizer mixed with 25% organic and biotreatment, exhibited the highest values in terms of vegetative growth, seed yield, and chemical components of Salvia hispanica. Subsequently, treatment T2, involving 100% R.D. of mineral NPK treatment, likewise demonstrated noteworthy results in all of these regards.

Due to their hormone content—including auxins, gibberellins, and cytokinins—biostimulants are safe substitutes for some chemical fertilizers [9]. They help to lower the total amount of fertilizer needed by increasing the absorption of both macro and micro elements [10].. Since seaweed contains vital minerals and hormones that promote growth, it has become more popular as a foliar spray for a variety of crops, such as flowers, grains, herbs, and medicinal and aromatic plants, helping them to grow and develop [16].It is recently recommended to include seaweed extract in fertilization programs for achieving a sustainable production system of medicinal plants [50].

According to Du Jardin [9] and Crouch and Van Staden [16], seaweed extracts are widely used as biostimulants and have been widely accepted worldwide." The increasing significance of these chemicals is reflected in the projection that the biostimulant market will reach 894 million Euros in 2022 [17].

Various studies have reported the major components of chia oil. Ayerza and Coates [2] found that the primary components were α-linolenic (63.23%), linoleic (18%), oleic (3.42%), palmitic (7.2%), and stearic (3.4%). Segura-Campos et al. [50] stated that chia oil contains α-linolenic (68.5%), linoleic (20.42%), oleic (2.43%), palmitic (7.74%), and stearic (0.29%). Silva et al. [52] studied the quantification of fatty acids in chia seed oils obtained with different solvents and reported α-linolenic (61.48–62.94%), linoleic (18.1–19.8%), oleic (6.92–6.87%), palmitic (9.13–9.95%), and stearic (2.92–2.99%). Moghith [53] identified 23 compounds in the fixed oil composition of chia, with the main components being α-linolenic acid (54.97–63.22%), linoleic acid (15.82–21.36%), oleic acid (6.19–15.86%), and palmitic acid (6.30–8.15%). Mohamed and Ghatas [40] reported that the main component in chia was α-linolenic acid (37.26–39.73%).It is worthy note that the quality of chia plant represented by crude fatty acids content improves when treated with bio-stimulants compared to the recommended mineral NPK fertilization [53].

5. CONCLUSION

In conclusion, it is advised that the combination of biostimulant (Daltons NZ) at 0.4 ml/L and organic fertilizer (Karni) at 1.4 ml/L can be used to improve the chia (*Salvia hispanica* L.) plant's growth, seed yield, chemical composition, fixed oil productivity, and omega fatty acid content.

Conflict of interest

The authors declare that there is no conflict of interest.

Data availability

The data supporting this study's findings are available at the request of the corresponding author.

Authorship Contribution Statement

Conceptualization, H.M.A., and Kh.Sh.; methodology, H.M.A. and Kh.Sh. A.E.E. M.S,H.; software, Kh.Sh.; validation, H.M.A., and Kh.Sh; formal analysis, M.S.H.; investigation, H.M.A., Kh.Sh., A.E.E. and M.S.H.; resources, M.S.H.; data curation, H.M.A., Kh.Sh. and M.S.H.; writing—original draft preparation, H.M.A., and Kh.Sh. and M.S.H.; writing—review and editing, H.M.A., Kh.Sh., A.E.E. and M.S.H..; visualization, H.M.A, and M.S.H.; supervision, H.M.A, and M.S.H.; project administration, H.M.A.; funding acquisition, H.M.A. All authors read and approved the final manuscript.

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