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Effects of brown algal fertilizers on tomato yield and fruit quality

SAID BAROUD♥, SAIDA TAHROUCH, ABDELHAKIM HATIMI
Laboratory of Plant Biotechnologies, Faculty of Sciences, Ibn Zohr University. PB 8106, Agadir, Morocco. Tel.: +212-528227125, Fax.: +212528227260, ♥email: saidbaroud@gmail.com

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Abstract. *Baroud S, Tahrouch S, Hatimi A. 2025. Effects of brown algal fertilizers on tomato yield and fruit quality. Asian J Agric 9: 454-462.* The purpose of this study was to evaluate the biofertilizer potential of three brown algae: *Fucus spiralis*, *Cystoseira gibraltarica*, and *Bifurcaria bifurcata*. Over ninety days, the growth of the algae was monitored. The algae were applied in two different forms and at varying concentrations: aqueous extract (0.5%, 1%, and 2%) and amendment (C1, C2, and C3). For each algal treatment, ten pots were used, with one plant per pot (10 replicates per treatment). Each pot received 50 mL/week of the algal extract, corresponding to three concentrations (0.5%, 1%, and 2%). For the amendment, the treatments consisted of three increasing concentrations: C1 (2.5 g/pot), C2 (5 g/pot), and C3 (10 g/pot). The low concentration algal extracts significantly improved growth parameters—such as length of the aerial part, root length, plant height, fresh weight, and dry weight—and yield indicators like the number of flowers, fruits, and the fresh weight of fruits, compared to the control. Fertilization with *F. spiralis* amendment C1 notably enhanced the length of the aerial part, root length, and overall plant height (115, 41, and 156 cm, respectively). Improvements in sugar content, Brix, and fruit diameter were observed in fruits treated with *C. gibraltarica* at 1% (4.95%, 4.33%, and 55.66 mm, respectively). Additionally, the algal extracts with low concentrations of *B. bifurcata* and *F. spiralis* exhibited the highest mineral content in tomato leaves. The aqueous extract of *B. bifurcata* at 0.5% showed the highest levels of organic matter and total nitrogen in leaves (84.68% and 2.1%, respectively). Overall, these three algae proved to be effective and suitable candidates for developing biostimulants aimed at enhancing tomato growth, yield, and fruit quality. This study provides valuable information regarding the identification and application of Moroccan algae resources in agriculture.

Keywords: Biofertilizer, macroalgae, nutrient uptake, organic amendments, tomato agronomy

INTRODUCTION

Greenhouse farming plays a vital role in Morocco's economy by supplying high-quality produce to the market during the off-season. By creating optimal growing conditions, greenhouses enable the production of superior vegetables that surpass those grown in natural environments. The primary purpose of greenhouses is to provide a controlled and favorable environment for market garden crops, shielding them from external threats and health risks (Lappalainen et al. 2016). By regulating the climate and minimizing hazards, greenhouses ensure ideal growing conditions, resulting in enhanced crop quality.

Container gardening, also called pot cultivation, involves growing plants, including vegetables, solely in pots rather than in the ground (Megersa et al. 2018). This method is especially useful in areas with poor soil quality or harsh environmental conditions. Additionally, growing plants in pots is advantageous for scientific experiments, as it allows for controlled conditions before scaling up to in-ground farming. When combined with optimal greenhouse conditions, algal fertilization can further boost crop growth and yield, making it a promising way to improve greenhouse productivity.

Morocco's unique marine currents and hydroclimatic conditions create an ideal environment for the rapid and efficient growth of various algae species, particularly brown algae, compared to terrestrial plants (Kindleysides et al. 2012). The Atlantic coast, especially the Cap Ghir area, is rich in brown algae, including species like *Cystoseira gibraltarica, Bifurcaria bifurcata,* and *Fucus spiralis*. This abundance warrants further research into harnessing these resources for industrial applications, particularly in agriculture. However, the biochemical composition of brown algae found on Morocco's coastline remains understudied, highlighting the need for more comprehensive investigations.

Morocco has made significant strides in agriculture, particularly in the Souss Massa region, known for its diverse crop production (Harbouze et al. 2019). To maintain its position, adopting effective organic fertilizers is crucial for achieving high-quality production. Research suggests that algal extracts can partially replace conventional fertilizers (Ammar et al. 2022). Moreover, algal extracts have been shown to enhance fruit yield, quality, phytochemical parameters, and mineral composition in plants (Elansary et al. 2016). Studies have consistently demonstrated the positive impact of algal extracts on vegetable plant growth and yield (Sharma et al. 2014). For instance, aqueous extracts of *Sargassum johnstonii* have been found to improve tomato plant growth, yield, fruit quality, lycopene, and vitamin C content (Abu et al. 2022). In spite of the evolving global interests and market demand for algal biomass and metabolites, studies and applications pertaining to sustainable agriculture challenges, such as soil nutrient deficiency, drought stress, soil toxicity, leaf discoloration, and plant growth stunts, are limited (Pan et al. 2020).

Algal fertilizers are rich in plant growth-promoting substances, including auxins, cytokinins, and betaines, which can enhance plant development (Mondal and Panda 2019). These substances influence both aerial and root growth (Ali and Baloch 2020). Additionally, algal fertilizers provide essential macronutrients (N, P, K, Ca, and Na) and micronutrients (Fe, Zn, Mn, and Cu) that promote fruit growth and yield (Hamouda et al. 2016). The benefits of algal fertilizers include improved plant growth, fruit quality, vigor, and resistance to pathogens (Mondal and Panda 2019). For instance, aqueous extracts of *Ascophyllum nodosum* have been shown to increase chlorophyll a and b content in tomato plants (Goñi et al. 2018). Given the advancements in agriculture, particularly in crop diversity (Harbouze et al. 2019), adopting effective biological fertilizers is crucial for maintaining high-quality production and sustaining our country's position in the field. Products derived from brown algae contain a large number of bioactive compounds (carbohydrates, phytohormones, vitamins, phenolic compounds, proteins, amino acids, carotenoids, and beneficial and essential elements) and have an important impact on agriculture due to their effectiveness in improving plant growth (Sariñana-Aldaco et al. 2025). This study evaluates the effects of foliar and soil-applied brown algal fertilizers on tomato yield and quality.

MATERIALS AND METHODS

Plant material

Three species of brown algae, *Cystoseira gibraltarica, Bifurcaria bifurcata,* and *Fucus spiralis* were collected at low tide, in the coastal area of Cap Ghir (30°38'37 "N, 09°53'20 "W), located about 43 km northwest of Agadir (Morocco). The collected seaweed species are washed on site and then put in seawater. In the laboratory, the samples are sorted, identified and then rinsed thoroughly with fresh water to eliminate all impurities: sand, salt, shell debris, and some epiphytes. For each wash, electrical conductivity measurements were taken. The algae were then dried at room temperature and protected from sunlight by spreading the samples on sieves for 10 days. After drying, the samples are reduced to a powder, which is stored in a dry place.

Preparation of treatments

Amendments

Three amendments are prepared based on the concentrations used in organic agriculture, 25 kg/100 m^2. Each pot contains 5 kg of substrate consisting of a mixture of 75% soil and 25% peat. Three amendments are determined: C1 (2.5 g/pot), C2 (5 g/pot), and C3 (10 g/pot).

Algal extracts

Five g of powder of each algal species are added to 100 mL of distilled water under magnetic stirring for 24 h. The recovered supernatant is filtered, and the obtained aqueous extracts are then stored in a cool place. These extracts are designated as stock solutions and coded according to genus and species: *C. gibraltarica* (CG), *B. bifurcata* (BB), and *F. spiralis* (FS). The stock solution of each alga was diluted with water to arrive at three concentrations (0.5, 1, and 2%).

Greenhouse growth bioassay

Certified tomato seeds (*Solanum lycopersicum*) of the Campbell variety, marketed by the Technisem company, were germinated in blister plates containing peat. After 25 days of germination, 200 plants were selected at the four-leaf stage and transplanted into pots containing 5 kg of a mixture of 75% soil and 25% peat. For each algal treatment, ten pots were used, with one plant per pot (10 replicates per treatment) (Table 1). Each pot receives 50 mL/week of the algal extract, which is represented by three concentrations (0.5, 1, and 2%). For the amendment the treatment is also represented by three increasing concentrations: C1 (2.5 g/pot), C2 (5g/pot), and C3 (10 g/pot). At the same time, we used a witness that received only water and a control treated with a chemical fertilizer (Maxi Greene: N:20, P:20, K:20) (Table 1).

Spraying with aqueous extracts was applied two weeks after sowing at a rate of 50 mL per week for three months. Fertilization through amendment was done at the time of transplanting the plants with the three different concentrations determined previously. All pots were irrigated with 50 mL of water every other day during the cultivation period. At flowering, the number of flowers per plant was counted. After 90 days of cultivation, the tomato fruits were harvested, and the plants were carefully removed and washed. Then, we measured various growth parameters such as the length of the aerial part, root length, total length, as well as the fresh and dry weights of the plant. Mineral analyses of the leaves, fruit yield (including the number of leaves, number of fruits per plant, and fruit weight), and fruit quality parameters (diameter, firmness, brix, sugar content, and maturity index) were also conducted.

Determination of growth parameters

Plant growth is measured based on length, fresh and dry weight of the plant, number of leaves, and number of flowers per plant. The dry weight is determined after drying at 80°C until the weight stabilizes. The dry weight is expressed in grams.

Determination of the mineral elements of the leaves

The determination of the mineral content of tomato leaves is carried out according to the method of Page et al. (1982).

Determination of fruit yield

Determination of fruit yield is done at the end of the crop at the time of harvest. We also determined the number of leaves, the number of flowers, the number of fruits per plant, and the fruit weight.

Table 1. Diagram of treatments (amendment and spraying) carried out in a pot greenhouse

	Concentrations	*B. bifurcata* (BB)	*C. gibraltarica* (CG)	*F. spiralis* (FS)	Witness (water)	Control (maxi greene)
Amendments	C1 (2.5 g/pot)	10 repetitions	10 repetitions	10 repetitions	10 repetitions	10 repetitions
	C2 (5 g/pot)	10 repetitions	10 repetitions	10 repetitions	10 repetitions	10 repetitions
	C1 (10 g/pot)	10 repetitions	10 repetitions	10 repetitions		
Spraying	0.50%	10 repetitions	10 repetitions	10 repetitions	10 repetitions	10 repetitions
	1%	10 repetitions	10 repetitions	10 repetitions	10 repetitions	10 repetitions
	2%	10 repetitions	10 repetitions	10 repetitions		
		10 repetitions	10 repetitions	10 repetitions	10	10

Determination of fruit quality

We measured some parameters of fruit quality, such as diameter, firmness, brix, sugar content, and fruit maturity index.

Fruit diameter

Caliper carries out the determination of the diameter, and it consists of measuring the equatorial diameter and the polar diameter of the fruit.

Fruit firmness

The firmness is measured with a penetrometer (dynamometer), which measures the force necessary to make a calibrated tip penetrate a certain depth in the fruit. The firmness of the fruit depends, among other things, on its level of maturity and its stage of development. The results are expressed in kg/cm².

Brix

Brix is defined as the number of grams of soluble dry matter per 100 g of product. This soluble dry matter is made up of about 80 to 85% sugars, 10% citric acid and its salts, and the rest is made up of nitrogenous substances and other soluble substances (Ting and Rouseff 1986). The Brix is determined according to the AFNOR standard (1988). To measure the refractometric index, it is sufficient to pour a few drops on the prism of the refractometer and turn the device towards a light source. The reading is done on the scale of the eyepiece, at the intersection of the light and dark areas.

Sugar content

The determination of the sugar content is based on the optical property of a sugar solution to reflect light. The percentage of dry matter measured is called the refractometric index, which is expressed in degrees brix (°Brix). The value read in °Brix must be corrected for the temperature of the juice according to the following relationship:

(Soluble Dry Extract) = °Brix lu ±z 0,08 x (T°C - 20°C)

Where:

z: + if the temperature is above 20°C, - if the temperature is below 20°C

0.08: correction index of the refractometer prism

Acidity (% of citric acid)

A sodium hydroxide solution (NaOH 0.1 N) is used to neutralize total free acidity in order to quantify acidity. The neutralization process is tracked using phenolphthalein, a colored reagent. When the pH reaches 8.1 to 8.2 (all acids are neutralized) or the indicator becomes pink or orange (phenolphthalein turning point), the experiment is terminated. Using 10 mL of filtered and homogenized juice and 10 mL of distilled water, perform the acid-base test by adding three to four drops of phenolphthalein and then gradually adding the sodium hydroxide solution (in a graduated burette) until the turning point (pink/orange) is achieved.

The following formula yields the percentage (%) of citric acid:

%A.C (% Citric acid)= (Q.AC)/(d x 10)

Where:

QAC (Quantity of acid): 0.64 x V(NaOH) (g citric acid/l juice).

d (Density of juice): (Weight of juice)/(Volume of juice)

Maturity index

The maturity index, which is the ratio of sugars to acidity of the juice, allows for determining the state of maturity of the fruits. The following formula calculates it:

$$\text{Maturity index} = \frac{\text{Soluble dry extract}}{\text{\% of citric acid in the juice}}$$

Statistical analysis

The STATISTICA software, version 6.0, has processed the data. The analysis of variance (ANOVA) was used to determine the degree of significance. The averages were compared using Duncan's Multiple Range Test (DMRT) at the probability level (P-value).

RESULTS AND DISCUSSION

Mineral analysis of the algae

The results obtained from the mineral analysis of the three brown algae (*Cystoseira gibraltarica, Bifurcaria bifurcata,* and *Fucus spiralis*) showed the presence of various macroelements and microelements (Table 2). K is well represented in the extracts of the three algae, with a higher content in *B. bifurcata* (5.02 g/100 g DM), followed by *F. spiralis* (4.96 g/100 g DM) and *C. gibraltarica* (4.12 g/100 g DM). In contrast to K, P is not very concentrated in all three algae (Table 2).

The concentration of N and Ca is high in *B. bifurcata* (1.75 and 3.24 g/100 g DM, respectively). While Mg, P and Na are rather high in *F. spiralis* extract (1.03, 0.2, 1.85

g/100 g M.S., respectively). The concentration of Fe, Cu, and organic matter is well represented in the extract of *C. gibraltarica* (55.92, 25.76 mg/kg, and 73.44 g/100 g DM, respectively) and *F. spiralis* (55.94, 25.76 mg/kg, and 73.74 g/100 g M.S, respectively). The concentration of Mn is higher in the extract of *C. gibraltarica* (18.45 mg/kg DM), and *B. bifurcata* has high contents of Zn (13.6 mg/kg DM) and Mn (18.44 mg/kg DM). On the other hand, the extract of *F. spiralis* contains the highest content of Mg (1.03 mg/kg DM). We notice in general that the macroelement contents of the algae are close to each other; on the contrary, the microelement contents are different from one species to another (Table 2).

Effect of algae on growth parameters of greenhouse tomato

Based on the results obtained in Table 3, we observed that there is a significant improvement (P≤0.05) in the growth parameters of tomato, whether through the use of aqueous extracts or amendments. The tomato plants treated with the amendments and aqueous extracts of the three brown algae generally show significant differences compared to the control. The algal extracts of *B. bifurcata, C. gibraltarica,* and *F. spiralis* significantly increased the length of the aerial part compared to the control.

Indeed, *C. gibraltarica* extract at 2% was significantly the most effective (134.8 cm), followed by *F. spiralis* extract at 0.5% (133.75 cm) and finally *F. spiralis* algal extract at 2% (126.1 cm). Regarding the amendments, *B. bifurcata* and *F. spiralis* were also statistically effective in improving the length of the aerial part of tomato plants compared to the control. Indeed, *B. bifurcata* at C2 was significantly effective (125.5 cm), followed by the alga *F. spiralis* at C1 (115 cm) and finally the C1 amendment of *B. bifurcata* (109.3 cm) (Table 3).

Table 2. The content of macro and microelements in the extract of the three brown algae

Species	g/100 g							mg/kg			
	OM	N	Ca	K	Mg	P	Na	Fe	Mn	Cu	Zn
BB	69.68	1.75±0.1	3.24±0.3	5.02±0.2	0.66±0.6	0.16±0.1	1.65±0.4	37.28±0.4	18.44±0.1	12.87±0.08	13.6±0.1
CG	73.44	1.38±0.1	2.46±0.1	4.12±0.3	0.74±0.1	0.12±0.1	0.98±0.2	55.92±0.5	18.45±0.1	25.76±0.9	5.45±0.1
FS	73.74	1.33±0.8	2.34±0.2	4.96±0.1	1.03±0.8	0.20±0.2	1.85±0.3	55.94±0.9	9.22±0.1	25.76±0.8	5.46±0.2

Note: The values represent the mean ± SD (n=3). BB*: B. bifurcata*, CG: *C. gibraltarica*, and FS: *F. spiralis*. OM: organic matter, N: nitrogen, Ca: calcium, K: potassium, Mg: manganese, P: phosphorus, Na: sodium, Fe: iron, Magnesium, Cu: copper, Zn: zinc

Table 3. Effect of the algae *C. gibraltarica* (CG), *B. bifurcata* (BB), and *F. spiralis* (FS) by both treatments (Spraying and amendment) at different concentrations on the growth parameters of tomato. Values are presented as mean ± standard deviation (n=10)

Treatments	Length of the aerial part (cm)	Length of the root part (cm)	Total length (cm)	Fresh weight of the plant (g)	Dry weight of the plant (g)
Spraying					
Control	125.2±2.61 c	40.6±2.22 f	176.8±2.04 b	54.74±1.07 c	11.9±0.46 a
Witness	86.1±2.23 g	34.9±1.28 h	121.1±2.93 h	36.88±0.72 g	5.96±0.32 h
BB 0.5%	125.1±1.52 c	46.8±0.75 b	171.9±2.03 c	57.74±0.34 a	10.43±0.71 b
BB 1%	105.8±3.01 f	42.1±0.56 e	147.9±2.92 f	38.47±0.89 h	10.51±0.49 b
BB 2%	94.45±3.56 g	43.05±1.16 de	137.5±4.57 g	41.16±0.59 f	8.03±0.26 f
CG 0.5%	122.55±1.77d	48.2±0.75 a	170.75±1.75 c	45.17±0.94 e	8.73±0.71 e
CG 1%	123.1±1.52 d	43.5±0.81 cd	166.6±1.59 d	39.76±0.60 g	6.92±0.46 g
CG 2%	134.8±1.61 a	47.1±0.87 b	181.9±1.79 a	55.65±0.35fb	10.02±0.37 c
FS 0.5%	133.75±1.9 a	38.7±0.67 g	172.45±2.31 c	47.43±0.68 d	9.18±0.35 d
FS 1%	114.2±1.87 e	44.4±1.34 c	158.6±3.16 e	44.85±0.35 e	9.09±0.22 de
FS 2%	126.1±1.59 c	38.2±1.03 g	164.3±1.49 d	56.01±0.80 b	10.47±0.2 b
Amendment					
Control	125.2±2.61 a	40.6±2.22 c	176.8±2.04 a	54.74±1.07 b	11.9±0.46 a
Witness	86.1±2.23 g	34.9±1.28 f	121.1±2.93 h	36.88±0.72 g	5.96±0.32 g
BB C1	109.3±3.16 bc	41.3±1.05 bc	150.6±2.71 d	40.38±0.37 e	7.49±0.31 d
BB C2	125.5±4.55 a	42.2±1.68 b	167.7±5.71 b	62.34±1.15 a	10.5±0.42 b
BB C3	98.35±2.66 fe	40.1±0.84 c	138.45±2.29 e	40.82±0.60 e	7.6±0.14 d
CG C1	105.5±2.50 d	45±0.81 a	150.5±2.5 d	50.08±0.46 c	8.16±0.38 c
CG C2	87.9±3.24 g	34.5±1.08 e	122.4±3.56 g	29.82±0.54 h	6.54±0.45 f
CG C3	98,75±3.12 e	37.2±1.31 d	135.95±3.04 ef	38.3±0.93 f	6.9±0.29 e
FS C1	115±2.44 b	41±1.24 bc	156±2.4 c	39.93±0.71 e	6.63±0.30 ef
FS C2	107.9±3.34 cd	40.9±1.37 bc	148.8±3.22 d	37.84±0.91 f	5.45±0.45 h
FS C3	95.9±1.37 f	38.4±0.96 d	134.3±1.56 f	42.55±0.94 d	7.57±0.39 d

Note: Values indicated by a different letter are significantly different, P≤0.05. Witness: water, control: chemical fertilizer (Maxi Greene)

The algal extracts of *B. bifurcata, C. gibraltarica,* and *F. spiralis* significantly improve (P≤0.05) the length of the root part compared to the control and even compared to the chemical fertiliser. Indeed, the 0.5% *C. gibraltarica* extract is significantly the most effective (48.2 cm), followed by the 2% *C. gibraltarica* extract (47.1 cm) and finally the 0.5% *B. bifurcata* algal extract (46.8 cm). For the *B. bifurcata, C. gibraltarica,* and *F. spiralis* amendments, they were also statistically effective in improving the length of the aerial part compared to the control. Indeed, *C. gibraltarica* at C1 was significantly effective (45 cm), followed by the alga *B. bifurcata* at C2 (42.2 cm) and finally the amendment of the same alga at C1 (41.3 cm) (Table 3). Regarding fresh weight, all algal extracts and amendments at all concentrations improve (P≤0.05) it or make it equivalent to the controls. We note that in general, *B. bifurcata* is more effective with either extract or amendment. Indeed, the 0.5% *B. bifurcata* extract is significantly effective (57.74 g), followed by the 2% *F. spiralis* extract (56.01 g) and finally the 0.5% algal extract of *B. bifurcata* (47.43 g). Regarding the amendments, *B. bifurcata*, *C. gibraltarica*, and *F. spiralis* were also statistically effective in improving the fresh weight of the tomato plant compared to the control. Indeed, *B. bifurcata* at C1 was significantly effective (62.34 g), followed by *C. gibraltarica* at C1 (50.08 g) and finally the *F. spiralis* amendment at C3 (42.55 g).

With regard to dry weight, all algal extracts and amendments at all concentrations improve it or make it equivalent to the controls. We note that in general, *B. bifurcata* is more effective with either extract or amendment. Indeed, the 1% *B. bifurcata* extract is significantly effective (10.51 g), followed by the 2% *F. spiralis* extract (10.47 g) and finally the 0.5% *B. bifurcata* algal extract (10.43 g, Table 3). Regarding the amendments, *B. bifurcata, C. gibraltarica* were also statistically effective in improving the dry weight of the plant compared to the control. Indeed, *B. bifurcata* at C2 was significantly the most effective (10.5 g), followed by *C. gibraltarica* at C1 (8.16 g) and finally *B. bifurcata* amendment at C3 (7.6 g).

From Table 3, it can be concluded that regardless of the treatment applied, aqueous extract or amendment, these three brown algae, *B. bifurcata*, *C. gibraltarica*, and *F. spiralis*, proved to be statistically effective in improving the growth parameters of tomato plants.

Effect of algal fertilizers on the mineral content of tomato leaves in a greenhouse

In general, the results obtained show a significant improvement (P≤0.05) in the mineral content of the leaves of tomato plants grown in the greenhouse and subjected to the two treatments, the algal extracts and the amendment (Table 4). Indeed, we notice that all extracts and all amendments of the three algae have a clearly significant effect on organic matter and total nitrogen compared to the control. All extracts, with the exception of *C. gibraltarica* at 2%, gave equivalent and even significantly higher values than the chemical fertiliser for organic matter. For total nitrogen, the amendment with *B. bifurcata* at C3, *C. gibraltarica* at C1 and C2, *F. spiralis* at C1 and C2 is significantly equivalent to the chemical fertiliser. The treatment with algal extracts of *B. bifurcata* showed a significant improvement in organic matter, phosphorus, and potassium compared to the control.

Table 4. Effect of the algae *C. gibraltarica* (CG), *B. bifurcata* (BB), and *F. spiralis* (FS) by the two treatments (spraying and amendment) at different concentrations on the mineral element content of the leaves

Treatments	MO (%)	N (%)	P (%)	Ca (ppm)	K (ppm)	Na (ppm)
Spraying						
Control	82.56±0.45 c	2.2±0.01 a	0.17±0.02 e	124.12±0.67 c	345±0.62 e	20.61±0.34 c
Witness	78.23±0.36 e	1.5±0.01 f	0.2±0.01 c	121.13±0.65 d	294.26±0.78 c	21.93±0.45 b
BB 0.5%	84.68±0.65 a	2.1±0.01 b	0.19±0.02 d	124.2±0.26 c	414.33±1.05 b	20.96±0.40 c
BB 1%	83.47±0.21 b	1.9±0.01 c	0.18±0.01 de	117.63±0.58 e	428.86±0.70 a	34.1±0.98 a
BB 2%	83.62±0.46 b	1.9±0.01 c	0.21±0.02 c	122.93±0.85 d	360.23±0.85 c	17±0.60 e
CG 0.5%	83.67±0.38 b	1.9±0.01 c	0.22±0.01 b	139.83±0.41 b	336.06±0.85 f	17.03±0.23 e
CG 1%	82.80±0.40 c	1.8±0.01 d	0.22±0.02 b	115.8±0.34 f	348.73±0.41 d	18.02±0.7 d
CG 2%	80.83±0.39 d	1.7±0.01 e	0,19±0.01 d	148.6±0.60 a	323.13±0.64 g	17.23±0.40 e
FS 0.5%	83.85±0.23 b	1.8±0.01 d	0,21±0.02 c	122.93±0.23 d	255.63±0.80 k	17.63±0.55 e
FS 1%	83.74±0.42 b	1.9±0.01 c	0,23±0.01 a	115.4±0.5 f	290.33±0.83 h	19±0.60 d
FS 2%	82.73±0.39 c	1.8±0.01 d	0,21±0.02 c	124±0.52 c	348.03±0.96 d	14.30±0.36 f
Amendment						
Control	82.56±0.45 a	2.2±0.01 a	0.17±0.02 c	124.12±0.67 a	345±0.62 b	20.61±0.34 h
Witness	78.23±0.36 d	1.5±0.01 c	0.2±0.01 b	121.13±0.65 b	294.26±0.78 g	21.93±0.45 g
BB C1	80.48±0.10 c	1.9±0.02 b	0.21±0.02 a	90.23±0.20 d	347.33±1.15 b	21.73±0.90 g
BB C2	81.47±0.18 b	1.8±0.03 b	0.19±0.01 f	64.3±0.1 h	271.16±1.46 h	19.56±0.95 k
BB C3	79.25±0.31 d	2.1±0.01 a	0.22±0.02 a	78.13±0.30 e	326.96±0.47 e	19.23±0.37 k
CG C1	78.58±0.32 d	2.3±0.02 a	0.20±0.01 b	116.83±0.30 c	340.23±1.45 c	41.93±0.49 b
CG C2	80.24±0.34 c	2.1±0.01 a	0.18±0.03 c	70.56±0.55 g	257.1±1.44 k	33.8±0.55 d
CG C3	79.58±0.04 e	1.9±0.02 b	0.17±0.01 c	80.53±0.51 d	306.36±0.96 f	31.7±0.5 e
FS C1	80.67±0.01 c	2.2±0.02 a	0.22±0.02 a	118.6±0.7 b	361±1.93 a	45±0.17 a
FS C2	82.60±0.77 a	2.1±0.01 a	0.21±0.01 a	80.86±1.33 d	337.9±1.99 d	36.46±0.50 c
FS C3	83.60±0.46 a	1.8±0.02 b	0.22±0.02 a	72.16±1.01 f	337.53±1.02 d	28.7±0.52 f

Note: Different letters indicate significant differences at P≤0.05. Witness: water; Control: chemical fertilizer (Maxi Greene). Values are mean ± SD (n: 3). Abbreviations: OM: organic matter, N: nitrogen, Ca: calcium, K: potassium, P: phosphorus, Na: sodium

The alga *B. bifurcata* at 1% showed significantly higher maximum values than the chemical fertilizer in potassium and sodium (428.86 and 34.1 ppm, respectively). For *C. gibraltarica* almost all the algal extracts showed significant improvement in leaf mineral elements, except for sodium, which showed low levels compared to the control. The treatment with 0.5% *C. gibraltarica* extracts significantly increases the organic matter, phosphorus and calcium content (83.67%, 0.22, and 139.83 ppm, respectively) compared to the control (Table 3). The same beneficial effect is shown by the 2% *C. gibraltarica* extract with maximum calcium content (148.6 ppm).

On the other hand, all the *C. gibraltarica* amendments increased the mineral content, with the exception of calcium and K, where the contents are decreased compared to the control. The treatment with *C. gibraltarica* amendment C1 significantly improved ($P \leq 0.05$) the phosphorus content with maximum sodium and total nitrogen contents (0.2%, 41.93 ppm, and 2.3%, respectively). At the same time, *C. gibraltarica* amendments C2 and C3 did not affect phosphorus and calcium content (Table 4). These results show that the extracts of *B. bifurcata* and *C. gibraltarica* have a higher effect compared to the amendment. The application of different algal extracts of *F. spiralis* was followed by a significant increase in the content of mineral elements except for sodium. The 1% *F. spiralis* extract significantly improved the organic matter content and had a maximum value of phosphorus content (83.74 and 0.23%, respectively). The *F. spiralis* amendment shows a significant improvement in mineral element content compared to the control, with the exception of calcium (Table 4). The C1, C2, and C3 amendments of *F. spiralis* showed maximum phosphorus contents (0.22, 0.21, and 0.22%, respectively) largely exceeding that of the chemical fertilizer. The most favorable amendment for the improvement of these mineral elements was *F. spiralis* at C1, which gave maximum levels of total nitrogen, phosphorus, potassium, and sodium (2.2, 0.22%, 361, and 45 ppm, respectively). The same beneficial effect was observed on organic matter content, total nitrogen and phosphorus in plants treated with *F. spiralis* amendment C2 (82.6, 2.1, and 0.21%, respectively). *F. spiralis* amendment C3 recorded maximum values of organic matter and phosphorus content (83.6 and 0.22%, respectively) (Table 4). In contrast to *B. bifurcata* and *C. gibraltarica,* the plants treated with *F. spiralis* amendments showed an effective improvement compared to those treated with algal extracts.

Effect of algal fertilizers on the fruit yield of tomato in a greenhouse

According to the results obtained (Table 5), tomato plants grown in pots in the greenhouse, treated with aqueous extracts (watering) or by amendment, generally show a significant improvement ($P \leq 0.05$) in fruit yield. Nevertheless, we note that the application of algal fertilizer in the form of aqueous extracts gives significantly better results than the amendment. The algal extracts of the three algae *B. bifurcata, C. gibraltarica,* and *F. spiralis,* significantly improve the number of leaves compared to the control, with a maximum obtained by the extract of *B. bifurcata* at 0.5% and 2% as well as 1% of *C. gibraltarica* (12.6, 12.4, and 12.5 leaves/plant, respectively). The amendments were also statistically effective in improving the number of leaves compared to the control, with a maximum number obtained by *B. bifurcata* at C2 (11.7 leaves/plant) (Table 5).

Table 5. Effect of the algae *C. gibraltarica* (CG), *B. bifurcata* (BB), and *F. spiralis* (FS) by both treatments (spraying and amendment) at different concentrations on tomato fruit yield. Values are presented as mean ± standard deviation (n=10)

Treatments	Number of leaves	Number of flowers	Number of fruits/plants	Fruit weight (g)
Spraying				
Control	12.5±0.7 a	11±0.81 a	1.33±0.51 c	79.19±2.97 a
witness	10.55±0.81 d	6.2±0.63 f	0.75±0.52 g	40.62±2.72 f
BB 0.5%	12.6±0.69 a	9.1±0.73 b	2.16±0.73 a	70.15±4.13 b
BB 1%	12.1±0.73 abc	6.8±0.78 def	1.16±0.51 d	44.40±0.97 f
BB 2%	12.4±0.69 a	6.8±0.63 def	1±0.00 e	59.64±1.40 c
CG 0.5%	11.6±0.69 bcd	8.8±0.91 b	1.16±0.51 d	53.72±1.08 d
CG 1%	12.5±0.52 a	6.6±0.51 ef	1±0.00 e	56.39±0.9 cd
CG 2%	11.5±0.52 cd	7±0.81 ed	0.83±0.53 f	77.89±3.44 a
FS 0.5%	12.2±0.63 ab	7.9±1.10 c	1.33±0.48 c	57.28±1.41 cd
FS 1%	11.6±0.51 bcd	7.4±0.51 cd	1.33±0.48 c	67.45±1.55 b
FS 2%	11.3±0.67 d	9±0.66 b	1.83±0.78 b	69.52±0.93 b
Amendment				
Control	12.5±0.7 a	11±0.81 a	1.33±0.56 a	79.19±2.97 a
witness	10.55±0.81 e	6.2±0.63 ef	0.75±0.52 d	40.62±2.72 e
BB C1	10.5±0.52 de	7.5±0.52 c	0.83±0.33 c	52.79±2.02 b
BB C2	11.7±0.48 b	7.3±0.48 cd	0.66±0.14 e	51.11±2.98 bc
BB C3	11.3±0.67 bc	8.7±0.67 b	0.83±0.31 c	40.63±1.3 e
CG C1	11.4±0.51 bc	7.6±0.51 c	0.66±0.22 e	38.6±1.01 e
CG C2	11.4±0.51 bc	6.4±0.51 ef	1±0.00 b	35.13±1.27 g
CG C3	10.9±0.73 cd	7.5±0.52 c	0.66±0.26 e	41.48±0.59 e
FS C1	11.1±0.73 c	6±0.66 f	0.66±0.34 e	48.68±0.59 cd
FS C2	10.9±0.56 cd	7.7±0.48 c	0.33±0.23 g	46.6±1.31 d
FS C3	10.5±0.52 de	6.7±0.48 ed	0.5±0.20 f	52.74±1.26 b

Note: Values indicated by a different letter are significantly different, $P \leq 0.05$. Witness: water, control: chemical fertilizer (Maxi Greene)

All the algal extracts of the three algae significantly improve the number of flowers and fruits of tomato compared to the control, with a maximum number obtained by *B. bifurcata* extract at 0.5% (9.1 flowers/plant and 2.16 fruits/plant) for tomato. On the other hand, amendments with *B. bifurcata* and *C. gibraltarica* were also statistically effective in improving the number of flowers and fruits compared to the control. *B. bifurcata* obtained the maximum number of flowers at C3 (8.7 flowers/plant) while *C. gibraltarica* recorded the number of fruits at CG C2 (1 fruit/plant).

The algal extracts of the three brown algae *B. bifurcata, C. gibraltarica,* and *F. spiralis,* significantly improve the fruit weight compared to the control. A maximum value is obtained by the 2% *C. gibraltarica* extract (77.89 g), followed by the 0.5% *B. bifurcata* and 2% *F. spiralis* extracts (70.15 g and 69.52 g, respectively). As for the algal extracts, the amendments by *B. bifurcata* and *F. spiralis* were statistically effective in improving tomato fruit weight compared to the control, with a maximum value obtained by *B. bifurcata* at C1 and *F. spiralis* at C3 (52.79 g and 52.74 g, respectively), followed by *B. bifurcata* at C2 (51.11 g).

Effect of algal fertilizers on the fruit quality of tomato in the greenhouse

In general, tomato plants treated with the algal extracts and amendments of the three brown algae showed significant improvement ($P \leq 0.05$) in fruit quality compared to the controls (Table 6). All extracts and amendments significantly improved fruit diameter and in addition, amendment C1 of *F. spiralis* and C3 of *C. gibraltarica* performed better than the control. Concerning firmness, we notice that except for the *B. bifurcata* 2% extract, all the other extracts and the different amendments significantly improved the fruit firmness compared to the control. The C2 amendment of *F. spiralis* had a value significantly close to that of the chemical fertilizer (6.41 kg/cm). For the quantity of soluble sugars, all the values obtained by the two treatments (aqueous extracts and amendments) are significantly higher compared to the control and even compared to the chemical fertilizer.

The plants treated with amendment C1 of *B. bifurcata* showed maximum values in brix, in quantity of sugars (4.36%, 4.78%, respectively). The alga *C. gibraltarica,* with all its concentrations and amendments, showed significant differences from the control in diameter, firmness, brix, and total sugar content of fruits, as well as maturity index (Table 6).

The 1% aqueous extract of *C. gibraltarica* recorded maximum values in fruit diameter, brix, and sugar content (55.66 mm, 4.33% and 4.95%, respectively). Likewise, the plants treated with the 0.5% concentration presented results in fruit firmness statistically equivalent to the chemical fertilizer (6.17 kg/cm). Regarding fertilization by amendment, *F. spiralis* at C1 showed a maximum diameter (59.5 mm) with a low maturity index (12.06); also, the amendment C2 of *F. spiralis* presents a maximum value of firmness (6.41 kg/cm) (Table 6).

Table 6. Effect of the algae *C. gibraltarica* (CG), *B. bifurcata* (BB), and *F. spiralis* (FS) by both treatments (spraying and amendment) at different concentrations on fruit quality. Values are presented as mean ± standard deviation (n=6)

Treatments	Diameter (mm)	Firmness (kg/cm)	Brix %	Quantity of sugars (%)	M.I
Spraying					
Control	57±1 a	6.4±0.1 a	3.9±0.1 b	4.51±0.11 b	15.02±0.04 b
Witness	44.5±0.5 f	3.65±0.2 f	3.33±0.05 e	3.93±0.05 e	15.99±0.23 a
BB 0.5%	48.66±0.76 d	4.5±0.11 e	3.73±0.11 cd	4.36±0.11 c	14.58±0.38 c
BB 1%	54.5±0.5 b	5.48±0.25 b	3.53±0.05 de	4.16±0.05 d	14.13±0.18 c
BB 2%	50.5±0.5 c	3.5±0.25 g	3.33±0.11 e	3.96±0.1 e	16.49±0.45 a
CG 0.5%	50.5±0.5 c	6.17±0.17 a	4.2±0.26 ab	4.82±0.26 ab	13.94±0.75 d
CG 1%	55.66±1.52 b	3.76±0.23 h	4.33±0.05 a	4.95±0.05 a	13.78±0.16 d
CG 2%	51.16±0.28 c	4.77±0.19 c	3.53±0.05 de	4.16±0.24 d	13.44±0.79 e
FS 0.5%	47.6±0.5 e	4.82±0.04 d	4±0.26 bc	4.61±0.26 b	12.47±0.7 f
FS 1%	48.83±0.28 d	3.69±0.05 f	3.73±0.26 cd	4.35±0.28 c	15.09±0.98 b
FS 2%	46.33±0.57 e	4.39±0.05 e	3.96±0.23 bc	4.57±0.21 b	13.61±0.63 e
Amendments					
Control	57±1 b	6.4±0.1 a	3.9±0.1 b	4.51±0.11 c	15.02±0.04 a
Witness	44.5±0.5 f	3.65±0.2 f	3.33±0.05 bcd	3.93±0.05 e	15.99±0.23 a
BB C1	55±0.5 c	4.97±0.85 d	4.36±0.58 a	4.78±0.01 a	11.48±0.38 d
BB C2	44.83±0.57 f	5.33±0.43 c	3.63±0.15 c	4.19±0.15 d	11.13±0.2 d
BB C3	48.33±1.01 e	4.91±0.62 d	3.53±0.15 cd	4.11±0.16 d	10.47±0.28 e
CG C1	48.5±0.5 e	4.47±0.12 e	3.4±0.17 d	3.98±0.17 e	12.6±0.36 c
CG C2	50.5±0.5 d	4.52±0.55 e	3.56±0.11 cd	4.16±0.11 cd	11.82±0.64 cd
CG C3	58.5±0.5 a	5.67±0.23 b	3.8±0.3 b	4.41±0.29 c	11.69±0.77 cd
FS C1	59.5±0.5 a	4.66±0.17 e	3.73±0.2 b	4.33±0.2 c	12.06±0.45 c
FS C2	52.5±0.5 cd	6.41±0.63 a	4.06±0.15 ab	4.66±0.14 b	13.14±0.39 b
FS C3	54.16±0.5 c	5.58±0.41 c	3.66±0.25 c	4.25±0.24 d	12.8±0.62 c

Note: Values indicated by a different letter are significantly different, $P \leq 0.05$. Witness: water, control: chemical fertilizer (Maxi Greene) M.I.: Maturity index

Discussion

The mineral analysis of the three brown algae *C. gibraltarica, B. bifurcata,* and *F. spiralis* highlighted the richness of these three brown algae in macroelements (Ca, K, P, Na, N), which is in agreement with previous works (El Khattabi et al. 2023).

In general, the results obtained after three months of cultivation in pots (under greenhouse conditions) are very satisfactory. The root and aerial growth of tomato plants is significantly enhanced by the addition of aqueous extracts and amendments, especially *B. bifurcata*. Similar results have been observed in other crops treated with extracts from different algae, such as A. *nodosum* (Górka et al. 2018). According to Yassen et al. (2019), algal extracts improve nutrient uptake, particularly Mg, K, and Ca, by lettuce roots. This stimulates root activity by increasing water and mineral absorption, which promotes better plant growth and vigor. Comparable findings reported by Baroud et al. (2024) show that the mineral content of tomato leaves improves when treated with extracts and amendments from all three algae. This could enhance water uptake by tomato roots, leading to an increase in the crop's fresh weight. Additionally, the rise in dry weight can be attributed to higher protein and organic matter content. Similar results have been observed where treatment with algal extracts increased both the fresh and dry weights of leaves (Xu and Leskovar 2015). These effects can be explained by the nutrients present in algae, including vitamins, amino acids, auxins, cytokinins, and macro- and micro-minerals, which influence cellular metabolism in treated plants, resulting in increased growth (du Jardin 2015).

The study shows a significant increase in several minerals in the leaves of plants treated with low concentrations of the three brown algae *B. bifurcata, F. spiralis*, and *C. gibraltarica*. The aqueous extracts of *B. bifurcata* at low concentrations show maximum values of organic matter, total nitrogen, potassium, and sodium content. The increase in mineral content in leaves can be explained by the increase in root biomass, which should increase the capacity of roots to absorb minerals from the soil (Ali et al. 2015). This is shown by the extract of *B. bifurcata* at 0.5% which also presented a maximum and significantly higher root part compared to the control and even compared to the chemical fertilizer. Indeed, the aqueous algal extract contains significant amounts of mineral elements that can be incorporated into plants (Michalak et al. 2016). Several other studies have demonstrated the positive effect of aqueous brown algae extracts on plant growth, which aligns with our results since the extracts from the three algae studied have a significant impact on tomato growth parameters. These extracts contain, in addition to mineral elements, other substances that enhance water retention, stimulate soil microbial activity, and improve mineral absorption (Halpern et al. 2015).

The yield of tomato fruits increases following treatment by drenching (extract) or amendment, especially the aqueous extract of *B. bifurcata* at low concentration. Similar results were shown by Baroud et al. (2024); the yield of pepper fruits increased following treatment with the extracts or amendment, especially the aqueous extract of *B. bifurcata* at low concentrations. According to Sarhan and Ismael (2014), algal extracts significantly increase cucumbers' number of flowers and fruits. This can be explained by algal extracts containing high amounts of auxins, cytokinins, and betaines, which affect cell division in the early stages of growth and consequently increase fruit yield (Chojnacka et al. 2015). Other results showed that aqueous extract of *Sargassum wightii* recorded an increase in yield and quality of *Vigna radiata* fruits (Bharath et al. 2018). The reproductive phase has higher nutrient requirements, which are met by application of aqueous extracts of *B. bifurcata* and *C. gibraltarica*, which contain both macro and micronutrients. Algal extracts demonstrate positive effects on vegetative growth, fruit set, and physiological activities in plants. These biostimulants improve the efficiency of nutrient utilization, increase resistance to diseases, and enhance fruit quality (Batelja Lodeta et al. 2025).

Fertilization (extracts and amendments) by the three brown algae (*B. bifurcata, F. spiralis,* and *C. gibraltarica*) improved the fruit quality (brix, quantity of sugars, diameter, firmness, maturity index) of tomato, especially the algae *B. bifurcata* and *C. gibraltarica,* which showed higher efficiency on the fruit quality of tomato. Similar results showed that fertilization with extracts and amendments of the three brown algae improved the quality of pepper fruit (brix, quantity of sugars, diameter, firmness, maturity index), in particular the alga *B. bifurcata,* which was more effective in improving fruit quality in pepper crops (Baroud et al. 2024). It can also be noted that low concentrations of the three brown algae showed maximum values of tomato fruit quality. Similar results were observed in other crops treated with other algal extracts, such as *A. nodosum* extract, which showed significant improvement in fruit firmness compared to untreated fruits (Ali et al. 2015). Our study also shows that fertilization by watering (extract) or amendment improves the quantity of sugar content of fruits. The increase in soluble sugar content also contributes to the nutritional value of the fruit. Other studies have shown that fruit diameter and weight were improved by algal extracts (Ali et al. 2015). These may be caused by the improvement of the absorption strength of the fruits to attract more water and assimilate due to higher concentrations of promoter substance (Halpern et al. 2015).

In conclusion, the present study aimed to evaluate the effect of three brown algae, *B. bifurcata, C. gibraltarica,* and *F. spiralis*, on the growth, yield, and fruit quality of a vegetable plant (tomato) grown in pots under greenhouse conditions. In general, fertilization with the three brown algae improved all parameters studied. Specifically, the two algae *B. bifurcata* and *F. spiralis* at low concentrations showed high efficiency in enhancing growth, yield, and tomato fruit quality. It is also notable that each algal species affects the various parameters differently. These three algae were found to be effective and promising candidates for developing biostimulants that can enhance the growth, yield, and fruit quality of vegetable plants.

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