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Research Article
Influence of Applying Seaweed Extracts and NPK Fertilizer on Vegetative Growth, Flowering Traits and Seed Yield of Borage (*Borage officinalis* L.)

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Abstract

Background and Objective: Borage is a medicinal plant with different culinary and medicinal uses. It is also cultivated for commercial oil production. Little information is available regarding the influence of the type of fertilizer on borage performance under different environmental conditions. Therefore, there is a need to determine the impact of some fertilizers such as seaweed and NPK on several agronomic parameters. **Materials and Methods:** Fertilizer treatments include seaweed (2 g L^{-1}) and NPK (2 g L^{-1}) in addition to control. The study was conducted using a completely randomized design with three replications. **Results:** Results showed that both types of fertilizers significantly increased plant traits measured over the control. Some of those traits included, plant height, vegetative biomass, chlorophyll content, seed yield and harvest index. **Conclusion:** It can be concluded that applying these fertilizers was beneficial in increasing vegetative growth as well as seed yield of borage.

Key words: Agronomy, inorganic fertilizer, organic fertilizer, plant nutrition, seaweed, mucilage, antithrombotic

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Medicinal plant species have been utilized to control several human diseases for thousands of years because these plants contain different active compounds with several beneficial pharmacological properties[1]. One of these medicinal plant species is borage (*Borago officinalis* L.) which is considered native to the Mediterranean area and is commercially cultivated in different regions of the world for its oil and other secondary metabolisms[2]. It is also planted for medicinal, culinary and oil production. The top producers in the world are the UK, Canada and New Zealand[3]. Leaves and flowers of borage also contain several active compounds that are utilized in different dietary supplements. These active compounds include tannin, saponins, mucilage, vitamin C and pyrrolizidine, in addition to calcium and potassium. Moreover, the seed oil of borage contains a high value of polyunsaturated fatty gamma-linolenic acid (GLA), used as antithrombotic, lower blood pressure, inhibited cholesterol and also is used for reducing side influences of diabetes[4-6].

Under different environmental conditions, the dry matter yield is estimated to be 2500 kg dry matter per hectare. The serious problem in borage production is the unlimited process of flowers and seeds falling. In general, the average rate of seed yield is estimated to be about 400 kg ha^{-1}. However, the average rate of seed fallen is about 320 kg ha^{-1}, while the seed yield of borage that can be obtained is estimated to be about 80 kg ha^{-1} seed[7]. Moreover, several abiotic and biotic factors also influence plant growth and seed production of borage[8,9].

There is little information on the effect of plant nutrient management (i.e., fertilizer type, application time, application rate and method of fertilizer application) on this medicinal plant, especially for its use during the plant growth and reproduction stage. The type of fertilizer used is a critical aspect of plant nutrient management since it affects the development and seed production of borage plants grown under a variety of environmental conditions. Thus, the purpose of this pot study was to determine the influence of seaweed extracts and NPK fertilizer on borage plant growth and yield components when grown in a shade-net house.

MATERIALS AND METHODS

Study area: The present study was carried out on borage (*Borago officinalis* L.) grown under shade-net house conditions in the College of Agriculture, University of Al-Qadisiyah, Iraq, in the 2021 season.

Experimental design: Each pot was filled with 10 kg of peat moss and sandy soil (1:1) and soil samples were taken from each pot for soil analysis. The soil texture used in the study was silty loam with a pH of 7.9. It contains total nitrogen (80 parts per million), total phosphorus (34.5 parts per million) and total potassium (96 parts per million) and has an EC of 0.93 (ds m^{-1}).

The borage's seeds were obtained from a local market in Al-Diwaniyah city, Al-Qadisiyah Province, Iraq and were sown in the nursery during the fall season of 2020. Uniform seedlings 40 days old were transported into plastic pots (10 kg) during the winter season of 2020. Two grams of seaweed extracts and NPK fertilizer were added to 1 L of distilled water and foliar application was applied to avoid the loss of plant nutrients by leaching if soil application was used. The control treatment was only sprayed with distilled water. These fertilizer treatments were laid out in a Completely Randomized Design (CRD) with three replications.

Numerous plant parameters were measured during the flowering stage and also at the time of harvest. These plant parameters included plant height, total leaf numbers, chlorophyll content, root length, root fresh and dry weight, stalk fresh and dry weight, leaf fresh and dry weight, leaves-to-shoot ratio and vegetative biomass, while flowering traits included total flower numbers, total flowering branch number and flowering branch fresh and dry weight. The seed yield per plant was determined.

Statistical analysis: The data on morphophysiological characteristics and seed yield were evaluated statistically using variance analysis in three replications and the treatment means were compared using the least significant difference (LSD) at the 0.05 level of probability. Excel was used to analyze variance and correlation analyses, as well as to create histograms comparing treatments.

RESULTS AND DISCUSSION

Figure 1a clearly showed that applying NPK or seaweed extract at 2 g L^{-1} for each caused a significant increase in plant height over the control. The NPK treatment was superior in its effect. Plant height was 53.4 cm at the NPK treatment in comparison to 40.0 cm for the control treatment. The same results were held for the number of leaves per plant. Treatment with NPK recorded the highest number (22.5 leaves per plant), while treatment with seaweed extract came second with 16 leaves per plant in comparison to control treatment which recorded the lowest number

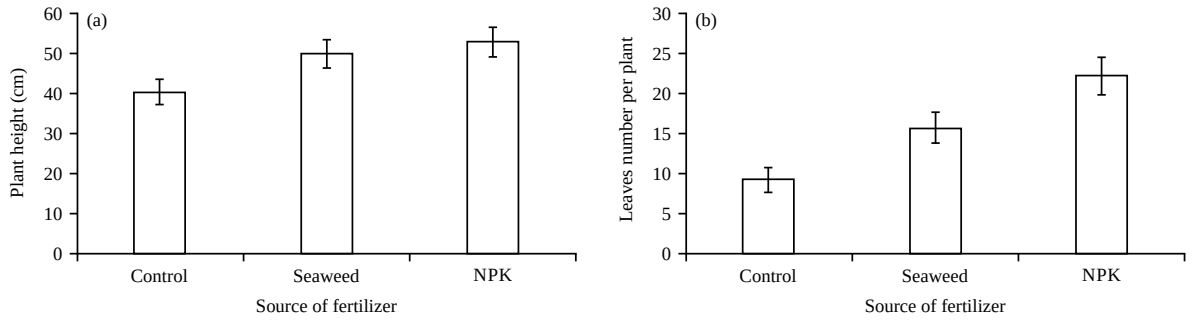

Fig. 1(a-b): Influence of applying two sources of fertilizer (seaweed and NPK fertilizer at 2 g L^{-1}) on (a) Plant height and (b) Leaves number per plant of borage (*Borage officinalis* L.)

(9 leaves per plant) (Fig. 1b). Thus, it was clear that spraying NPK fertilizer increased plant growth. These macronutrients are required for growth because they are involved in the manufacture of chlorophyll, nucleic acids, proteins, enzymes and cell membranes. Additionally, NPK nutrients are required for photosynthesis, respiration and transpiration, as well as osmotic control[10]. Berti *et al.*[11] reported that, plant height was affected by nitrogen and phosphorus and the interaction between nitrogen and potassium. Additionally, Alhasan and Hussein[12] concluded that nitrogen applied at rates of 60 or 80 kg N ha^{-1} had positive effects on spearmint's vegetative growth as well as agronomic characteristics and production of essential oil. The current study's findings corroborated previous findings[13-15]. Additionally, the enhancing effect of seaweed extract on plant height and leaf number was because the extract contains a diverse array of macro and micro nutrients and organic components such as plant growth hormones, amino acids, vitamins, betaines and sterols[16,17], all of which have been shown to stimulate plant growth and yield while increasing nutrient uptake from the soil. Halpern *et al.*[18] revealed that, seaweed fertilizer was effective as a source of extra nutrients, biostimulants and organic fertilizers (biofertilizers). The current results have been proven earlier[19-21].

The SPAD chlorophyll meter has been used to measure the chlorophyll content. The SPAD chlorophyll measured during the three intervals behaves similarly in each interval in response to the different treatments (Fig. 2a-c). Based on the results of the analysis of variance, the effect of the two kinds of fertilizers on chlorophyll content was significant. Seaweed extract treatment resulted in the highest SPAD chlorophyll for the three intervals. Values for chlorophyll due to seaweed extract treatment were 31.5, 36.5 and 41.4 after 30, 40 and 50 days, respectively. However, plants of control treatment had the lowest SPAD chlorophyll with values of 23.8, 25.9 and 26.8 for the intervals mentioned above, respectively. Numerous investigations confirmed that seaweed extract application raised leaf chlorophyll concentrations positively[18,20,22,23], which was consistent with our findings. Yusuf *et al.*[24] stated that, the application of seaweed extract resulted in a higher chlorophyll content compared to the control treatment, which they attributed to the seaweed extract's betaines reducing chlorophyll breakdown. Also, Ashour *et al.*[21] found that, using seaweed extract (commercially called True-Algae-Max, TAM®) on *C. annuum* at different concentrations improved significantly yield components of the plant in addition to increasing the amounts of chlorophyll, ascorbic acid, flavonoids and total nutrients. Additionally, several researchers discovered that applying seaweed extract enhanced leaf surface area, indirectly increasing chlorophyll content[25]. However, NPK treatment increased SPAD chlorophyll significantly over the control treatment but not to the extent of seaweed extract treatment. Nitrogen and potassium are essential nutrients that affect the growth and performance of plants. Nitrogen influences chlorophyll synthesis and photosynthetic efficiency, whereas potassium influences the permeability of the cell wall, the activity of several components and hence the overall activity of the plant[26]. Additionally, nitrogen and magnesium elements can be released by chemical fertilizers and incorporated into the chlorophyll molecule's porphyrin ring. Potassium enhances nitrogen's influence on photosynthesis through an oligodynamic role or participation in the energy transformation, activating kinases and osmotic absorption[27]. Current results agreed with other results[26,28-31].

For flowering branches number per plant, the results showed that the highest number was due to NPK treatment (11.7 flowering branches number per plant). Control treatment gave the lowest number (4.8), while seaweed extract treatment resulted in 7.1 flowering branches number per plant (Fig. 3a). However, the results revealed that seaweed extract treatment recorded the highest number of flowers per plant

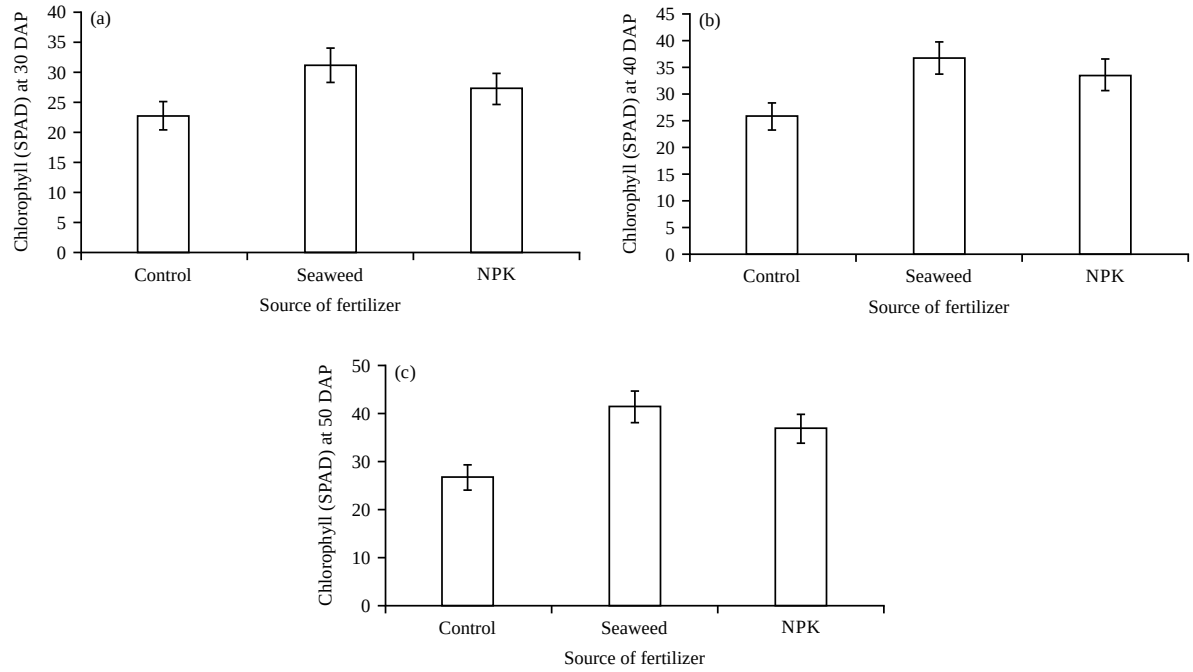

Fig. 2(a-c): Influence of applying two sources of fertilizer (seaweed and NPK fertilizer at 2 g L^{-1}) on (a) Chlorophyll content at 30 days after planting, (b) Chlorophyll content at 40 days and (c) Chlorophyll content at 50 days of borage (*Borage officinalis* L.)

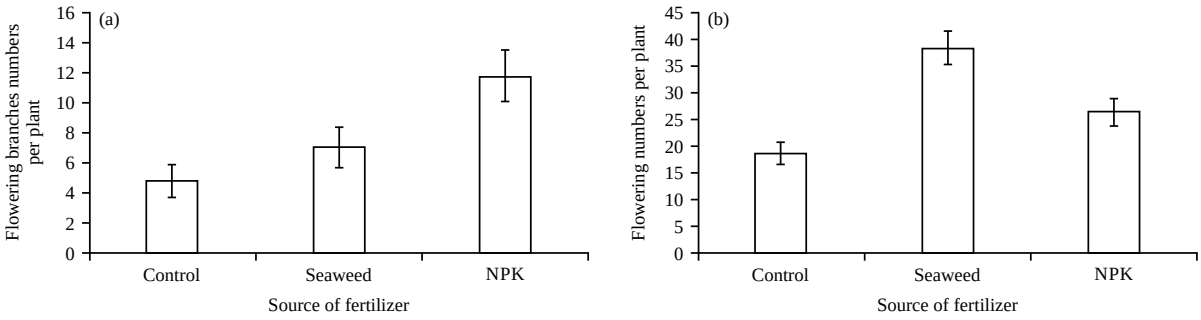

Fig. 3(a-b): Influence of applying two sources of fertilizer (seaweed and NPK fertilizer at 2 g L^{-1}) on (a) Flowering branches number per plant and (b) Flower number per plant of borage (*Borage officinalis* L.)

which gave 38.5 flowers number per plant compare to 26.5 and 19.0 flowers number per plant for NPK and control treatments, respectively (Fig. 3b). This increase in these two plant parameters due to NPK and seaweed extract treatments can be attributed to the promoting effect of the two kinds of fertilizers. The NPK fertilizer increases plant growth and development due to the enhancement of the biochemical and physiological functions of plants such as photosynthesis, respiration, protein, enzymes and lipid synthesis and cell membranes[10]. In addition to other components, seaweed extracts contain hormones such as auxin, gibberellin and cytokinin. These hormones are meant to stimulate vegetative and reproductive growth in plants, allowing them to grow and bear flowers[32]. The current results agreed with previous results which confirmed that foliar application of NPK caused a significant increase in cucumber plant height and the number of branches, leaves and flowers[33] and the results of Rathore *et al.*[34], who found that number of branches per plant was significantly affected by the foliar application of seaweed extract.

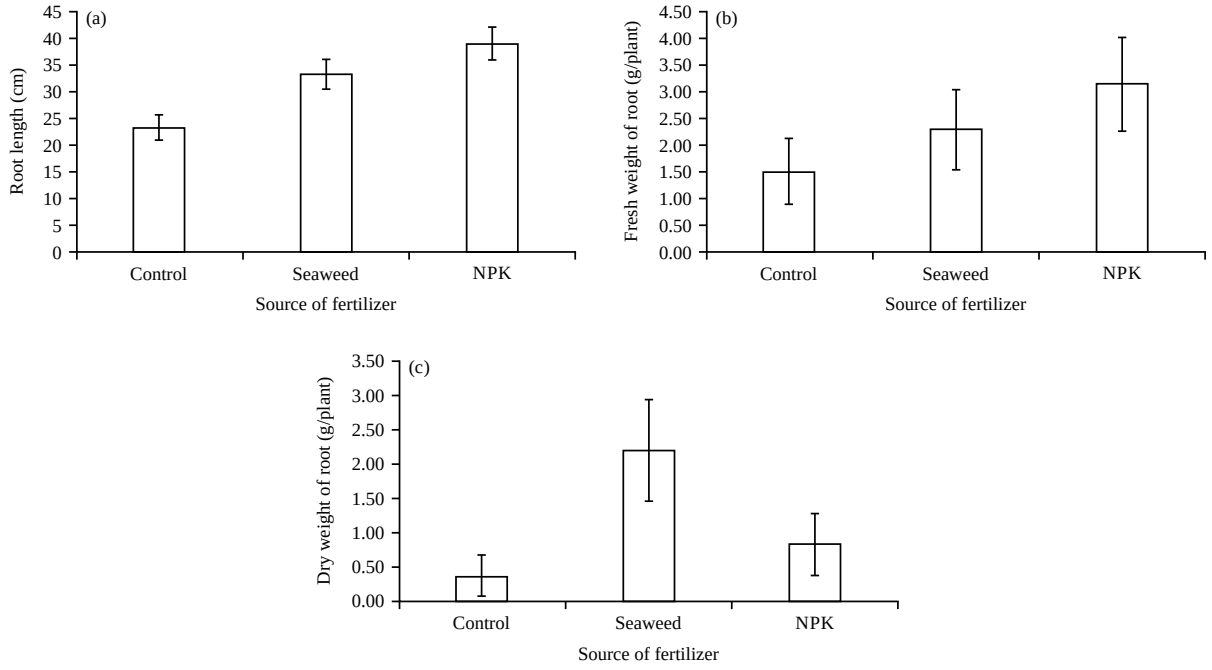

Fig. 4(a-c): Influence of applying two sources of fertilizer (seaweed and NPK fertilizer at 2 g L^{-1}) on (a) Root length cm, (b) Fresh dry weight of root (g/plant), (c) Dry weight of root (g/plant) of borage (*Borage officinalis* L.)

Concerning root length, the NPK treatment recorded the highest value (39.0 cm), while the control treatment recorded the lowest value (23.8 cm). The seaweed extract treatment recorded a value of 33.9 cm for root length (Fig. 4a). It was reported that the application of various NPK:TAM (seaweed extract) ratios have an enhancing effect on growth, yield and NPK content of cucumber (*Cucumis sativus*) under greenhouse conditions. Also, applying TAM with and without mixes of ordinary NPK applications improves chemical and physical features related to immunity, productivity and stress defense[35]. For root fresh weight, the NPK treatment recorded the highest value (3.15 g/plant), which is significantly different from the other treatment and the control. The seaweed extract treatment recorded a value of 2.30 g/plant for the root fresh weight (Fig. 4b). Interestingly, root dry weight behaves differently from the fresh weight trend where seaweed extract resulted in a higher value rather than NPK treatment (Fig. 4c). The current results agreed with other results[15,21,27].

For leaves and stalk fresh weight, spraying NPK fertilizer also resulted in the highest values of leaves and stalk fresh weight compare to applying seaweed extract on the borage plant or control treatment (Fig. 5a-b). The fresh weight of leaves and stalk were 15.1 g/plant and 16.5 g/plant, respectively at the NPK treatment compared to 11.8 and 13.7 g/plant, respectively for the two parameters at the control treatment. In the same way, flowering branches fresh weight (Fig. 5c) recorded the highest value at NPK treatment (43.0 g/plant), while seaweed extract treatment recorded a value of 30.0 g/plant. However, the control treatment gave the least fresh weight value and was far from the other two treatments (10.0 g/plant). The increase in fresh weight of these parameters due to spray with NPK and seaweed extract was due to the enhancement of the plant growth by the two kinds of fertilizers. Organic and non-organic fertilizers are known to promote nutrient uptake, activate the physiological/biochemical process in the plant and enhance the action of plant growth regulators. Ngosong *et al.*[33] reported that, the relative increase in cucumber yield and vegetative parameters after the application of foliar NPK fertilizer is likely due to the target-oriented foliar feeding that delivered an appropriate amount of essential nutrients directly to plants with greater nutrient use efficiency (NUE). Additionally, Ashour *et al.*[21] shown that seaweed extracts have a substantial effect on the growth and yield of eggplant plants. Dry weight supposes to behave similarly to that of fresh weight due to the use of NPK and seaweed extract fertilizers. Dry weight accumulation reflects plant growth activity. For leaves, stalk and flowering branches' dry weight, results showed that dry weight was the highest due to NPK treatment (Fig. 6a-c). The current results agreed with the previous results[15,21,27,29,31,33,36].

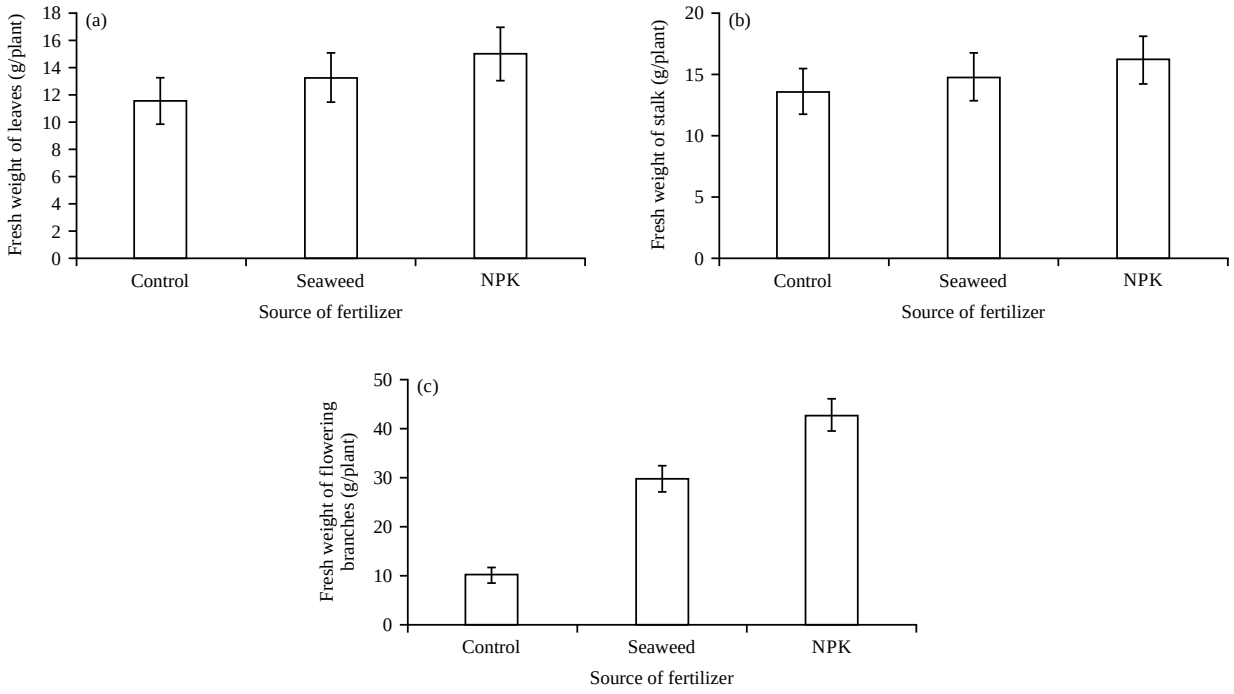

Fig. 5(a-c): Influence of applying two sources of fertilizer (seaweed and NPK fertilizer at 2 g L^{-1}) on (a) Fresh weight of leaves (g/plant), (b) Fresh weight of stalk (g/plant) and (c) Fresh weight of flowering branches (g/plant) of borage (*Borage officinalis* L.)

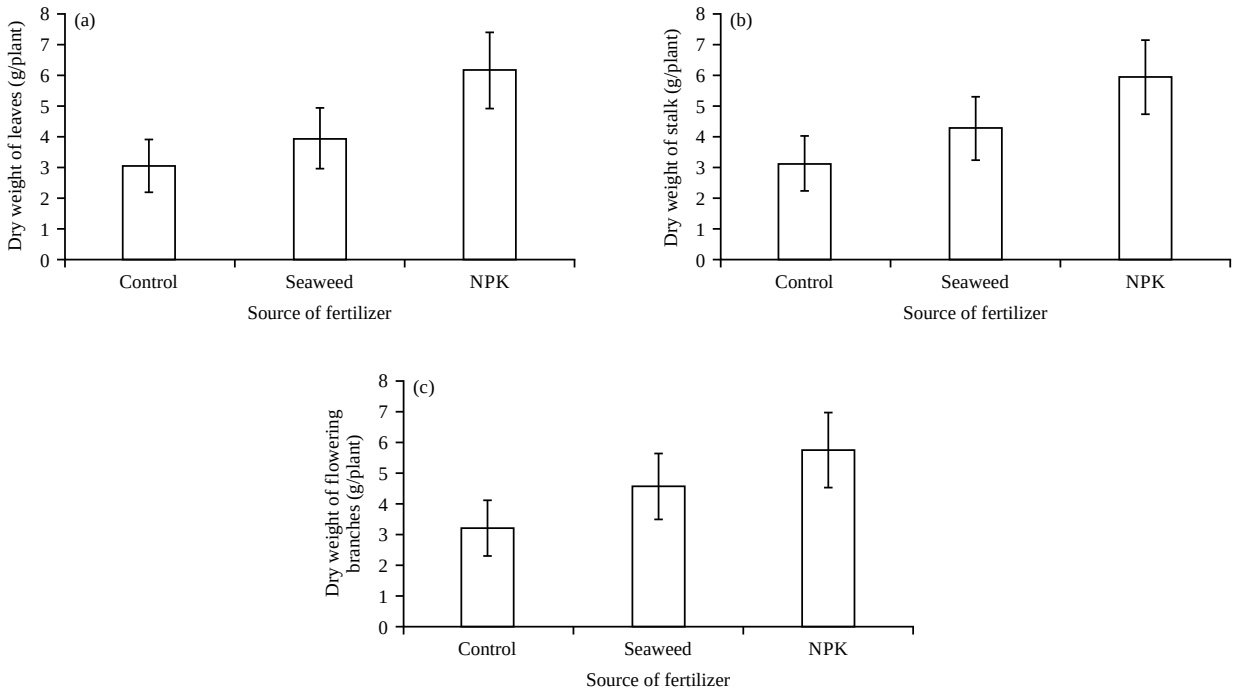

Fig. 6(a-c): Influence of applying two sources of fertilizer (seaweed and NPK fertilizer at 2 g L^{-1}) on (a) Dry weight of leaves (g/plant), (b) Dry weight of stalk (g/plant) and (c) Dry weight of flowering branches (g/plant) of borage (*Borage officinalis* L.)

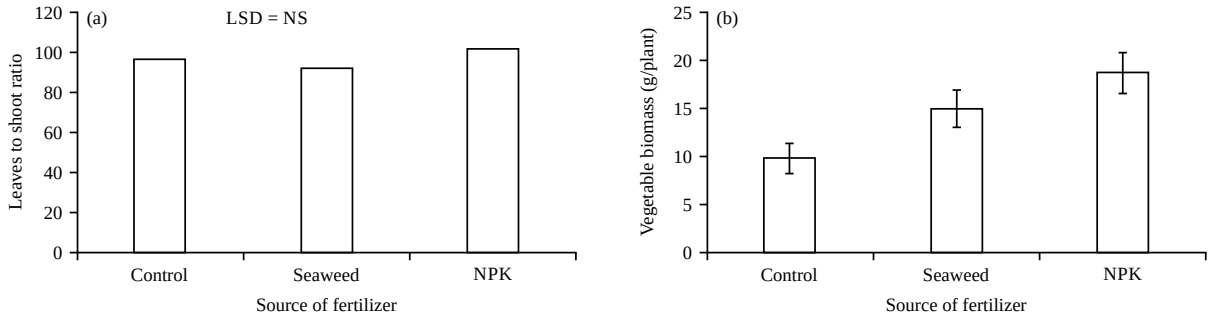

Fig. 7(a-b): Influence of applying two sources of fertilizer (seaweed and NPK fertilizer at 2 g L^{-1}) on (a) Leaves to shoot ratio and (b) dry weight of vegetative biomass (g/plant) of borage (*Borage officinalis* L.)

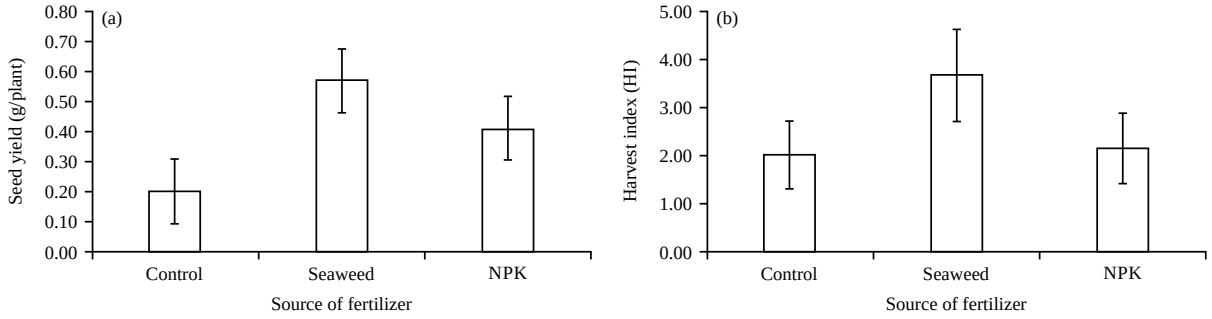

Fig. 8(a-b): Influence of applying two sources of fertilizer (seaweed and NPK fertilizer at 2 g L^{-1}) on (a) Seed yield (g/plant) and (b) Harvest index (HI) of borage (*Borage officinalis* L.)

Table 1: Correlation coefficients of studied traits

Traits	1	2	3	4	5	6	7	8
1: Chlorophyll content	1							
2: Leaves number per plant	0.1455	1						
3: Number of flowering branches	0.4514	0.3791	1					
4: Number of flowers	0.7998	0.2287	0.0783	1				
5: Root length	0.3984	0.6319	0.6930	0.3774	1			
6: Vegetative Biomass	0.6688	0.6452	0.7815	0.4403	0.7473	1		
7: Seed Yield	0.6931	0.2657	0.4472	0.7231	0.6509	0.4835	1	
8: Harvest Index	0.4548	-0.0438	0.1101	0.5936	0.3258	0.0221	0.8811	1

Leaves to shoot ratio didn't show significant differences due to the use of either seaweed extract or NPK fertilizer in comparison to the control treatment (Fig. 7a). Vegetative biomass yield increased significantly due to both seaweed extract and NPK treatments. It reached the value of 15.0 and 18.2 g/plant for the two treatments, respectively, while the control treatment resulted in the lowest biomass (9.9 g/plant) (Fig. 7b). In addition, seed yield also increased significantly due to the fertilizer treatments over the control. Seaweed extract produced the highest value of seed yield (0.57 g/plant), which differs significantly from that of foliar application of NPK treatment (0.41 g/plant) and control (0.20 g/plant) (Fig. 8a). It has been found that the foliar application of NPK increased grain yield of basil[30] and yield components of soybean[37]. Also, Yao *et al.*[38] indicated that, the application of seaweed extract significantly increased tomato yield, which is regarded as the increased photosynthetic capacity of plant leaves. Additionally, Rathore *et al.*[34] reported that, foliar application of seaweed extracts considerably improved soybean yield characteristics. The harvest index (HI) is a ratio of the economic performance of total dry matter output that serves as a proxy for a plant's capacity to distribute resources between vegetative and reproductive structures[39]. The analysis of variance revealed a significant influence of seaweed extract and NPK fertilizers on the harvest index. Harvest index followed a similar trend to seed yield, with seaweed extract having a greater harvest index than NPK treatment or control (Fig. 8b).

Correlation coefficients: Association coefficient analysis (Table 1) revealed a substantial positive correlation between seed yield and chlorophyll content, root length and flower

number per plant trait. So, improving morphological traits such as chlorophyll content, root length and vegetative biomass could increase the number of flowers, which leads to an increase in the seed yield because seed yield had a strong positive correlation with the flowering trait (0.7231). Between the number of leaves per plant and the harvest index, the least significant negative connection was identified (-0.0438). As a result, each increase in the number of leaves results in a decrease in the harvest index of borage.

CONCLUSION

The seaweed extract and NPK fertilizer were effective in increasing significantly the plant growth parameters measured for the borage crop over the control treatment. The NPK treatment is superior over seaweed extract treatment in most plant parameters measured, while seaweed extract was superior in some others such as chlorophyll content, seed yield and harvest index.

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