Journal of Applied Botany and Food Quality 97, 115 - 126 (2024), DOI:10.5073/JABFQ.2024.097.014

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Insights into seeds priming effects using a magnetic field and algal treatments on growth and productivity of faba bean under salinity stress conditions

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(Submitted: March 15, 2024; Accepted: June 16, 2024)

Summary

Soil fertility and crop productivity in the Nile Delta are severely threatened by soil salinization. Hence, the development of reliable techniques to enhance the salinity tolerance of plants is an essential prerequisite for the desirable sustainable agricultural development in Egypt. In the present study, we evaluated the influence of seeds priming using a magnetic field (MF) at different exposure times (0, 15, 30, and 45 min), either alone or combined with seeds pre-soaking or foliar spraying with seaweed extracts of *Hydroclathrus clathratus* and *Acanthophora spicifera*. The effects on soil properties, growth, yield, and seed quality of *Vicia faba* grown in saline soil were assessed. Results indicated that MF-treated seeds (MFTS), either alone or coupled with seaweed treatments, distinctly improved soil characterization by decreasing EC and pH niches, and also increased the availability of soil macro- and micronutrient elements, particularly at MF long exposure time (≥30 min). MFTS and/or MFTS with seaweed treatments at 30 min improved soil fertility indices (CO_2 evolution and nitrogenase activity) and induced the highest increases of macro- and micro-nutrient contents in seeds, plant growth and seed quality. Additionally, enhancement of chlorophyll *a* and *b*, carbohydrates and amino acids, and decreasing proline levels were the bases of salinity stress alleviation. Conclusively, seed priming in the MF coupled with foliar spraying of seaweed extracts could be a sustainable and affordable approach for cultivating *V. faba* plants under salinity stress conditions.

Key words: Faba bean, seed priming, seaweed extracts, magnetic field, salt stress tolerance, green technology

Introduction

Salinity is one of the main environmental stressors that constraints plant growth all over the world, leading to a massive loss of crop productivity (Ibrahim et al., 2104). Almost 831 million hectares of cultivated lands worldwide are affected by different salinity levels, and this huge area is rising yearly by 1-2% (Athar and Ashraf, 2009). It has been estimated that people's living security is threatened by soil salinization in more than 100 countries (Srivastava et al., 2019). In Egypt, saline soils are widespread in coastal zones of the Nile Delta, and this accounts for 30-40% of Egyptian soils of the Nile Delta (Hammam and Mohamed, 2020). Soil salinization in Egypt is mostly caused by seawater intrusion, high water table levels, inadequate irrigation systems, and poor drainage conditions.

Salinity induced stressful physiological states in plants and altered several biochemical processes in plant cells (e.g., nitrogen and carbon metabolism, photosynthesis activity, transpiration rate, and antioxidant defence system) (Yahmi et al., 2021). It has been reported that salinity stress drastically decreased the weights of seeds, total proteins, and NPK uptake in faba beans (Selem, 2019). Several agronomic studies evaluated the inhibitory effect of salt stress on seed germination (e.g., Tian et al., 2014) and growth and development limitation in various plant crops such as faba bean (Selem, 2019), cowpea (Manaf, 2016), and Zea mays (Hussein et al., 2021).

Several approaches have been used to reduce levels of soil salts such as increasing the applied irrigation water that plants need to reach sufficient leaching (Hammam and Mohamed, 2020), which is not economically feasible. Also, the application of chemical amendments or fertilizers is either impractical or too expensive to reach low salinity levels (El-Kamar et al., 2013). In modern agriculture technology, multiple agronomic practices and techniques have been employed to alleviate salinity stress on plants. Seed priming (pre-sowing) has been known as an effective approach to producing tolerant plants against various abiotic stressors by pretreating seeds with natural or synthetic compounds before germination (Jisha et al., 2013). In addition, seed pre-sowing using a magnetic field (MF) has been elucidated to improve the seedling growth and development in faba beans (Podleśna et al., 2019). The seed priming process was found to induce the physiological state of plants through activation of some biochemical and physiological processes in seeds and seedlings (Podleśna et al., 2019).

Marine macroalgae, also known as seaweeds, are promising multifunctional bioinoculants. Their biomass or extracts provide a rich source of high-value bioactive compounds, such as proteins, carotenoids, polyphenols, carbohydrates, and bioflavonoids (Hamed et al., 2018), offering an environmentally friendly and sustainable approach to nourishing the world's growing population (Yadav and Yadav, 2024). Previous studies highlighted the positive activities of seed priming with algae extracts to alleviate the salinity stress in salt-affected lands (Ibrahim et al., 2104; Hussein et al., 2021; Mutale-Joan et al., 2021). Their phytostimulatory effects had been elucidated to increase plant growth, yield components, and seeds biochemical composition under normal and salt stress conditions in wheat (Ibrahim et al., 2104; Ibrahim, 2016), canola (Hashem et al., 2019), and cowpea (Manaf, 2016). High organic matter content of algal extracts, on the other hand, contributed to soil nutrient boost (Layek et al., 2018).

The faba bean (*Vicia faba*) is the fourth most important legume crop in the world due to the high protein content of its seeds. This crop is a reliable source of protein nutrition for many people in the Middle East (Ammar et al., 2017), besides its key role in upgrading soil fertility (Salah El Din et al., 2008). In Egypt, there has been a decline in the faba bean production during the past nineteen years from about 2715 thousand acres in 2000 to approximately 1754 thousand acres in 2019 (Abdelaal and Soliman, 2002). Therefore, improving the

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salt tolerance of faba bean is an essential goal to increase crop yield on the one hand, and to promote soil fertility index on the other hand. The current study mainly aimed to (1) investigate the possible effect of seed priming using MF and seaweed extracts as a promising, sustainable, and safe approach to alleviate salinity stress on the growth and yield of faba bean plants and seeds quality under field condition; (2) comparatively evaluate the performance of two different seaweed extracts and methods of application, either pre-soaking or foliar spray, on crop productivity and soil chemical properties; and (3) highlight the beneficial effects of seaweed extracts not only as protective agents against ecological stress but also as effective biofertilizers. This study, for the first time, investigated the integrated application of seed priming in MF with seaweed treatments to improve faba bean growth and productivity under salt-stress conditions.

Materials and methods

Seaweeds sampling and extracts preparation

The two marine macroalgal species *Hydroclathrus clathratus* (brown seaweed) and *Acanthophora specifera* (red seaweed) were collected during the spring season of 2020 from the seashore of Hurghada, Red Sea coast, Egypt (34° 17' E and 26° 06' N). The collected samples were transferred to the laboratory in an icebox. Algal samples were washed thoroughly with tap water and then distilled water to remove extraneous materials and debris. Algal species were morphologically identified according to the available literature of Aleem (1993) and Coppejans et al. (2009). The macroalgal samples were air-dried in the shade at room temperature (Supplementary Fig. 1). The algal biomasses were ground by the electric mill and then were extracted in 300 ml of methanol 99% for each 150 g powdered sample in a 500 ml Soxhlet extractor vessel. Whatman filter paper No.1 was used to filter the crude algal extracts and filtrates were concentrated in a rotatory evaporator (GG SENCO, WKIE LAB Instrument, Zhengzhou, Henan, China) under reduced pressure until complete dryness according to the protocol described by Ibraheem et al. (2017). The obtained dry crude material was stored at 4 °C for further applications.

Magnetic Field (MF) exposure

Seeds priming using MF was conducted at four different exposure times (i.e., 0, 15, 30, and 45 min). The MF was generated using a stainless-steel MF device (Delta Water System, Egypt). The diameter of the magnetic device was 2 inches with the MF intensity of 1.5 Tesla (Fig. 1).

Experimental conditions and soil preparation

The field experiment was conducted at Khaled ibn El-Waled village (32° 00' to 32° 15' N and 30° 50' to 31° 15' E), Sahl El-Husseiniya, Sharqiyah governorate, Egypt during the winter season of 2021. Before planting, the soil field was initially analysed according to the standard protocol described by Page et al. (1982) and Cottenie et al. (1982). Briefly, random samples were taken from the surface (0-30 cm), air-dried, ground, mixed thoroughly, and sieved through a 2-mm sieve. The physical and chemical properties of the composite soils are shown in Tab. 1. Field treatments were laid out in a randomized complete block design in three independent lines, 10 meters each with at least 20 plants. Seeds of faba bean (*Vicia faba*, cultivar Nobaria 1) were supplied by the Department of Field Crop Research Institute (FCRI), Agricultural Research Centre (ARC), Egypt. The field soil was fertilized using super phosphate as P_2O_5 (15.5%) at a rate of 200 kg/fed before planting. Nitrogen as urea (46.5%) was also applied at a rate of 30 kg/fed after 31, 45, and 65 d from planting. Potassium sulphate (48% K_2SO_4) was applied 31 and 45 days after sowing. All cultivation practices were achieved as recommended by FCRI.

Fig. 1: Delta water Magnetic field device.

Determination of soil physical and chemical properties

The Pipette method was used to determine the particle size distribution according to Piper (1950). Calcimeter was used to estimate soil $CaCO_3$ content as described by Page et al. (1982). Walkly and Black's method was used to measure the soil organic matter content following the protocol adapted by Page et al. (1982). Soil: water suspension (1: 2.5) was used to measure soil pH using a calibrated pH meter (HANNA HI 991301) as described by Jackson (1967). A soil past extract was used to determine the ions' conductivity. The ions, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, and SO_4^{2-}, were measured using ionic chromatography (ICS 1500 Dionex Corp.). Available soil nitrogen (N) content was extracted by 2 N KCl solution and the ammonium steam was trapped in 10 ml boric acid (pH 5.0) using the distillation unit (Kjeltec system 1002, Tecator, Phoenix Equipment Inc., USA) according to the modified Kjeldahel's method as described by Jackson (1967). Available soil phosphorus (P) content was extracted by $NaHCO_3$ (5N) and measured calorimetrically according to the method adapted by Olsen and Sommers (1982). Micro- and macronutrients were extracted by diethylenetriaminepentaacetic acid

Tab. 1: Physical and chemical properties of the field soil before planting faba bean seeds. Data represent the mean of three replicates (n = 3).

coarse sand (%)	fine sand (%)	silt (%)	clay (%)	texture	organic matter (%)	EPS (%)	$CaCO_3$ (%)	
4.2	22.69	36.45	36.66	clay loam	0.52	14.60	13.52	
pH	**EC** (dS m^{-1})	**cations (meq L^{-1})**				**anions (meq L^{-1})**		
		Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}
8.45	10.25	15.98	22.53	63.16	0.83	10.35	57.62	34.53
macronutrients (mg kg^{-1})			**micronutrients (mg kg^{-1})**					
N	P	K	Fe	Mn	Zn			
37.25	4.10	180.0	7.14	3.66	0.52			

ESP: exchangeable sodium percentage; EC: ions conductivity.

(DTPA) following the procedures adopted by SOLTANPOUR (1985) and were analysed by means of ICP–OES (Optima 5300 Perkin Elmer Corp.).

Experimental design and treatments

The study was executed to investigate the effect of seeds priming using MF and/or seaweeds extracts, either as seed pre-soaking or foliar application, on faba bean growth and productivity in salt-affected soil. Treatments were designed accordingly as the following: (1) control (untreated seeds); (2) MFTS at different exposure times (0, 15, 30, and 45 min); (3) MFTS with algal pre-soaking for 12 h; (4) MFTS combined with foliar spraying with the aqueous algal extracts which prepared by dissolving of 1 g from the crude dried algal matter in 1 l distilled water). The foliar application of seaweed extracts of *H. clathratus* and *A. spicifera* was performed twice during the vegetative growth stage, i.e., at 30 and 45 d. Seed pre-soaking treatment was achieved by soaking faba bean seeds in aqueous seaweeds extract (1 g l^{-1}) for 12 h before MF exposure. At the age of 75 d, plant growth characteristics, i.e., total chlorophyll, shoot and root length, the number of nodules, soil macro- and micronutrients, CO_2 evolution, and nitrogenase activity were determined. At harvest (120 d), the plant height (cm), number of branches/plant, number of pods/plant, weight of seeds/plant (g), and weight of 100 seeds were determined. Pods and seeds were left to be air-dried for fifteen days until the moisture content was >11% to save the physical quality and physiological performance of the seeds (SCARIOT et al., 2017). Seeds yield (ton/fed) and pods yield ton/fed were calculated.

Assessment of soil microbial activity

CO_2 evolution, as a biomarker of microbial activity in the rhizosphere soil of faba bean, was determined after 75 days of plant growth using the method adopted by PRAMER and SCHMIDT (1964). A mixture of 100 ml NaOH (0.05 N) and 3 ml $BaCl_2$ (50%) ml was placed in 500 ml serum bottles. 10 g of fresh soil sample were fitted into a clean polyethylene pouch and then were hung individually in the head space area of each bottle. The containers were tightly sealed with rubber stoppers and then were incubated at 30 ºC for 72 h. CO_2 amount (mg 100 g^{-1} soil) was measured by titrating the remaining NaOH with 0.05 N HCl (1 ml HCl = 1 mg CO_2). A soil-free bottle was used as a blank. As regards nitrogenase activity, N_2-fixation potential in faba bean nodules (µmol C_2H_4 g^{-1} dry nodules h^{-1}) was determined using Agilent HP 5890 series II gas chromatography (Conquer Scientific, USA) fitted with a dual flame detector and capillary column (50 m × 0.53 cm× 15.0 µm film thickness), following the standard procedure adopted by DILWORTH (1966). The activity of the nitrogenase enzyme was calculated as ethylene produced g^{-1} dry nodules h^{-1}.

Plant analyses

Pigments content

Leaves from three independent plants per line were collected after 75 days of plant growth. The total chlorophyll was determined according to the method described by LICHTENTHALER *(*1987) as follows: 50 mg from the middle leaf tissue was soaked in 10 ml acetone 80% (*v/v*) and then frozen for 96 h in darkness. The chlorophyll extract was separated by centrifugation at 3000 rpm for 10 min, and then total chlorophyll was measured spectrophotometrically and expressed as mg g^{-1} fresh wt.

Nutrient and phytochemical analyses

The seed samples at the harvest stage were dried in an oven at 70 ºC for 48 h and then crushed using the electric mill. A digestion mixture of H_2SO_4 and $HClO_4$ was used to digest 0.5 g of powdered sample. Nitrogen (N%) was determined using the modified Kjeldahel method, phosphorus (P%) was estimated spectrophotometrically using stannous chloride reagent, and potassium (K) was measured by inductively coupled plasma optical emission spectroscopy (ICP-OES) (Optima 5300 Perkin Elmer Corp., USA) according to the standard procedures described by CHAPMAN and PRATT (1961). The micronutrient elements (Fe, Mn, and Zn) in seed digestate were analysed by means of ICP-OES. Proline content was determined following the method adopted by ROSEN (1957), and free amino acids were measured according to the protocol described by BATES et al. (1973). Protein content (%) was determined using nitrogen-to-protein conversion factors (NPCF, 6.25) as described by HYMOWITZ et al. (1972).

Statistical analysis

The obtained data were statistically analysed using COSTAT software, and mean values were statistically compared using the least significant differences (L.S.D.) at multiple range tests at a significance value of $p \leq 0.05$ (GOMEZ and GOMEZ, 1993).

Results

Influence of seeds priming on soil characteristics

As illustrated in Tab. 2, after 75 days from planting, the soil chemical properties were altered as compared to the initial values (Tab. 1). Seeds priming using MF and algal extracts, as either seed pre-soaking or foliar spraying, marginally decreased soil pH niches. The highest reduction was observed in the soil of seeds exposed to the sole MF with a time-dependent response. Similar observations were also detected in MFTS combined with the algal treatments, and the reduction effect was also correlated with MF exposure time, regardless of the algal species or application method, i.e., pre-soaking or foliar spray. Interestingly, the soil EC value was considerably decreased in all the treatments after 75 days from planting, and the highest reduction was observed in MFTS, ranging from (3.78 to 4.21 dS m^{-1}), particularly at long exposure time (≥ 30 min). Similar EC reduction patterns were also reported in MFTS combined with the algal treatments, and this reduction was greater in foliar spray application compared to seeds pre-soaking. Moreover, foliar spraying and seeds pre-soaking with *A. spicifera* + seeds priming for 45 min showed greater soil EC reduction (4.33 and 4.28 dS m^{-1}, respectively) compared to those in *H. clathratus*.

The available soil macronutrients (NPK) were remarkably increased with plant growth. The MFTS, either alone or combined with different algal amendments, increased the levels of the available soil NPK, particularly in seeds exposed to long-time MF (45 min > 30 min > 15 min > 0 min). The highest increase was found in MFTS combined with algal treatments as either foliar spray or seeds pre-soaking when compared with MFTS alone. Foliar application of *A. spicifera* + MFTS at 45 min, for instance, showed the highest soil NPK concentrations (i.e., 48.3, 5.3, and 198.6 mg kg^{-1}) followed by *H. clathratus* + MFTS at 45 min (i.e., 47.3, 5.3 and 196.8 mg kg^{-1}). A similar finding was found in the contents of micronutrients where the treatment with MFTS concomitant with the algal treatments, especially under foliar spraying, resulted in the highest Fe, Zn, and Mn in soil rhizosphere. This induction was progressively increased with increasing the seeds priming in the MF (45 min > 30 min > 15 min > 0 min), where foliar application of *A. spicifera* + MFTS at 45 min showed the highest soil Fe, Mn, and Zn (i.e., 8.31, 4.23, and 0.73 mg kg^{-1}) followed by *H. clathratus* + MFTS at 45 min (i.e., 8.27, 4.22, and 0.69 mg kg^{-1}) (Tab. 2).

At the harvest stage, seeds priming using the MF and algal extracts, either as seeds pre-soaking or foliar spray, showed a similar effect on the vegetative growth stage on soil pH (Tab. 3). The highest reduction in pH levels (8.01 to 8.06) was observed in seeds exposed to

the sole MF for 45 min as compared to the initial pH of 8.45 (see Tab. 1). The soil EC was considerably decreased in all treatments, and the highest EC reduction (3.22 dS m^{-1}) was observed in the treatment with MFTS at 45 min. Similar observations were also noticed in the treatment with MFTS and algal applications, where foliar application of *H. clathratus* combined with 30 min and 45 min seeds priming decreased EC gradients to 3.69 and 4.10 dS m^{-1}, respectively.

The available soil NPK and micronutrients (Fe, Zn, and Mn) were progressively increased at the harvest stage in all treatments, particularly at long exposure time to MF. The highest increases in N (55.0 mg kg^{-1}), P (6.3 mg kg^{-1}), K (213.8 mg kg^{-1}), Fe (8.7.5 mg kg^{-1}), Mn (5.33 mg kg^{-1}), and Zn (0.77 mg kg^{-1}) were observed in the treatment with MFTS at 45 min. Combining MFTS with *H. clathratus* or *A. spicifera*, either as foliar spraying or seeds pre-soaking, also enhanced levels of the soil NPK. For instance, foliar application of *H. clathratus* with MFTS at 45 min increased the soil NPK contents (i.e., 53.1, 5.6, and 209.9 mg kg^{-1}) followed by *A. spicifera* with MFTS at 45 min (i.e., 50.3, 5.2, and 199.4 mg kg^{-1}). Fe, Mn and Zn were much more increased by foliar application of *H. clathratus* with MFTS at 45 min (8.49, 4.99, and 0.74 mg kg^{-1}, respectively) than the foliar treatment with *A. spicifera* and MFTS at 45 min (i.e., 8.39, 4.85, and 0.67 mg k^{-1}, respectively).

Influence of seeds priming on faba bean yield

Seeds treated with MF, either alone or in combination with algal treatments, considerably increased the plant growth characteristics with a time-dependent response (Tab. 4). The highest inductive effect was obtained at 30 min of MF exposure time followed by 45 min dose. The MFTS at 30 min significantly increased plant height (17.7 - 22.7%), number of branches/plant (18.8 - 19.7%), number of pods per plant (57.5 - 67.7%), the weight of seeds/single plant (24.0 - 26.2%),

Tab. 2: Effect of seed priming with magnetic field (MF) and/or algal treatments on the soil properties after 75 days from planting. Data represent the mean of three replicates ($n = 3$).

Treatments	MF exposure times (min)	Methods	pH	EC (dS m^{-1})	available macronutrients (mg kg^{-1})			available micronutrients (mg kg^{-1})		
					N	P	K	Fe	Mn	Zn
A. spicifera	0	Seeds soaking	8.21	5.43	41.15	4.95	188.41	8.05	3.97	0.58
	15		8.16	5.36	44.56	5.04	192.00	8.09	4.02	0.62
	30		8.12	4.98	45.31	5.13	194.32	8.14	4.07	0.65
	45		8.08	4.28	48.20	5.22	195.20	8.19	4.09	0.69
average values			8.18	5.35	43.75	5.00	190.85	8.09	4.01	0.62
H. clathratus	0		8.27	6.13	40.85	4.82	186.32	8.03	3.84	0.57
	15		8.14	5.45	42.36	4.98	189.74	8.07	3.88	0.59
	30		8.11	4.88	43.69	5.06	190.00	8.12	3.97	0.61
	45		8.08	4.45	45.10	5.09	194.32	8.18	4.05	0.65
average values			8.20	5.25	43.15	4.99	190.25	8.10	3.95	0.61
MF	0		8.12	6.11	40.87	4.80	185.00	8.01	3.80	0.56
	15		8.09	5.25	42.56	4.89	188.00	8.03	3.85	0.57
	30		8.06	4.44	43.89	5.03	189.00	8.06	3.89	0.59
	45		8.03	4.21	44.17	5.07	191.00	8.14	3.96	0.62
average values			8.09	5.00	42.93	4.96	188.65	8.07	3.89	0.59
LSD for algal treatments			ns	ns	ns	ns	ns	ns	ns	ns
LSD at MF exposure times			ns	1.14	ns	ns	3.03	ns	ns	0.01
LSD for interaction			ns	*	ns	ns	*	ns	ns	***
A. spicifera	0	Foliar application	8.15	5.78	43.67	4.97	193.00	8.07	3.95	0.62
	15		8.08	5.20	46.10	5.07	194.63	8.15	4.06	0.67
	30		8.06	4.76	47.52	5.19	197.65	8.23	4.15	0.69
	45		8.04	4.33	48.33	5.32	198.55	8.31	4.23	0.73
average values			8.10	5.08	45.87	5.11	194.94	8.17	4.08	0.67
H. clathratus	0		8.18	5.80	43.22	4.95	190.22	8.04	3.90	0.59
	15		8.13	5.35	45.75	5.04	193.48	8.12	4.02	0.64
	30		8.09	4.89	46.44	5.17	194.66	8.20	4.12	0.66
	45		8.07	4.45	47.33	5.26	196.75	8.27	4.22	0.69
average values			8.13	5.17	45.30	5.08	193.19	8.14	4.05	0.64
MF	0		8.12	5.12	41.95	4.88	188.00	8.02	3.87	0.57
	15		8.06	4.55	43.11	4.96	193.45	8.10	3.95	0.62
	30		8.02	3.93	44.57	5.05	194.36	8.17	4.03	0.64
	45		8.00	3.78	46.37	5.11	194.89	8.19	4.08	0.67
average values			8.05	4.35	44.00	5.00	192.68	8.12	3.98	0.63
LSD for algal treatments			ns	ns	ns	ns	ns	ns	ns	ns
LSD at MF exposure times			ns	0.36	3.19	0.31	8.16	ns	0.32	0.018
LSD for interaction			ns	**	*	ns	***	ns	**	***

ns: non-significant; *: significant at $p < 0.05$, **: significant at $p < 0.01$; ***: significant at $p < 0.001$.

weight of 100 seeds (11.6 - 12.7%), seeds yield (ton fed^{-1}) (33.3 - 41.8%), and pods yield (ton fed^{-1}) (25.5 - 32%). Similarly, MFTS at 30 min exposure time, combined with seeds pre-soaking using *A. spicifera* or *H. clathratus* extracts, showed equivalent greater patterns in plant height (14.8, 21%), number of branches per plant (21.4, 19.5%), number of pods per plant (50.3, 62.8%), weight of seeds per plant (15.6, 17.7%), weight of 100 seeds (13.3, 9.9%), seeds yield (ton fed^{-1}) (13.9, 29.6%), and pods yield (ton fed^{-1}) (15.3, 17.2%), respectively. Also, MFTS at 30 min exposure time, concomitant with foliar application of *A. spicifera* or *H. clathratus* extracts, resulted in considerable increases in plant height (17.9, 17.4%), number of branches/plant (34.5, 18.7%), number of pods/plant (34.1, 61.7%), weight of seeds/plant (27.6, 28.5%), weight of 100 seeds (14.6, 13.8%), seeds yield (ton fed^{-1}) (32, 38.4%), and pods yield (ton fed^{-1}) (10.5, 13.3%).

In general, the total chlorophyll content was increased by MF exposure time either alone or in combination with algal treatments. The highest induction of total chlorophyll content (22.8-24.4%) was found at 45 min. However, applying MFTS at 45 min with seeds pre-soaking with *A. spicifera* or *H. clathratus* increased the level of total chlorophyll by 17.7 and 14.3%, respectively. Similar patterns were also obtained by the foliar algal applications. Overall, seeds priming in MF remarkably induced faba bean yield and yield components either applied alone or combined with the algal treatments, irrespective of the algal species. Interestingly, seeds priming by MF at 30 min induced the highest stimulating effects on faba bean yield components.

Effects of seeds priming on macro-micronutrients in seeds

The present study indicated that MFTS, either alone or in combination with algal treatments, significantly improved levels of macro- and micronutrients in seeds as compared to their respective controls (Tab. 5). Interestingly, the highest inductive effect in all treatments was observed in seeds exposed to 30 min MF. However, it is worth

Tab. 3: Seed priming effect using MF and/or algal treatments on the soil chemical properties at harvest. Data represent the mean of three replicates ($n = 3$).

Treatments	MF exposure times (min)	Methods	pH	EC (dS m^{-1})	available macronutrients (mg kg^{-1})			available micronutrients (mg kg^{-1})		
					N	P	K	Fe	Mn	Zn
A. spicifera	0	Seeds soaking	8.13	7.65	43.69	4.65	189.36	7.88	3.92	0.59
	15		8.09	6.24	45.21	4.89	192.00	8.03	4.15	0.62
	30		8.06	5.88	47.20	4.95	193.14	8.12	4.38	0.65
	45		8.07	5.96	45.66	4.88	190.25	8.05	4.25	0.63
average values			8.08	6.43	45.44	4.84	191.19	8.02	4.18	0.62
H. clathratus	0		8.15	7.35	42.65	4.78	191.00	7.95	3.98	0.61
	15		8.07	6.20	44.85	4.96	195.36	8.09	4.26	0.64
	30		8.05	5.33	46.95	5.10	198.33	8.22	4.49	0.68
	45		8.06	5.49	45.89	5.02	196.58	8.17	4.39	0.65
average values			8.08	6.09	45.09	4.97	195.32	8.11	4.28	0.65
MF	0		8.10	6.59	45.62	4.88	193.00	7.98	4.05	0.62
	15		8.07	5.12	47.35	5.08	197.63	8.15	4.68	0.66
	30		8.04	4.31	48.66	5.23	198.65	8.35	4.86	0.69
	45		8.06	4.68	47.88	4.98	197.88	8.25	4.75	0.67
average values			8.07	5.18	47.38	5.04	196.79	8.18	4.59	0.66
LSD for algal treatments			ns	ns	ns	ns	ns	ns	ns	ns
LSD at MF exposure times			ns	1.14	ns	ns	3.03	ns	ns	0.01
LSD for interaction			ns	*	ns	ns	*	ns	ns	***
A. spicifera	0	Foliar application	8.13	6.95	46.14	4.96	195.42	8.03	4.18	0.63
	15		8.08	5.24	49.35	5.12	198.32	8.29	4.88	0.68
	30		8.05	4.36	52.17	5.36	201.45	8.45	4.97	0.69
	45		8.06	4.50	50.32	5.22	199.38	8.39	4.85	0.67
average values			8.08	5.26	49.50	5.17	198.64	8.29	4.72	0.67
H. clathratus	0		8.13	6.48	46.85	5.03	196.00	8.05	4.28	0.65
	15		8.09	5.22	52.14	5.96	208.32	8.33	4.96	0.72
	30		8.05	3.69	55.36	6.21	214.65	8.56	5.07	0.75
	45		8.07	4.10	53.14	5.57	209.89	8.49	4.99	0.74
average values			8.09	4.87	51.87	5.69	207.22	8.36	4.83	0.72
MF	0		8.09	5.41	47.85	5.09	196.85	8.12	4.36	0.68
	15		8.05	4.36	53.14	5.99	212.00	8.65	5.18	0.74
	30		8.03	3.22	56.23	6.45	215.20	8.89	5.47	0.78
	45		8.01	3.85	55.00	6.33	213.75	8.75	5.33	0.77
average values				4.21	53.06	5.97	209.45	8.60	5.09	0.74
LSD for algal treatments			ns	ns	ns	ns	ns	ns	ns	ns
LSD at MF exposure times			ns	0.36	3.19	0.31	8.16	ns	0.32	0.018
LSD for interaction			ns	**	*	ns	***	ns	**	***

ns: non-significant; *: significant at $p < 0.05$, **: significant at $p < 0.01$; ***: significant at $p < 0.001$.

Tab. 4: Influence of seed priming with MF and/or algal treatments on faba bean yield. Data represent the mean of three replicates ($n = 3$).

Treatments	MF exposure times (min)	Methods	Plant height (cm)	No. of branches/ plant	No. of pods/ plant	Weight of seeds/plant (g)	Weight of 100 seeds (g)	Seeds yield (ton fed^{-1})	Pods yield (ton fed^{-1})	Total chlorophyll (mg g^{-1} fresh wt.)
A. spicifera	0	Seeds soaking	56.34	4.86	8.95	120.58	75.30	1.87	2.55	4.23
	15		58.33	5.32	11.00	134.00	82.95	1.95	2.79	4.76
	30		64.70	5.90	13.45	139.40	85.30	2.13	2.94	4.90
	45		60.53	5.65	15.39	135.33	84.88	2.10	2.85	4.98
average values			56.98	5.43	12.20	132.33	82.11	2.01	2.78	4.72
H. clathratus	0		60.51	4.98	9.12	123.75	80.73	1.89	2.68	4.89
	15		67.49	5.86	12.30	138.95	85.40	2.22	2.95	5.12
	30		73.20	5.95	14.85	145.66	88.76	2.45	3.14	5.23
	45		69.76	5.88	13.44	140.95	86.85	2.34	3.06	5.59
average values			67.74	5.67	12.43	137.33	85.44	2.23	2.96	5.21
MF	0		61.60	5.13	9.78	132.55	83.20	1.96	2.75	5.65
	15		69.55	5.75	13.54	152.33	87.60	2.43	3.14	6.75
	30		75.60	6.14	16.40	167.34	96.78	2.78	3.45	6.89
	45		72.89	5.96	15.84	160.88	93.10	2.64	3.33	6.94
average values			69.91	5.75	13.89	153.28	90.17	2.45	3.17	6.56
LSD for algal treatments			ns	ns	ns	ns	2.52	ns	ns	ns
LSD at MF exposure times			2.20	ns	2.21	6.42	2.39	ns	0.38	0.96
LSD for interaction			***	ns	***	***	**	ns	ns	ns
A. spicifera	0	Foliar application	62.10	5.10	12.89	137.00	78.20	1.94	2.86	4.85
	15		64.30	6.30	15.33	156.08	86.40	2.20	2.90	5.50
	30		73.20	6.40	17.29	174.77	89.62	2.56	3.16	5.88
	45		70.79	5.88	19.30	170.74	85.99	2.45	3.12	6.12
average values			67.60	5.92	16.20	159.65	85.05	2.29	3.01	5.59
H. clathratus	0		63.20	5.39	13.29	144.20	83.74	1.98	2.94	5.60
	15		66,85	5.98	18.20	168.40	89.70	2.55	3.12	6.86
	30		74.20	6.86	21.49	185.30	95.29	2.74	3.33	6.96
	45		72.19	6.20	20.54	183.10	92.72	2.65	3.30	7.12
average values			69.86	6.11	18.38	170.25	90.36	2.48	3.17	6.64
MF	0		67.40	5.80	17.40	152.40	88.30	2.13	2.84	5.85
	15		73.50	6.23	22.43	184.30	94.50	2.75	3.44	7.13
	30		79.30	6.89	27.40	188.94	98.50	2.84	3.75	7.22
	45		77.88	6.63	26.40	186.40	94.99	2.80	3.69	7.28
average values			74.52	6.39	23.41	178.01	94.07	2.63	2.43	6.87
LSD for algal treatments			ns	ns	ns	1.34	ns	ns	ns	ns
LSD at MF exposure times			3.17	ns	4.12	1.27	6.84	ns	0.22	ns
LSD for interaction			**	**	**	***	**	ns	ns	**

ns: non-significant; *: significant at $p < 0.05$, **: significant at $p < 0.01$; ***: significant at $p < 0.001$.

indicating that, further increase in MF exposure time marginally reduced amounts of macro- and micronutrients. In general, MFTS at 30 min resulted in the highest increases in NPK in seeds (i.e., 23.5%, 40%, and 18.5%, respectively) and also contents of Fe, Mn, and Zn (i.e., 6.6%, 18.0%, and 26.8%, respectively), as compared to the control. The foliar spraying with *H. clathratus* combined with MFTS at 30 min significantly increased NPK in seeds by 21%, 44.7%, and 19.3%, respectively, and concentrations of Fe, Mn, and Zn by 4.4%, 13.2%, and 21%, respectively. Meanwhile, foliar spraying of *A. spicifera* with MFTS at 30 min significantly increased NPK by 19.2%, 29.7%, and 17%, respectively, and Fe, Mn, and Zn by 8.3%, 10.7%, and 12.9, respectively. Combination of MFTS with pre-soaking in *A. spicifera* or *H. clathratus* extract showed also comparable patterns of macro-micronutrient elements to those obtained by foliar spraying. Overall, seeds priming with MF, particularly at 30 min exposure time, significantly induced levels of NPK and Fe, Mn, and Zn concentrations in faba bean seeds, irrespective of algal treatments.

Influence of seeds priming on the biochemical composition of seeds

The biochemical composition of seeds at harvest implies crop quality and indicates plant health. Data presented in Tab. 6 revealed that proteins (%) and free amino acid contents were markedly increased by MF exposure either alone or in combination with algal treatments. For more details, MFTS for 30 min considerably increased protein content by 22.2-23.-5%. Moreover, MF priming for 45 min had the highest stimulatory effects on free amino acid contents (13.4-14.9%). Correspondingly, MFTS for 30 min concomitant with seeds pre-soaking in *A. spicifera* or *H. clathratus* increased seed protein content by 22.2% and 17.5%, respectively. The highest free amino acid contents (15.4-16.3%) were obtained by MFTS for 45 min along with seeds pre-soaking with *A. spicifera* or *H. clathratus*, respectively. Similar patterns were also obtained in MFTS for 30 min with algal foliar applications (Tab. 6).

Interestingly, seeds priming in MF, either applied individually or coupled with algal treatments, remarkably decreased proline content

Tab. 5: Seeds priming effects using MF and/or algal treatments on macro-micronutrient elements in faba bean seeds. Data represent the mean of three replicates ($n = 3$).

Treatments	MF exposure times (min)	Methods	macronutrients (%)			micronutrients (mg kg^{-1})		
			N	P	K	Fe	Mn	Zn
A. spicifera	0	Seeds soaking	3.87	0.35	1.89	72.19	22.10	40.50
	15		4.22	0.43	2.13	74.22	23.39	43.20
	30		4.73	0.46	2.16	76.53	24.85	43.96
	45		4.63	0.44	2.15	75.10	23.90	43.67
average values			4.36	0.42	2.08	74.51	23.56	42.83
H. clathratus	0		3.88	0.36	1.94	73.00	22.44	41.90
	15		4.28	0.46	2.18	75.10	24.18	45.29
	30		4.56	0.49	2.22	78.22	24.88	45.87
	45		4.49	0.47	2.20	76.64	24.33	45.77
average values			4.30	0.45	2.14	75.74	23.96	44.71
MF	0		3.94	0.38	1.95	74.73	22.85	41.98
	15		4.47	0.48	2.23	77.40	25.85	46.75
	30		4.75	0.54	2.25	79.33	26.33	48.65
	45		4.66	0.49	2.24	77.98	25.56	47.90
average values			4.46	0.47	2.17	77.36	25.15	46.32
LSD for algal treatments			ns	ns	ns	ns	ns	ns
LSD at MF exposure times			ns	0.14	0.06	1.58	ns	0.66
LSD for interaction			**	***	***	*	**	*
A. spicifera	0	Foliar application	3.91	0.37	1.93	78.40	25.74	42.00
	15		4.36	0.45	2.22	82.90	27.30	45.75
	30		4.66	0.48	2.26	84.89	28.49	47.40
	45		4.55	0.46	2.19	80.33	27.10	45.98
average values			4.37	0.44	2.15	81.63	27.16	45.28
H. clathratus	0		3.95	0.38	1.97	82.10	26.20	43.90
	15		4.55	0.53	2.26	84.93	28.33	47.59
	30		4.78	0.55	2.35	85.75	29.67	53.10
	45		4.70	0.54	2.28	84.65	28.54	51.75
average values			4.50	0.50	2.22	84.36	28.19	49.09
MF	0		3.95	0.40	2.05	83.00	28.33	44.75
	15		4.82	0.54	2.35	86.54	32.19	51.30
	30		4.88	0.56	2.43	88.50	33.45	56.74
	45		4.84	0.58	2.38	87.90	30.75	54.87
average values			4.62	0.52	2.30	86.49	31.18	51.92
LSD for algal treatments			2.91	ns	ns	1.27	ns	ns
LSD at MF exposure times			2.24	0.04	0.05	0.84	2.13	1.14
LSD for interaction			***	***	***	**	ns	**

ns: non-significant; *: significant at $p < 0.05$, **: significant at $p < 0.01$; ***: significant at $p < 0.001$.

of faba bean seeds at the harvest stage. This reduction was a dose-dependent response, where MFTS at 45 min significantly decreased the proline by 55.3-60.8% with respect to the control. Similarly, the treatment by MFTS for 45 min and seeds pre-soaking with *A. spicifera* or *H. clathratus* decreased proline by 44.1% and 47.6%, respectively, and by 50.2% and 57% in the case of foliar application.

Effects of seeds priming on N_2-fixation efficiency and soil microbial activity

The interactive effects of seeds priming in MF, either alone or combined with seaweeds treatments, on soil microbial activity such as nitrogenase activity and CO_2 evolution are represented in Fig. 2. The nitrogenase activity and CO_2 evolution were progressively decreased with increasing exposure time to MF when MF was combined with algal treatments. For instance, MFTS at 15 min combined with seeds pre-soaking with *A. spicifera* or *H. clathratus* had greater nitrogenase activity, i.e. 7.8 and 3.6 µmol C_2H_4 g^{-1} dry nodule h^{-1}, respectively, and CO_2 evolution, *i.e.* 385 and 550 CO_2 mg 100 g^{-1} soil, respectively.

A similar observation was found in the foliar application where higher nitrogenase activities, *i.e.* 2.7 and 5.1 µmol C_2H_4 g^{-1} dry nodule h^{-1}, and CO_2 evolution, *i.e.* 385 and 418 CO_2 mg 100 g^{-1} soil, were obtained by applying MFTS at 15 min and *A. spicifera* or *H. clathratus*, respectively. Contrarily, the individual application of MF exhibited the highest nitrogenase activity at 45 min of exposure by 9.4 C_2H_4 g^{-1} dry nodule h^{-1}, followed by 3.8 C_2H_4 g^{-1} dry nodule h^{-1} at 30 min. This result was in accordance with CO_2 evolution showing a greater evolution by 490 and 368 CO_2 mg 100 g^{-1} soil at 45 min and 30 min, respectively.

Tab. 6: Effects of seed priming with MF and/or algal treatments on chemical composition of seeds. Data represent the mean of three replicates ($n = 3$).

Treatments	MF exposure times (min)	Methods	Protein (%)	Proline (mg g^{-1} dry wt.)	Free Amino acids (mg g^{-1})
A. spicifera	0	Seeds soaking	24.19	54.78	97.80
	15		26.38	47.80	99.54
	30		29.56	37.84	104.75
	45		28.94	30.64	112.84
average values			27.27	42.77	103.73
H. clathratus	0		24.25	50.54	106.44
	15		26.75	42.40	114.84
	30		28.50	32.19	120.75
	45		28.08	26.48	123.74
average values			26.90	37.90	116.44
MF	0		24.63	48.50	113.46
	15		27.94	35.55	122.40
	30		29.69	27.89	126.80
	45		29.13	18.99	130.32
average values			27.85	32.73	123.25
LSD for algal treatments			ns	ns	ns
LSD at MF exposure times			1.44	2.10	4.93
LSD for interaction			*	***	***
A. spicifera	0	Foliar application	24.44	45.66	116.44
	15		27.25	36.86	123.89
	30		29.13	29.54	126.84
	45		28.44	22.76	133.47
average values			27.32	33.71	125.16
H. clathratus	0		24.69	35.87	118.55
	15		28.44	26.43	125.43
	30		29.88	19.54	132.66
	45		29.38	15.44	136.00
average values			28.10	24.32	128.16
MF	0		24.69	30.75	122.53
	15		30.13	21.86	128.96
	30		30.50	17.90	135.67
	45		30.25	13.76	138.90
average values			28.89	21.07	131.52
LSD for algal treatments			ns	1.36	ns
LSD at MF exposure times			ns	3.82	2.14
LSD for interaction			*	***	***

ns: non-significant; *: significant at $p < 0.05$, **: significant at $p < 0.01$; ***: significant at $p < 0.001$.

Discussion

Seeds priming using MF and algal treatments improved the soil's chemical properties:

Salt stress has a detrimental effect on seed germination either osmotically through low water absorption or ionically through induced imbalance of nutrient uptake due to Na^+ and Cl^- accumulation (Murillo-Amador et al., 2002; Khajeh-Hosseini et al., 2003). Among soil chemical properties, pH and EC significantly affect plant growth and productivity, particularly under salinity stress. The high soil pH negatively affects the pH-dependent charge of clay and organic matter, which in turn have severe effects on the structure and physical characteristics of the soil (Abbas et al., 2014). The present study indicated that MFTS, either alone or concomitant with algal treatments, decreased the soil EC level and slightly shifted soil pH from 8.45 to 8.01, particularly under MF long priming time (≥ 30 min). Our findings coincide with the results obtained by El-Shakweer et al. (2008), where they observed significant decreases in soil EC and sodium adsorption ratio (SAR) in an algae-amended sandy loam soil. Furthermore, it has been found that incorporating algae with pumice to a sandy soil alleviated the impact of irrigation with saline water on the growth of *Medicago sativa* (Kong et al., 2021). Algal residues have also been shown to reduce EC because they offer cation exchange sites, and they, therefore, can reduce SAR by displacing Na^+ with additional cations that are added with the residues (El-Shakweer et al., 2008). In our study, treating faba bean seeds with the MF, either alone or pre-soaking or foliar application with the algal extracts, distinctly increased concentrations of the soil available macro- and micronutrients as compared to the untreated seeds under salt stress conditions. Supporting our observations, soaking the fodder beet seeds in organic solutions of polyethylene glycol and humic acid remarkably increased available soil NPK under salinity stress conditions (Abbas et al., 2014). Marine algae are rich sources of bioactive and plant growth promoting hormones.

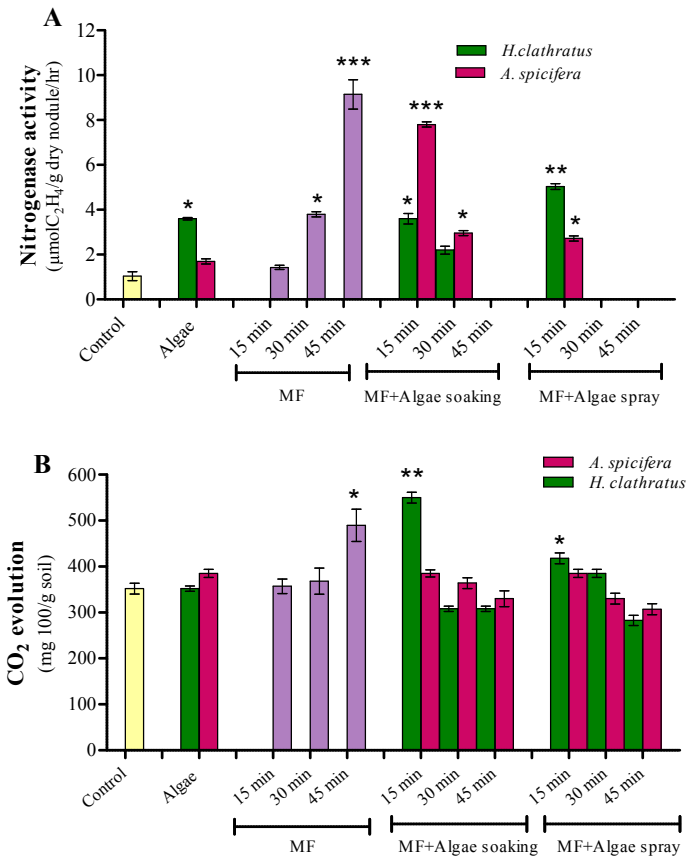

Fig. 2: Effects of faba been seeds priming with magnetic field (MF) and/or algal treatments on N_2-fixation efficiency (A) and soil microbial activity (B). Algal treatments were applied as seeds pre-soaking or foliar spraying using extracts of *Hydroclathrus clathratus* and *Acanthophora spicifera*. Data represent the mean of three replicates ($n = 3$). *: significant at $p < 0.05$, **: significant at $p < 0.01$; ***: significant at $p < 0.001$.

Thus, seed priming and/or foliar application of algal extract induce the symbiotic relationship between plant and soil microflora, which synergistically improve the free living and symbiotic N_2 fixers, and phosphate solubilizing bacteria, leading to increased NPK levels in soil rhizosphere (Kang et al., 2021).

Seeds priming using MF and algal treatments increased faba bean productivity and quality:

Plant resistance to abiotic stresses is increased by seed priming via a variety of metabolic pathways. Primed seeds exhibited early and uniform germination as well as a rapid cellular defense response to abiotic stressors (Jisha et al., 2013; Podleśna et al., 2019). Our findings revealed that MFTS at 30 min, either alone or concomitant with algal treatments, significantly increased the plant growth characteristics such as number of branches/plant, number of pods/plant, weight of seeds/single plant, weight of 100 seeds, seeds yield (ton/fed), and pods yield (ton/fed). MFTS displayed greater weight dynamics at the time of imbibition and considerably increased the amount of amylolytic enzymes as well as gibberellic acid 1 (GA1) and indole-3-acetic acid (IAA) in faba bean seedlings (Podleśna et al., 2019) and *Pisum sativum* (Podleśny et al., 2021). MF has been reported to increase the number of hydrogen bonds in molecules and raise cell permeability and active energy in cell electrolyte solutions, which, in turn, may have a positive impact on the plant enzymatic activity and other biochemical and physiological processes (Dhawi, 2014).

Marine macroalgae have several powerful agricultural advantages. They can efficiently enhance crop productivity under a variety of habitats (Hamed et al., 2018). The phytoelicitor activity of marine macroalgae significantly contributed to induce plant resistance to several diseases, pests, and abiotic stressors (e.g., salinity, cold, and drought) (Ali et al., 2021). Their unique components have been emphasized to up-regulate the plant phytohormones and antioxidants (Ibrahim, 2016; Ali et al., 2021). Under salinity stress, seeds presoaking using different marine macroalgal species resulted in a highly significant improvement in seed germination and growth parameters in wheat (Ibrahim, 2016). Inductive effects of seaweeds on faba bean growth and productivity been previously reported by Salah El Din et al. (2008). In agreement with our findings, foliar spraying of extracts of *Sargassum latifolium*, *Halimeda opuntia*, in a field experiment, improved the root and shoot growth parameters, increased pigment concentrations, number of tillers and pods per plant, and grain and straw yields. In this context, soil amendments by applying seaweeds effectively alleviated the salinity stress on canola plants by increasing the levels of chlorophyll *a* and *b*, growth-promoting hormones, and carbohydrates. In the present study, MFTS and/or algal treatments decreased proline content in seeds. Salt stress on barley roots enhances proline utilization by expression of genes encoding cell wall proteins (proline rich protein and extensin) (Ueda et al., 2007). Thus, we assume that at the harvest stage, an increased level of proline utilization for proteins synthesis, which enhances proteins turnover in seeds. Thus, in our study, the stimulatory effects of seaweeds with MF on faba bean productivity and yield under salt stress conditions, indicating their valuable applications as biostimulant agents and plant osmoprotectants.

Seeds priming with MF and/or algal treatments improved seeds quality:

In our study, MFTS either applied individually or integrated with algal treatments, significantly increased seeds macro- and micronutrient elements at harvest stage (see Tab. 5), protein (%) and free amino acid contents (see Tab. 6). In line with our observations, seeds priming with the MF remarkably enhanced enzymatic activities of α- amylase and protease in maize and soybean seeds, which led to early germination and vigor seedling growth under different salinity levels (Kataria et al., 2017). In the present study, seaweed treatments, either as seed pre-soaking or foliar application, positively improved the biochemical composition in seeds at harvest. Our findings are in accordance with the results obtained by Hussein et al. (2021) where they found that seeds priming in the extracts of *Ulva fasciata*, *Cystoseira compressa*, and *Laurencia obtusa* ameliorated salinity stress, improved seed germination, and promoted NPK and seeds biochemical composition of *Vigna sinensis* and *Zea mays* under salt stress. Based on our findings, we can say that foliar applications of the seaweed extract increased levels of carbohydrates, proteins, total soluble sugars, free amino acids, and percentages of N, P, and K in faba bean seeds (Salah El Din et al., 2008). In agreement with our observations, foliar application of combined microalgae-cyanobacteria formulations improved osmotic adjustment and ion homeostasis and boosted nutrient uptake and growth under salt stress conditions in tomato (Mutale-Joan et al., 2021). The recent study conducted by Selem (2019) also supports well our findings where she investigated the physiological effects of *Spirulina platensis* in salt-stressed *Vicia faba* plants, and reported increased activity in photosynthesis, total protein, and NPK levels, suggesting that exogenously applied *S. platensis* (100 mg l^{-1}) is highly effective against salinity stress.

Seeds priming with MF and algal treatments improved soil fertility indices:

Our field study demonstrated that MFTS at 15 min and algal treatments achieved the best soil fertility indices (CO_2 evolution and nitrogenase activity). In fact, seaweed extracts and their derivatives

significantly change the microbiome components of soil leading to vigorous plant growth with optimal yields (Ali et al., 2021). Seaweeds are widely investigated and traditionally used as biofertilizers and soil conditioner agents (Hamed et al., 2018). Their high levels of organic matter, nitrogen, phosphorus, and potassium led to soil nutrient enrichment and increased microbial soil diversity (Layek et al., 2018). Lastly, the combined effect of seed priming in MF, particularly at ≥30 min exposure time with algal treatments, alleviated salinity stress on faba bean, improved growth parameters, yield components, and seeds quality, and positively upgraded soil fertility under natural salt stress conditions.

Conclusions

In the present study, MFTS of faba bean, either alone or coupled with the seaweed treatments of *Hydroclathrus clathratus* and *Acanthophora spicifera*, manipulated the soil chemical properties by decreasing soil conductivity and pH gradients, and also increased the availability of soil macro- and micro-nutrients, particularly at an exposure time ≥30 min. It is worth indicating that MFTS and/or MFTS coupled with seaweed treatments at 30 min obviously induced the whole plant growth parameters, raised levels of macro- and micronutrients in seeds, improved seeds quality, and upgraded the soil fertility indices (CO_2 evolution and nitrogenase activity). Furthermore, the aforementioned treatments alleviated the salinity stress on *V. faba* plants by distinct increases in concentrations of proteins and amino acids, as well as decreasing the stress osmoprotectant 'proline'. Overall, seeds priming in a MF is an easily applicable technology that could be applied with the seaweed extracts, in particular the foliar application, to enhance planting *V. faba* seeds under salinity stress conditions.

Author contributions

Conceptualization, S.M.H.; N.M.E. and K.A.H.S.; methodology, S.M.H.; N.M.E. and K.A.H.S.; software, S.M.H.; N.M.E. and K.A.H.S.; validation, S.M.H.; N.M.E., A.A.S. and K.A.H.S.; formal analysis, S.M.H.; N.M.E. and K.A.H.S.; investigation, S.M.H.; N.M.E. and K.A.H.S.; resources, S.M.H.; N.M.E. and K.A.H.S.; data curation, S.M.H.; N.M.E., A.A.S. and K.A.H.S.; writing-original draft preparation, S.M.H.; N.M.E. and K.A.H.S.; writing-review and editing, S.M.H.; N.M.E., M.Y.A.M. and A.A.S., A.S.A. and S.M.K.; visualization, S.M.H.; N.M.E., M.Y.A.M., K.A.H.S. and A.A.S.; supervision, S.M.H.; N.M.E., M.Y.A.M. and K.A.H.S.; project administration, S.M.H.; N.M.E. and K.A.H.S; funding acquisition, A.S.A. and S.M.K. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2024R357), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Data availability statement

Data are available upon request from the authors.

Acknowledgments

The authors deeply thank the Soils, Water and Environment Research Institute (SWERI), and the Sandy and Calcareous Soils Department, Soils, Water and Environment Research Institute, Agricultural Research Center, Giza, Egypt for providing all facilities and consulting to conduct this research work. The authors thank Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2024R357), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Conflicts of interest

No potential conflict of interest was reported by the author.

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Supplementary Material

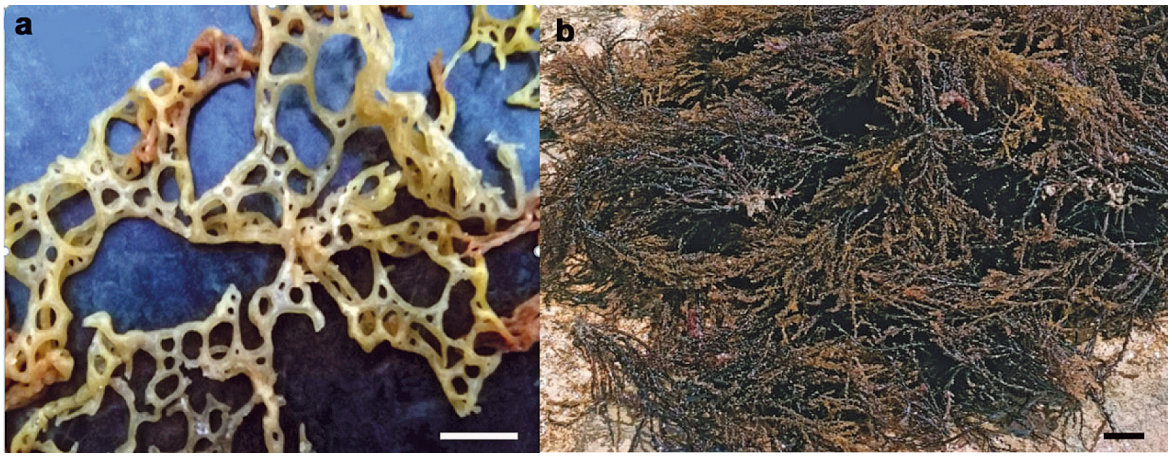

Fig. S1: Phenotypic examination of the seaweeds (**a**) *Hydroclathrus clathratus* and (**b**) *Acanthophora spicifera* used in the present study. Scale bars: (a) = 1 cm (a); (b) = 2 cm.