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Effect of brown algae as biofertilizer materials on pepper (*Capsicum annuum*) growth, yield, and fruit quality

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Abstract. *Baroud S, Tahrouch S, Hatimi A. 2024. Effect of brown algae as biofertilizer materials on pepper (*Capsicum annuum*) growth, yield, and fruit quality. Asian J Agric 8: 25-31.* Our study aims to evaluate the effect of three brown algae, *Cystoseira gibraltarica* (Sauvageau) P.J.L.Dangeard, *Bifurcaria bifurcata* R.Ross, and *Fucus spiralis* L., as biofertilizers on pepper (*Capsicum annuum* L.). These three algae were applied in two forms and at different concentrations: amendment (C1, C2, and C3) and concentrations of aqueous extract (0.5%, 1%, and 2%). Generally, the studied parameters were significantly improved using the aqueous extracts or the amendment at low concentrations. Indeed, the extract of *F. spiralis* at 1% shows a maximum length of the aerial and root parts (75.8 and 33.2 cm, respectively) and the dry weight of the plants (9.88 g). Aqueous extracts of *F. spiralis* at 1% show the maximum values of organic matter and nitrogen content of pepper leaves (88.3% and 4.4%, respectively). In addition, the 0.5% *B. bifurcata* extract presented significant values for the number of flowers (8.8 flowers/plant), and the 1% *F. spiralis* extract showed a better result for the number of fruits (7.1 fruits/plant). The alga *C. gibraltarica* at 1% showed a maximum fruit weight (82.65 g). On the other hand, *F. spiralis* at 1% showed maximum values of fruit diameter (48.33 mm). Similarly, *F. spiralis* at 0.5% showed maximum values in brix and sugar content (5.33% and 5.4%, respectively). These three algae were found to be effective and good candidates for the efficient development of biostimulants to improve growth and yield as well as the fruit quality of pepper. This study provides important information on identifying and utilizing Moroccan algal resources in agriculture.

Keywords: Algal fertilization, extract and amendment, fruit quality, growth, yield

INTRODUCTION

Greenhouse cultivation is the most common type of cultivation because it can increase agricultural production in Morocco (Harbouze et al. 2019). It can also create optimal climatic conditions for plant growth and grow more per square foot than growing crops in the field. In addition to the optimal conditions provided by the greenhouse, algae fertilization could significantly improve the growth and yield of greenhouse crops.

In Morocco, sea currents and hydroclimatic conditions rapidly favor the development and expansion of marine algae such as brown seaweed (Riadi 1998), and many species of algae grow rapidly and efficiently, especially compared with terrestrial plants (Kindleysides et al. 2012). Brown algae are very abundant along the Atlantic coast, especially in the Cap Ghir region. This calls for better management of this biomass while promoting research aimed at exploiting these brown algae, particularly *Cystoseira gibraltarica* (Sauvageau) P.J.L.Dangeard, *Bifurcaria bifurcata* R.Ross, and *Fucus spiralis* L., in several fields, particularly agriculture. However, few studies have been conducted to identify the various molecules in the brown algae harvested on Morocco's double seafront.

Potting is the practice of growing plants, including vegetables, exclusively in pots instead of planting them in the ground (Mills 2012). Farmers use pot growing in areas where the soil or climate is unsuitable for the crop. Thus, this method is useful for scientific trials before growing in the ground. In addition to the optimal conditions of the greenhouse, fertilization with algae could significantly improve the growth and yield of greenhouse crops.

Using polar solvents, phenolic compounds, organic acids, tannins, and salts can be extracted from algae (Sabeena and Jacobsen 2013). Some studies indicate that algal extracts can partially substitute fertilizers (Hong et al. 2007; Zodape et al. 2010) because they contain both minor and major mineral elements. Saccharides in algal extracts can act as elicitors of plant defensive mechanisms (Khan et al. 2009). Algae-based fertilizers contain various plant growth-promoting substances such as auxins, cytokinins, and betaines (Khan et al. 2009). These substances can influence the development of the aerial and root plant parts of *Arabidopsis thaliana* (L.) Heynh. (Durand et al. 2003). In addition, macronutrients (N, P, K, Ca, and Na) and micronutrients (Fe, Zn, Mn, and Cu) promote fruit growth and yield (Hamouda et al. 2016). These algal extracts also increase phytochemical parameters (Lola-Luz et al. 2014). Positive responses include improved plant growth, fruit quality, plant vigor, and pathogen resistance (Khan et al. 2009). Whapham et al. (1993) showed that applying aqueous extracts of *Ascophyllum nodosum* (L.) Le Jol. algae increased omato plants' chlorophyll 'a' and 'b' content.

The field of agriculture has had a remarkable improvement in recent years as it is characterized by the diversity of crops, including pepper (*Capsicum annuum* L.)

(Harbouze et al. 2019). Therefore, to maintain the position of our country in this field, it is essential to use more effective biological fertilizers to produce significant and good-quality productive activity. Several researches indicate algal extracts can partially substitute conventional fertilizers (Dhargalkar and Pereira 2005; Hong et al. 2007; Zodape et al. 2010). Moreover, algal extracts are among the methods used to improve plant yield, fruit quality, and mineral composition (Elansary et al. 2016). Previous studies have shown that algal extracts positively affect the growth and yield of vegetable plants (Sharma et al. 2014).

In this context, we aim to conduct a greenhouse pot experiment on pepper growth parameters, yield, and fruit quality to test the effect of three brown algae: *B. bifurcata*, *C. gibraltarica,* and *F. spiralis*.

MATERIALS AND METHODS

Plant materials

Three species of brown algae, *C. gibraltarica*, *B. bifurcata*, and *F. 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 were washed on-site and put in a seawater box. In the laboratory, the samples were 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 conducted. 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 were ground to a powder and stored in a dry place.

Preparation of treatments

Amendments

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

Algal extracts

Five grams of powder of each algal species were added to 100 ml of distilled water under magnetic stirring for 24 h. The recovered supernatant was filtered, and the obtained aqueous extracts were stored in a cool place. These extracts were designated as stock solution 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 make three concentrations (0.5, 1, and 2%).

Greenhouse growth bioassay

Certified pepper seeds (*C. annuum*) of the Roldan variety were germinated in peat blister plates. 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). Each pot receives 50 ml/week of the algal extract, represented by three concentrations (0.5, 1, and 2%). For the amendment, the treatment was also represented by three increasing concentrations: C1 (2.5 g/pot), C2 (5 g/pot), and C3 (10 g/pot). At the same time, we used a witness that received only water and the control treated with a chemical fertilizer (Maxi Greene: N:20, P:20, K:20).

Aqueous extracts were sprayed two weeks after sowing at a 50 ml/week rate for three months. Fertilization by amendment was done when transplanting the plants with the three different concentrations determined previously. All pots were irrigated with 50 ml of water every other day during cultivation.

The number of flowers per plant was counted at the time of flowering. After 90 days of cultivation, the pepper fruits were harvested, and the plants were carefully removed and washed. Then we measured the various growth parameters (length of the aerial part, length of the root and total length, fresh weight and dry weight of the plant), the mineral analyses of the leaves, the analyses of the fruits such as the yield (number of leaves, number of fruit/plant and weight of fruit) and the quality of the fruits (diameter, firmness, brix, sugar content, and maturity index).

Determination of growth parameters

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

Determination of the leaves' mineral elements

The mineral content of pepper leaves was determined based on the method of Page et al. (1982).

Determination of fruit yield

Determination of fruit yield was done at the end of the crop at the time of harvest; we also determined the number of leaves, number of flowers, number of fruit/plant, and fruit weight/plant.

Determination of fruit quality

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

Fruit diameter

The caliper determined the diameter and measured the equatorial and polar diameters of the fruit.

Fruit firmness

Fruit firmness was 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 maturity level and development stage. The results were expressed in kg/cm².

Brix

Brix is the number of grams of soluble dry matter per 100 g of product. This soluble dry matter consisted of about 80 to 85% sugars, 10% citric acid and salts, and nitrogenous and other soluble substances (Ting and Rouseff 1986). The Brix was determined according to the AFNOR NNFX standard (1988) and done by sufficiently pouring a few drops on the refractometer's prism and turning the device towards a light source to measure the refractometric index. The reading was done on the piece scale at the intersection of the light and dark areas.

Sugar content

The sugar content was determined based on the optical property of a sugar solution to reflect light. The percentage of dry matter measured is the refractometric index, expressed in degree 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.

Maturity index

The maturity index, which is the ratio of sugars to acidity of the juice, allows us to determine the state of maturity of the fruitsThe following formula calculated it:

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

Statistical analysis

The data were processed by STATISTICA software, version 6.0. Analysis of variance was performed to determine the level of significance. The means were compared using Duncan's tests at the probability threshold (P <5%).

RESULTS AND DISCUSSION

Effect of algal fertilization on growth parameters of greenhouse pepper

The results (Table 1) show that the growth parameters improved significantly overall through aqueous extracts or amendments. The algal extracts of *B. bifurcata*, *C. gibraltarica*, and *F. spiralis* significantly improved the length of the aerial part compared to the control.

Indeed, the 1% *F. spiralis* extract gave statistically the maximum length of the aerial part (75.8 cm), followed by the 0.5% *B. bifurcata* extract (70.85 cm) and finally the 1% *C. gibraltarica* extract (68.40 cm). The amendments *B. bifurcata* and *F. spiralis* were also statistically effective in improving the length of the aerial part compared to the control. Indeed, *F. spiralis* at C2 gave a statistically significant length (68.00 cm), followed by the amendment of *B. bifurcata* at C1 (67.20 cm) and finally, the amendment of the same alga at C2 (61.1 cm) (Table 1).

All the algal extracts of *B. bifurcata*, *C. gibraltarica*, and *F. spiralis* significantly improve the length of the root part compared to the control and even the chemical fertilizer. Indeed, *F. spiralis* at 1% is significantly the most effective (33.2 cm), followed by *B. bifurcata* extract at 1% (31.5 cm), and finally, *C. gibraltarica* extract at 2% (31.20 cm). Regarding the amendments, *B. bifurcata*, *C. gibraltarica*, and *F. spiralis* were also statistically effective in improving the length of the aerial part compared to the control. Indeed, *F. spiralis* at C2 gave a statistically significant length (31.10 cm), followed by the amendment of *B. bifurcata* at C2 (29.30 cm) and finally, the amendment of *C. gibraltarica* at C2 (28.80 cm) (Table 1).

Regarding the fresh weight, all the algal extracts and all the amendments at all concentrations improve it or make it equivalent to the controls. We note that, in general, *F. spiralis* is more effective than either the extract or the amendment, but at medium concentrations (1% for the extract and C2 for the amendment). Indeed, *F. spiralis* at 1% gives statistically the best result (50.47 g), followed by the extract of *C. gibraltarica* at 2% (50.06 g) and finally the extract of *B. bifurcata* at 0.5% (40.04 g). Regarding the amendments, *B. bifurcata*, *C. gibraltarica*, and *F. spiralis* were also statistically effective in improving the fresh weight of the plant compared to the control. Indeed, *F. spiralis* at C2 was significantly effective (50.64 g), followed by the amendment of *C. gibraltarica* at C3 (47.57 g) and finally the amendment of *B. bifurcata* at C2 (36.31 g).

Regarding dry weight, all algal extracts and all amendments at all concentrations improve it or make it equivalent to the controls. We notice that *F. spiralis* is more efficient than the extract or the amendment, but at medium concentrations (1% for the extract and C2 for the amendment). Indeed, *F. spiralis* at 1% is significantly effective (9.88 g), followed by the extract of *B. bifurcata* at 0.5% (8.32 g) and finally the extract of *C. gibraltarica* at 2% (8.21 g). Concerning the amendments, *B. bifurcata*, *C. gibraltarica* at C1 and C3, and *F. spiralis* at C2 were also statistically effective for improving the plant dry weight compared to the control. Indeed, the alga *F. spiralis* at C2 gave statistically the best result (11.75 g), followed by the amendment of *C. gibraltarica* at C3 (9.54 g) and finally, the amendment of the same alga at C1 (7.38 g) (Table 1).

Fertilization by amendment also showed a clear improvement in the leaves of these elements (OM, N, and P). Indeed, amendment C2 of *B. bifurcata* positively affected organic matter content (86.68%), while amendment C2 and C3 of *F. spiralis* significantly improved nitrogen and phosphorus content (3.30% and 0.27%, respectively).

Table 1. Effect of the three algae *Cystoseira gibraltarica* (CG), *Bifurcaria bifurcata* (BB), and *Fucus spiralis* (FS) by both treatments (Spraying and amendment) at different concentrations on the growth parameters of pepper

Spraying	**Aerial part (cm)**	**Root part (cm)**	**Fresh weight of the plant (g)**	**The dry weight of the plant (g)**
Witness	54.15±1.59 e	23.15±0.78 f	31.05±1.26 f	5.11±0.24 h
Control	64.70±0.94 d	22.70±0.82 f	45.03±3.09 b	9.44±0.24 b
BB 0,5 %	70.85±4.21 b	25.95±2.45 e	40.04±1.23 c	8.32±0.33 c
BB 1 %	68.30±2.32 c	31.50±2.49 b	31.79±0.89 f	6.00±0.24 f
BB 2%	65.20±1.61 d	30.30±1.18 bcd	35.43±1.49 e	6.94±0.43 e
CG 0,5%	64.50±2.27 d	29.70±0.85 cd	37.38±2.92 d	7.61±0.68 d
CG 1 %	68.40±1.83 c	29.40±1.84 d	31.19±1.29 f	6.16±0.41 f
CG 2 %	65.55±1.49 d	31.20±1.7 b	50.06±0.97 a	8.21±0.3 c
FS 0,5 %	55.85±1.10 e	30.90±0.87 bc	37.87±1.2 d	7.29±0.24de
FS 1 %	75.80±1.54 a	33.20±0.91 a	50.47±1.37 a	9.88±0.2 a
FS 2 %	55.70±1.35 e	24.90±1.02 e	30.00±0.85 f	5.80±0.77 g
Amendment				
Witness	54.15±1.59 f	23.15±0.78 h	31.05±1.26 g	5.11±0.24 f
Control	64.70±0.94 b	22.70±0.82 h	45.03±3.09 c	9.44±0.24 b
BB C1	67.20±2.34 a	24.14±0.57 g	33.54±1.08 f	6.51±0.5 e
BB C2	61.10±1.02 c	29.30±0.71 b	36.31±0.65 d	6.55±0.3 e
BB C3	58.25±2.09 ed	28.10±0.87 d	33.04±1.28 f	6.55±0.23 e
CG C1	59.18±3.6 d	28.40±0.65 cd	35.95±0.57 ed	7.38±0.29 d
CG C2	52.90±2.07 f	24.55±0.76 fg	26.93±0.44 k	5.17±0.18 f
CG C3	56.75±1.31 e	28.80±0.78 bc	47.57±0.92 b	9.54±0.28 c
FS C1	51.10±1.28 f	25.54±0.70 e	34.51±0.54 ef	6.69±0.26 e
FS C2	68.00±3.02 a	31.10±0.73 a	50.64±0.56 a	11.75±0.58a
FS C3	57.60±3.57 ed	25.05±0,6 ef	28.56±0.49 h	5.05±0.23 g

Note: Values show the mean ± standard deviation (n=10). Values indicated by a different letter differ significantly (P ≤0.05)

Table 2. Effect of *Cystoseira gibraltarica* (CG), *Bifurcaria bifurcata* (BB), and *Fucus spiralis* (FS) algae by both treatments (Spraying and amendment) at different concentrations on the mineral element content of leaves

Spraying	**OM (%)**	**P (%)**	**N (%)**	**K (ppm)**	**Ca (ppm)**	**Na (ppm)**
Witness	80.78±0,43 e	0.24±0.01 f	2.3±0.13 f	340.80±0.3 d	106.13±0.6e	18.93±0.45c
Control	86.48±0.76 c	0.26±0.02 f	3.3±0.24 c	344.13±1.08c	98.74± 0.26h	33.76±0.4 a
BB 0.5%	85.90±0.3 d	0.36±0.03 b	2.6±0.12 e	393.80±1.03b	109.20±0.5c	17.96±0.98c
BB 1%	84.53±0.67 d	0.39±0.02 a	2.5±0.15 e	408.50±0.7 a	102.63±0.85f	31.10±0.6 b
BB 2 %	86.65±0.65 c	0.36±0.01 b	2.6±0.13e	340.25±0.85d	107.93±0.4d	14.00±0.23e
CG 0.5 %	86.78±0.62 c	0.35±0.01 c	2.8±0.16 d	315.90±0.94f	124.83±0.3b	14.04±0.7 e
CG 1 %	86.94±0.62 c	0.36±0.01 b	2.8±0.18 d	328.80±0.41e	100.80± 0.6g	15.20±0.4de
CG 2 %	86.73±1.07 c	0.34±0.02d	2.8±0.25 d	302.90±0.64g	133.60±0.23a	14.23±0.55e
FS 0.5 %	88.10±0.78 a	0.33±0.01 d	4.00±0.24 b	235.25±0.8 k	107.93± 0.5 d	14.63±0.6 e
FS 1 %	88.30±0.79 a	0.32±0.01 d	4.4±0.14 a	269.85±0.85h	100.40±0.52g	16.00±0.36d
FS 2 %	87.30±0.55ab	0,31±0.01 e	3.5±0.17 c	327.60±0.96e	109.00±0.79c	11.30±0.34f
Amendment						
Witness	80.78±0.01 f	0.24±0.02 d	2.30±0.13 d	340.80±1.8 b	106.13±0.15a	18.93±0.45g
Control	86.48±0.01 a	0.26±0.01 b	3.30±0.18 a	344.13±1.15a	98.74±0.20 c	33.76±0.4 c
BB C1	85.93±0.02 b	0.21±0.02 f	1.90±0.13 f	327.33±1.46d	75.23±0.1 d	18.73±0.9 g
BB C2	86.68±0.02 a	0.23±0.02 e	1.90±0.19 f	251.16±0.47k	49.30±0.30 k	16.56±0.37h
BB C3	85.18±0.03 b	0.21±0.01 f	2.00±0.35 e	306.96±1.45f	63.13±0.34 f	16.23±0.49h
CG C1	83.49±0.01 d	0.26±0.02 b	2.10±0.14 e	320.23±1.44e	101.83±0.55b	38.93±0.55b
CG C2	83.86±0.02 d	0.19±0.02 g	2.10±0.26 e	237.10±0.96k	55.56±0.51 h	30.80±0.5 d
CG C3	81.16±0.01 e	0.23±0.03 e	2.10±0.15 e	286.36±1.93h	65.53±0.7 e	28.70±0.17e
FS C1	83.98±0.02 d	0.23±0.02 e	3.00±0.15 b	341.00±1.99b	103.60±1.33a	42.00±0.52a
FS C2	84.49±0.02 c	0.25±0.01 c	3.30±0.15 a	317.90±1.02e	65.86±0.73 e	33.46±0.5 c
FS C3	81.69±0.02 e	0.27±0.01 a	2.60±0.18 c	317.53±2.47e	57.93±0.34 g	25.70±0.83f

Note: Values show the mean ± standard deviation (n=3). Values indicated by a different letter differ significantly (P ≤0.05)

The plants treated with the aqueous extracts (spraying) or by amendment show, in general, an insignificant improvement of the content of potassium (K), sodium (Na), and calcium (Ca) in the leaves (Table 2). this study shows that the fertilization with the aqueous extracts of the three brown algae showed a significant improvement in the calcium content, with a maximum value obtained by the aqueous extract of *C. gibraltarica* at 2% (133.60 ppm). On the other hand, the 1% aqueous extract of *B. bifurcata* showed highly significant potassium and sodium content

(408.50 and 31.10 ppm, respectively). Amendment fertilization generally shows an improvement in leaf sodium content with a maximum value for C1 of *F. spiralis* (42.00 ppm). On the other hand, this treatment showed no significant effect on potassium (Table 2).

Effect of algal fertilization on fruit yield of pepper

The study shows that the plants cultivated in pots in a greenhouse, treated by aqueous extract (spraying) or amendment, generally significantly improved fruit yield (Table 3). Nevertheless, we notice that the contribution of algal fertilizer in the form of aqueous extracts gives significantly more important results than the amendment.

The algal extracts of the three algae *B. bifurcata, C. gibraltarica,* and *F. spiralis* significantly improved the number of leaves compared to the control, with a maximum obtained by the extract of *B. bifurcata* at 1% and 2% (32.10 and 31.40 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 *F. spiralis* at C2 (32.00 leaves/plant) (Table 3).

All the algal extracts of the three algae improved the number of flowers and fruits significantly compared to the control. Indeed, the extracts of *B. bifurcata* at 0.5% and 1% showed significant values for the number of flowers (8.80 and 8.60 flowers/plant, respectively). In comparison, the extract of *F. spiralis* at 1% showed a better result for the number of fruits (7.10 fruits/plant). 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. Furthermore, *B. bifurcata* at C3 statistically gave the best result for flowers and fruits (8.80 flowers/plant and 6.10 fruits/plant).

The algal extracts of the three brown algae *B. bifurcata*, *C. gibraltarica*, and *F. spiralis* significantly improved fruit weight over the control, with a maximum value being obtained by *C. gibraltarica* at 1% (82.65 g), followed by *B. bifurcata* extract at 1% and *F. spiralis* at 2% (72.66 and 72.38 g, respectively). As with the algal extracts, amendments with *B. bifurcata* (49.82 g) and *F. spiralis* (44.61 g) were statistically effective in improving fruit weight compared to the control (58.34 g); Table 3 shows the highest weight in the control; hence, it is not effective in improving fruit weight. Likewise, all amendments by *C. gibraltarica* (48.79 g) positively affected fruit weight but were lower than the control at 58.34 g (Table 3).

Effect of algal fertilization on fruit quality of pepper

Fertilization with algae, aqueous extracts, or amendment significantly improved the quality of fruits grown in greenhouse pots (Table 4). Table 4 shows that Brix % aqueous extracts (5.33%) are higher than amendment (5.10%) and also the quantity of sugars (%) and MI that aqueous extracts are higher than their amendments.

The extracts of *B. bifurcata*, all concentrations combined, the 2% extract of *C. gibraltarica*, and 1% *F. spiralis* significantly improved the firmness of the fruits compared to the control. The same algal extracts at 1% showed maximum fruit diameter values of 47.83 mm for *B. bifurcata* at 1% and 48.33 mm for *F. spiralis* at 1% (Table 4). Regarding firmness, the amendment by *B. bifurcata* to C2 recorded maximum values for firmness and diameter (3.62 kg/cm and 53.50 mm, respectively). The *F. spiralis* amendment C1 also presented maximum values for a fruit diameter of 52.66 mm.

Table 3. Effect of *Cystoseira gibraltarica* (CG), *Bifurcaria bifurcata* (BB), and *Fucus spiralis* (FS) algae by the two treatments (spraying and amendment) at different concentrations on pepper yield parameters

Spraying	Number of leaves	Number of flowers	Number of fruits/plant	Fruit weight (g)
Witness	20.30±0.94 g	5.40±0.69 f	3.10±0.73 d	42.07±2.38 g
Control	33.60±0.84 a	12.20±0.91 a	6.00±0.47 b	58.34±2.32 e
BB 0.5 %	28.50±1.85 d	8.80±0.91 b	3.70±0.94 cd	59.29±0.88 d
BB 1 %	32.10±1.02 b	8.50±0.70 b	3.80±0.91 cd	72.66±1.01 b
BB 2%	31.40±1.17 b	6.50±0.52 e	6.10±1.79 b	63.46±0.88 c
CG 0.5%	30.40±0.96 c	8.20±0.42 c	5.80±0.63 b	63.52±1.01 c
CG 1%	21.80±0.78 f	4.60±0.69 gh	6.30±0.82 b	82.65±0.63 a
CG 2%	22.70±0.94 f	4.00±0.66 h	6.10±0.56 b	63.53±0.71 c
FS 0.5%	24.20±0.78 e	7.40±0.51 d	4.00±1.05 c	57.95±0.78 d
FS 1%	22.50±0.52 f	5.00±0.81 gf	7.10±0.87 a	56.18±0.72 f
FS 2%	19.60±0.84 g	6.40±0.51 e	5.80±0.63 b	72.38±1.16 b
Amendment				
Watering	20.30±0.94 h	5.40±0.69 f	3.10±0.73 d	42.07±2.38 d
Control	33.60±0.84 a	12.20±0.91 a	6.00±0.47 a	58.34±2.32 a
BB C1	26.50±0.84 e	8.20±0.42 c	4.80±0.78 c	49.82±0.72 b
BB C2	24.90±0.56 f	7.80±0.42 cd	5.60±0.51 b	39.16±0.94 f
BB C3	25.80±0.63 e	8.80±0.78 b	6.10±0.56 a	42.58±1.15 d
CG C1	22.20±0.78 g	7.60±0.51 cd	6.20±0.63 a	48.79±2.19 b
CG C2	25.80±0.91 e	6.50±0.52 e	5.30±0.48 b	47.73±2.53 b
CG C3	27.70±0.82 d	6.40±0.51 e	3.40±0.69 d	45.73±0.48 c
FS C1	29.70±0.82 c	6.30±0.48 e	5.40±0.51 b	44.61±3.06 c
FS C2	32.00±0.66 b	7.40±0.51 d	4.70±0.67 c	42.21±1.37 d
FS C3	29.60±1.07 c	7.70±0.48 cd	5.90±0.73 ab	38.81±0.94 f

Note: Values show the mean ± standard deviation (n=10). Values indicated by a different letter are significantly different ($P \leq 0.05$)

Table 4. The effect of the algae *Cystoseira gibraltarica* (CG), *Bifurcaria bifurcata* (BB), and *Fucus spiralis* (FS) at different concentrations on fruit quality by both treatments (spraying and amendment). The values are presented as mean ± standard deviation (n=6)

Spraying	Firmness (kg/cm)	Diameter (mm)	Brix %	Quantity of sugars (%)	MI
Witness	2.11±0.06 d	40.50±1.00 f	4.90±0.62 b	4.98±0.59 b	53.39±0.95 b
Control	3.50±0.61 a	52.50±0.50 a	4.66±0.23 bc	4.68±0.23 c	43.45±2.20 d
BB 0.5 %	3.03±0.56 b	46.33±1.25 c	4.36±0.05 bd	4.48±0.05 d	46.49±0.52 c
BB 1 %	3.23±0.16 b	47.83±3.21 b	4.46±0.23 cd	4.54±0.23 c	69.58±3.57 a
BB 2 %	2.95±0.18 b	45.50±0.50 c	3.73±0.15 ef	3.79±0.15 f	41.84±1.75 e
CG 0.5 %	2.03±0.11 d	42.33±1.01 d	4.26±0.15 d	4.33±0.15 e	18.30±0.64 h
CG 1 %	2.03±0.07 d	43.00±1.00 d	3.46±0.15 f	3.51±0.16 g	31.07±1.48 f
CG 2 %	2.64±0.12 c	45.00±1.00 c	4.23±0.20 d	4.29±0.20 e	43.16±2.09 d
FS 0.5 %	1.86±0.1 d	40.83±1.52 f	5.33±0.05 a	5.40±0.05 a	24.42±0.24 g
FS 1 %	2.56±0.23 b	48.33±1.25 b	3.93±0.15 e	3.98±0.16 f	46.05±1.93 c
FS 2 %	1.88±0.10 d	41.16±1.25 e	4.33±0.2 d	4.37±0.19 e	40.20±1.79 e
Amendment					
Witness	2.11±0.06 e	40.50±1.00 d	4.90±0.62 a	4.98±0.59 b	53.39±0.95 a
Control	3.50±0.61 b	52.50±0.50 a	4.66±0.23 b	4.68±0.23 c	43.45±2.20 d
BB C1	2.77±0.18 d	48.50±1.00 b	3.90±0.10 d	4.04±0.01ab	44.51±0.05 c
BB C2	3.62±0.07 a	53.50±1.80 a	3.76±0.32 d	3.88±0.31 f	35.22±2.90 f
BB C3	3.50±0.61 b	44.33±3.21 c	4.13±0.46 c	4.24±0.48 d	46.43±0.76bc
CG C1	3.23±0.16 c	48.5±2.17 b	4.03±0.55 c	4.12±0.55 e	40.19±1.12 e
CG C2	2.95±0.18 d	45.16±1.04 c	4.23±0.25 ab	4.32±0.25 d	37.75±2.19 ef
CG C3	2.03±0.11 e	40.00±2.64 d	3.80±0.45 d	3.87±0.46 f	30.37±1.49 g
FS C1	2.03±0.07 e	52.66±1.52 a	4.63±0.05 b	4.72±0.06 c	36.01±0.45 f
FS C2	2.64±0.12 d	46.66±0.57 c	4.73±0.11 b	4.81±0.10 b	45.83±1.03 c
FS C3	1.86±0.10 f	47.33±2.08 b	5.10±0.10 a	5.18±0.11 a	48.45±1.04 b

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

The organoleptic qualities of pepper fruits (Brix, quantity of sugars, maturity index), grown in greenhouse pots, were significantly little affected by the two treatments, aqueous extracts and amendment (Table 4); However, the algal extracts significantly improved the organoleptic qualities of the fruits. Indeed, *F. spiralis* at 0.5% showed maximum values in brix and amount of sugar (5.33% and 5.40%, respectively). Similarly, *B. bifurcata* at 1% significantly improved the maturity index (69.58).

Furthermore, we noted that the amendment treatment had no significant effect on the organoleptic qualities of the fruits except for the amendment with *F. spiralis* at C3, which showed a significant difference in sugar content (5.18%) compared to the control treatment (Table 4).

Discussion

Moreover, to evaluate the effect of algal fertilization on plant growth and productivity, we tested increasing concentrations of extracts and amendments of the three brown algae (*B. bifurcata, C. gibraltarica,* and *F. spiralis*) on the pepper crop.

The results obtained after three months of cultivation in pots under greenhouse conditions are generally very satisfactory. The root and aerial growth and the fresh and dry weight of the pepper plants are clearly improved after treatment with the aqueous extracts and the amendments, particularly *B. bifurcata.* Similar results showed that treatment with the alga *A. nodosum* as an extract effectively affected the growth of several crops (Danesh et al. 2012; Bozorgi 2012). In addition, algal extracts improve nutrient uptake by roots, especially Mg, K, and Ca (Yassen et al. 2018). This stimulates root activity by increasing the uptake of water and mineral elements, which improves plant growth and vigor. These results are consistent with those obtained by Zermeno-Gonzalez et al. (2015), who showed that applying organic fertilizers derived from algal extracts to the soil on maize crops increased plant height, stem diameter, and plant dry weight. Our study clearly shows that the mineral contents of pepper leaves are improved in the presence of extracts and amendments of the three algae. This could increase the water uptake by the roots of the pepper plants, which would increase the fresh weight of the crop. At the same time, their dry weight increment can be explained by the increase in their protein and organic matter content. Similar results showed that treatment with algal extracts increased the leaves, fresh weight, and dry weight (Xu and Leskovar 2015). These results can be explained by the constituents of algae that contain nutrients, namely vitamins, amino acids, auxins and cytokinins, and macro and micro minerals that affect the cellular metabolism of treated plants, resulting in increased growth of these plants (Khan et al. 2009; Spann and Little 2010; Craigie 2011; du Jardin 2015).

The yield of pepper fruits increased following treatment with the extracts or amendment, especially the aqueous extract of *B. bifurcata* at low concentrations. Similar results showed that the aqueous extract of *Sargassum wightii* recorded an increase in yield and quality of *Vigna radiata* fruits (Kumar et al. 2012). 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 (Roussos et al. 2009). The reproductive phase has higher nutrient requirements, which are met by applying aqueous extracts of *B. bifurcata* and *C. gibraltarica,* which contain both macro and micronutrients. Fertilization (extracts and amendments) by the three brown algae improved the fruit quality (brix, soluble sugars, diameter, firmness, maturity index) of pepper, especially the alga *B. bifurcata*, which showed higher efficiency on the fruit quality of both crops. It can also be noted that the low concentrations of the three brown algae showed maximum values of pepper fruit quality.

Similarly, according to Ali et al. (2016), plants treated with *A. nodosum* alga in extract form significantly improved fruit quality. This study revealed clearly that fertilization with extracts or amendment improves the soluble sugar content of pepper fruits. Increasing soluble sugar content also contributes to the fruit's nutritional value, except for MI on the amendment (FS at 48.45) that shows a lower result than Witness (53.39).

In conclusion, fertilization with the three brown algae improved all studied parameters. In particular, the two algae, *B. bifurcata* and *F. spiralis* highly efficiently increased pepper's growth, yield, and fruit quality. The three algae used in our study effectively develop biostimulants to improve the vegetable plant's yield and fruit quality.

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