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Research Article

Biostimulant Effect of Four Moroccan Seaweed Extracts Applied as Seed Treatment and Foliar Spray on Maize

[1]Lahbib Fayzi, [1]Mohamed Dayan, [2,3]Ouafa Cherifi, [4]El Houssine Boufous and [1]Khalil Cherifi

[1]Laboratory of Biotechnologies and Valorization of Natural Resources, Faculty of Sciences, Ibn Zohr University, Agadir, Morocco
[2]Laboratory of Hydrobiology, Ecotoxicology, Sanitation and Global Changes, Cadi Ayyad University, Marrakech, Morocco
[3]National Center for Studies and Research on Water and Energy, Cadi Ayyad University, Marrakech, Morocco
[4]Department of Biochemistry and Microbiology, Laval University, Quebec City (Quebec), Canada

Abstract

Background and Objective: Over the past decades, the use of seaweeds as biostimulants in agriculture has been increasing steadily. These have been proven to be a safe and economical method for improving plant growth and crop quality. Hence, this research was initiated to explore the influence of four Moroccan seaweed aqueous extracts prepared from *Corallina elongata*, *Corallina officinalis*, *Jania rubens* and *Ulva fasciata* on germination and growth of maize (*Zea mays* L.). **Materials and Methods:** Seaweed aqueous extracts at 10%, commercial biostimulant product (SM6®) and distilled water as control were applied either as seed treatment for ten days of *in vitro* culture or as foliar spray under greenhouse conditions, to evaluate their effects on seed germination, plant growth and chlorophyll content. **Results:** The results obtained indicated significant stimulatory response on germination speed, seedling length and weight, as well as a greater number of lateral radicles. The highest effectiveness was observed for seeds exposed to *J. rubens* extract with more than 50%, as compared to the control. In pot experiments, foliar application enhanced the growth of maize, resulting in improved growth parameters and total chlorophyll content, chiefly *J. rubens* and *C. elongata*. Shoot and root length, leaf area, fresh and dry weights of corn plants were markedly increased (from 10-53%). **Conclusion:** The present investigation revealed that the four Moroccan seaweeds, especially *J. rubens*, significantly improved seed germination, seedling vigor and plant growth of maize. Therefore, these macroalgae could be used as a suitable promising biostimulant or biofertilizer in corn cropping systems and should contribute to more sustainable agricultural practices.

Key words: Seaweed extracts, biostimulant, foliar spray, seed germination, plant growth, maize

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Corresponding Author: Khalil Cherifi, Laboratory of Biotechnologies and Valorization of Natural Resources, Faculty of Sciences of Agadir, Ibn Zohr University, BP 8106, 8000 Agadir, Morocco

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

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

INTRODUCTION

In most countries of the world, increasing population pressure has led to agricultural intensification practices and expansion of cultivated lands, which tended to reduce the fallow time. This not only caused soil erosion and the loss of soil quality but also results in rapid nutrients depletion, including the global nitrogen and phosphorus soil balance alteration[1]. In order to boost sustainable productivity and maintain optimum soil fertility, the producers use diverse synthetic fertilizers, to overcome the effects of nutrient deficiency. However, the massive introduction of this conventional fertilization in intensive agriculture had markedly endangered biodiversity and human health, causing pollution of various environmental components, such as soils, groundwater, air and vegetation. To prevent this problem, sustainable improvement of soil characteristics is required by renovating fertilization practices and developing innovative new methods to increase agricultural yields, minimize inputs with a focus on promoting environmentally friendly agriculture[2]. This has prompted researchers to explore alternatives by replacing inorganic fertilizers with biofertilizers, which derived from natural products such as fermentation concentrates, seaweed extracts and composts. These have proven to have remarkable effects, not only on plant nutrient and growth but also on abiotic stress tolerance and crop quality[3]. Seaweeds and their products have recently attracted increasing attention due to their various bioactivities that include biostimulant, fertilizer and antimicrobial properties. Several studies have demonstrated the benefits of the algal extract on seed germination, plant growth as well as stress tolerance[3]. Marine macroalgae biomass is already used for a wide range of other products in food, nutrient supplements, including application in agriculture and horticulture as plant growth stimulators or as soil conditioners[4]. They may be applied as a foliar spray, application to soil or for pre-sowing seed treatment. Thus, they were intended to enhance seed germination, plant nutrient uptake, biotic and abiotic stresses, photosynthetic activity and plant productivity[5,6]. Seaweeds and their products contain many plant growth regulators such as cytokinins[7], auxins[8], gibberellins[9], betaines[10], macronutrients like K, N, Mg, P and Ca and micronutrients such as Cu, Mn, Zn and Fe[11].

In Morocco, seaweeds are abundant and constitute a reservoir of species with a high economic value. However, only a few species are commercially exploited, except *Gelidium sesquipedale*, which is overharvested alongside the coastal Atlantic and used for the agar-agar industrial production[12]. Investment in this area requires the inventory of Moroccan algal resources on both the Atlantic and Mediterranean coasts, as well as an exploration of new approaches to manage and valorize these marine natural resources, which represent a mine of useful products. Therefore, the present study was an attempt to investigate the effect of four marine macroalgae extracts, collected from the Moroccan Atlantic coastline, northern Agadir city, on improving seed germination, chlorophyll content and growth of maize plants under laboratory and in pot studies.

MATERIALS AND METHODS

Collection and preparation of seaweeds: In this work, four species of marine macroalgae: three red algae (*Corallina officinalis*, *Jania rubens* and *Corallina elongata*) and a green alga (*Ulva fasciata*) were studied. Seaweeds were collected by hand picking at low tide in February 2019 from the Moroccan Atlantic coast at Tamri National Park area, northern Agadir coastline. Immediately after they arrived at the laboratory, the algae were cleaned, washed with distilled water to eliminate salt, epiphytes, sand particles and then dried in the shade at room temperature. The dried algae were crushed and finely grounded to powder and then stored at 4°C in an airtight container until analysis.

Preparation of seaweed aqueous extracts: The aqueous extract was prepared by the maceration process according to Souhaili *et al.*[13] with several modifications. Ten grams of powdered seaweed was soaked in 100 mL of sterile distilled water for 48 hrs then centrifuged at 4000 rpm for 10 min. After centrifugation, the supernatant was collected and filtered through Whatman filter paper (pore size 11 μm). The filtrate thus obtained was diluted at 10% and stored in screw cap glass bottle at 4°C for further studies. In this preliminary experiment, this concentration level indicated that it was the optimal concentration that led to the best enhancement effect and for this reason, it was adopted to investigate the biostimulant potential of the studied seaweeds.

Mineral analysis of the seaweeds: Mineral analysis of the selected seaweeds was carried out following the methods of Rupérez[14]. Minerals were obtained by ashing the dried samples by calcination in a muffle furnace set at 550°C for 6 hrs. The ash was dissolved in hydrochloric acid and nitrogen content was determined by the Kjeldahl technique. The mineral elements were determined by atomic absorption spectrophotometry and the concentrations of potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), manganese (Mn), copper (Cu), zinc (Zn) and iron (Fe) were calculated. Otherwise, the phosphorus (P) content was determined using the colorimetric method. All measurements were carried out in triplicates.

Germination and early seedling emergence under *in vitro* conditions: Certified seeds of maize (*Zea mays* L.) (Cecilia variety) with uniform dimension, weight and color, were selected for surface-sterilized using 0.5% sodium hypochlorite solution (NaOCl) for 10 min, then rinsed with sterile distilled water several times and briefly blotted on filter paper. Fifteen seeds were placed in plastic Petri dishes (90 mm diameter) on filter paper wetted with distilled water for control, with a commercial biostimulant product (SM6®) at the dose suggested by the producer 2% and with seaweed liquid extract at 10% for seed treatment. Petri dishes were placed in a precision incubator and incubated in the dark at 25±0.5°C. All experiments were done in triplicate and seed germination was regularly monitored, for 10 days and considered as germinated when radicle was longer than three millimeters. Parameters such as final germination percentage (FGP) and germination energy (GE) were measured according to Hernández-Herrera *et al.*[15], where:

$$GE = \frac{\text{Germinated seeds number}}{\text{Total germinated seeds per treatment within 3 days}} \times 100$$

After 10 days, the number of lateral radicles and radicle and plumule length of the seedlings were measured using a digital caliper. In addition, the average total fresh weight per seedling was determined after removing the substrate on the root surface.

Foliar spray application: The experiment was performed during the spring-summer season of 2019 under greenhouse conditions in Agadir City. Seedlings selected for the present study were sprayed after 20 days from transplanting with the same solutions described previously for germination tests. Each plant received two foliar sprays every week throughout the experiment of 90 days. Furthermore, during foliar application procedures, the surface was covered to avoid liquid flow sprayed from contacting the potting soil. For enabling greater foliar infiltration, the sprays were applied in the morning when leaf stomata were open due to water pressure[2]. All pots were hand-watered regularly but after leaf spraying, they were not watered for 24 h. The foliar spray application was tested in ten treatments with three replicates per treatment.

Growth parameters: Plants were uprooted carefully from each treatment at the end of the experiment and various growth parameters were measured including shoot and root length, third leaf from the apex, stem diameter and leaf number. At the same time, the fresh and dry weight (drying at 60°C for 48 h) of the tested plants were also determined.

Photosynthetic pigments: The content of photosynthetic pigments was carried out using essentially Lichtenthaler method[16]. One hundred milligrams of fresh maize leaves were homogenized with 10 mL of 80% acetone using mortar and pestle. After the homogenate was first filtered through four layers of gauze, the filtrate was then centrifuged at 5000 rpm for 15 min. The supernatant absorbance was read spectrophotometrically at 663 nm for chlorophyll a and 645 nm for chlorophyll b. The total amount of chlorophyll was evaluated and expressed in mg g^{-1} fresh leaves as described by Lichtenthaler[17].

Statistical analyses: Each treatment of the experiment consisted of three replicates in a completely randomized design. Before performing statistical analysis, all data determined as percentages were arcsine square-root transformed before normalizing variances. Data were analyzed by one-way analysis of variance (ANOVA) and Newman Keuls multiple post hoc test was carried out when the F value was significant ($p<0.05$). All experimental data were statistically processed by Xlstat software for windows version 2016[18].

RESULTS

Chemical composition: Chemical analysis results of the four seaweed extracts showed that the most essential minerals such as phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn) and iron (Fe) were found in significant amounts (Table 1). Among these metals, calcium was the most abundant element in *Corallina elongata*, *Corallina officinalis* and *Jania rubens* (18.77, 16.37 and 12.79 g/100 g DM respectively). The seaweed *J. rubens* showed the highest potassium content (2.27 g/100 g DM) as well as magnesium (1.89 g/100 g DM). However, the extract from *Ulva fasciata* showed higher content of total nitrogen (2.17 g/100 g DM), copper (89.41 mg kg^{-1} DM) and iron (157.99 mg kg^{-1} DM), compared to the red seaweeds considered in this work. Sodium, zinc and manganese were

Table 1: Major minerals (g/100 g dry weight) and trace elements (mg kg^{-1} dry weight) content in the four selected seaweeds

Minerals	*Jania rubens*	*Corallina elongata*	*Corallina officinalis*	*Ulva fasciata*
K (g/100 g)	2.27±0.50^{a}	0.83±0.01^{c}	1.03±0.17^{b}	0.31±0.04^{d}
Ca (g/100 g)	12.79±0.85^{c}	18.77±1.19^{a}	16.37±0.17^{b}	2.35±0.17^{d}
Mg (g/100 g)	1.89±0.04^{a}	1.72±0.07^{b}	1.68±0.14^{b}	1.72±0.14^{b}
P (g/100 g)	0.26±0.00^{d}	0.34±0.01^{c}	0.43±0.03^{b}	0.54±0.02^{a}
N (g/100 g)	1.33±0.00^{b}	0.95±0.02^{c}	1.23±0.02^{b}	2.17±0.02^{a}
Na (g/100 g)	0.42±0.08^{a}	0.32±0.01^{b}	0.31±0.02^{b}	0.48±0.02^{a}
Fe (mg kg^{-1})	6.15±0.03^{b}	3.10±0.00^{c}	3.17±0.23^{c}	157.99±0.85^{a}
Mn (mg kg^{-1})	12.01±0.56^{c}	14.57±0.00^{b}	16.71±0.49^{a}	16.04±0.02^{a}
Zn (mg kg^{-1})	3.83±0.46^{a}	3.87±0.49^{a}	3.49±0.51^{b}	3.14±0.01^{c}
Cu (mg kg^{-1})	13.10±0.24^{c}	12.30±0.00^{d}	15.11±0.68^{b}	89.41±0.18^{a}

The values represent the average (n=3) ± standard error. For each parameter, means having the same ending letter do not differ significantly at 5% by Newman-Keuls test

Table 2: Physicochemical characterization of aqueous seaweed extracts and commercial biostimulant product (CBP)

Parameters	Control	CBP	*Jania rubens*	*Corallina elongata*	*Corallina officinalis*	*Ulva fasciata*
EC (mS cm^{-1})	0.00±0.00^{d}	2.08±0.12^{b}	1.42±0.21^{c}	1.99±0.13^{b}	2.71±0.02^{a}	2.56±0.16^{a}
pH	7.05±0.04^{b}	6.23±0.03^{c}	7.61±0.05^{a}	7.83±0.11^{a}	7.85±0.10^{a}	6.42±0.18^{c}

The values represent the average (n = 3) ±standard error, EC: Electrical conductivity, For each parameter, means having the same ending letter do not differ significantly at 5% by Newman-Keuls test

also detected in all seaweed extract samples with different concentrations. The highest manganese amount was found in *Ulva fasciata* and *Corallina officinalis* (16 mg kg^{-1} DM).

The pH of all seaweed extracts was neutral, approximately seven except for *Ulva fasciata* and the commercial biostimulant product where they were slightly acidic, around 6 (Table 2). The electrical conductivity (EC) values revealed significant differences among the extracts and ranged from 1.42-2.56 mS cm^{-1}. The highest value was from *U. fasciata*, whereas the lowest value recorded in *J. rubens* extract.

Effect of seaweed extracts on seed germination: The results of this study revealed that corn seed emergence occurred in all treatments after 2 days. Kinetics during germination of *Zea mays* seeds treated with different extracts of algae showed a net variation, especially at the 3rd day after sowing (Fig. 1).

At this stage, the *Jania rubens* extract triggered faster seed germination by 38.46% over the control, since after only 3 days it reached 86%, followed respectively by the three aqueous extracts of *Corallina elongata*, *Corallina officinalis* and *Ulva fasciata* which had attained 76%. In contrast, after the 6th day, most seeds exposed to the different seaweed extracts had achieved full germination percentage. This value was ranged between 90 and 96% and there were no statistically significant differences in final germination between treatments. A similar trend was also confirmed by the results of the germination energy percent of corn seeds treated with the various aqueous seaweed extracts (Fig. 2). For this parameter, the greatest seed germination speed

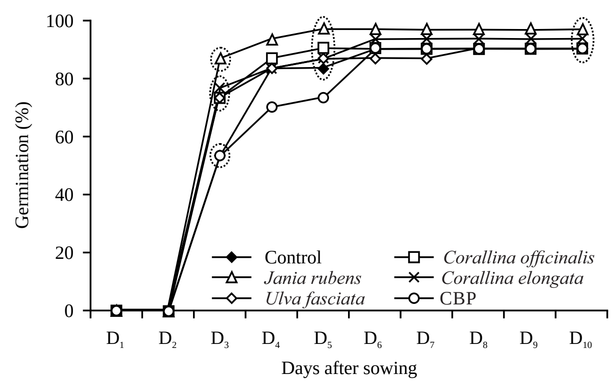

Fig. 1: Daily germination percentage of maize seeds treated with the different aqueous seaweed extracts and Commercial Biostimulant Product (CBP)

At each day, values within an ellipse do not differ significantly at 5% by Newman-Keuls test

was obtained with *Jania rubens* extract (86.66%) but the commercial liquid fertilizer showed a lesser percentage (53.33%), which indicated that seeds emerged much more slowly compared to other seaweed extracts.

Effect of seaweed extracts on early corn seedling growth: The different seaweed extracts also had a significant positive effect ($p \leq 0.05$) on corn seedlings growth. In comparison with control, all aqueous extracts, except for the commercial liquid fertilizer, showed a great stimulatory effect on plumule and radicle length (Fig. 3a), seedling fresh weight (Fig. 3b) and lateral root development (Fig. 3c) after only ten days of sowing. The highest average seedling length was found in seeds treated with *Jania rubens* and *Corallina officinalis* (30.42 and 25.13 cm respectively), with an increase of 61 and 43% respectively, compared with the control (Fig. 3a). In the same way, the results of fresh weight per seedling indicated considerable improvement and *Jania rubens* extract induced the highest total fresh weight (0.96 g), which was approximately 50% higher than the control (distilled water) (Fig. 3b). The initiation of a large number of lateral radicles, observed in germinated seeds, showed similar results across the different treatments. *Corallina elongata* and *Ulva fasciata* revealed on the average lower proportion (22%) when compared to the control (Fig. 3c). Thereby, application of *Jania rubens* extract showed by far the highest proportion of increase (50%) (Fig. 3d), followed by *Corallina officinalis* (40%), In contrast, commercial liquid extract, at the recommended concentration, manifested remarkable inhibitory effect, generating seedlings with reduced weight and length growth (45%) associated with low emerged lateral root number (71% lesser than the control) (Fig. 3d).

Foliar spray: In the greenhouse experiment, foliar application of seaweed aqueous extracts significantly enhanced ($p \leq 0.05$) the growth of *Zea mays* plants compared to commercial liquid fertilizer and control. At the end of the growing period, treatments applied as foliar spray of *Corallina elongata* and *Jania rubens* displayed the highest increase in plant shoot (66 cm in average), with a relative increase of 21% (Table 3). Compared to shoot length, the root length had shown the same percentage of increase. Additionally, the variation in fresh and dry weights revealed similar trends. The favourable

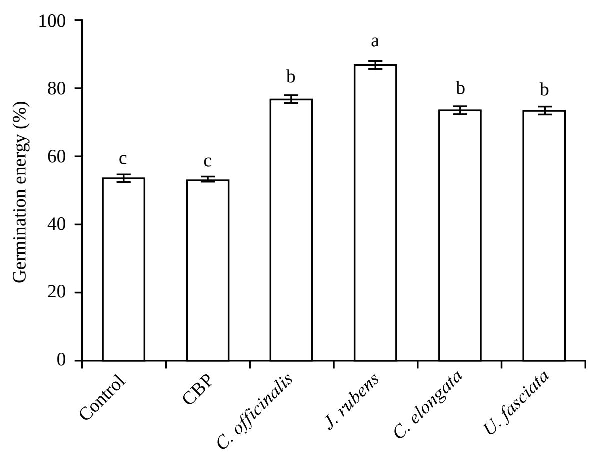

Fig. 2: Effect of the aqueous seaweed extracts and commercial biostimulant product (CBP) on germination energy parameter

Means having identical letter do not differ significantly at 5% by Newman-Keuls test

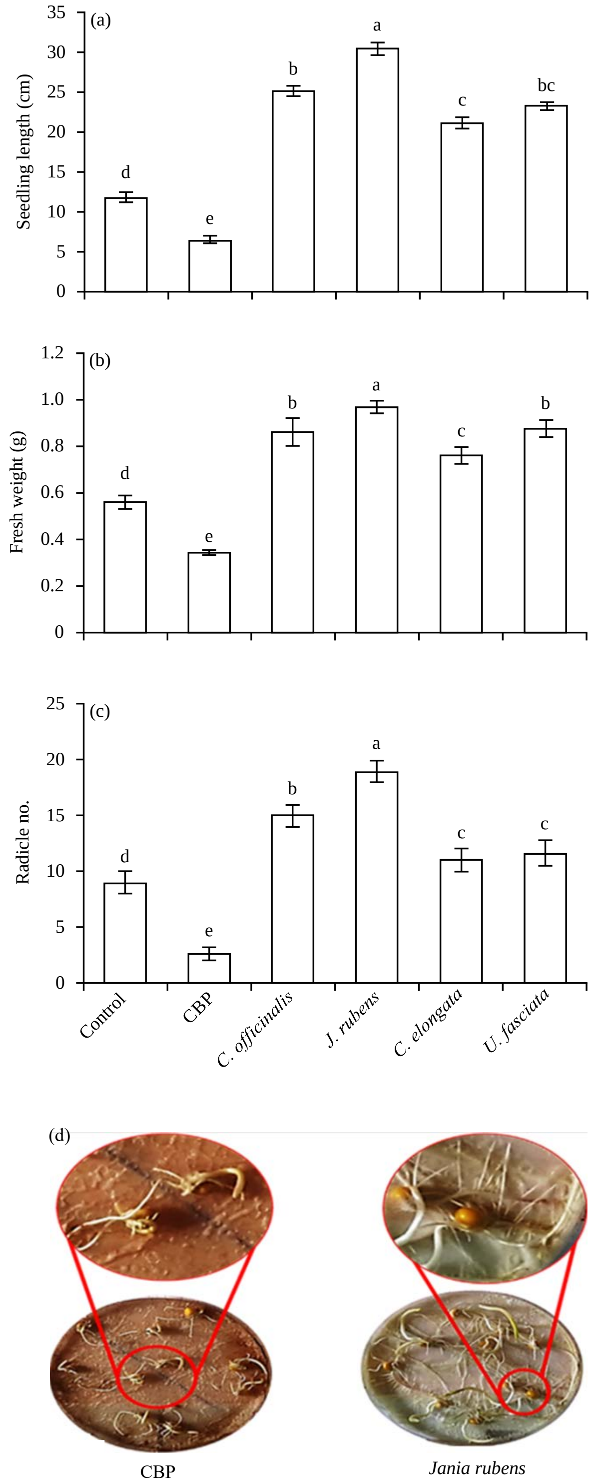

Fig. 3(a-d): Effect of the aqueous seaweed extracts and commercial biostimulant product (CBP) on corn seedlings growth ((a) Seedling length, (b) Fresh weight and (c and d) Number of lateral radicles)

Means having identical letter do not differ significantly at 5% by Newman-Keuls test

Table 3: Effect of applying different seaweed aqueous extracts and commercial biostimulant product (CBP) as leaf spray on growth parameters of maize

Growth parameters	Control	CBP	*Corallina officinalis*	*Jania rubens*	*Corallina elongata*	*Ulva fasciata*
Shoot length (cm)	52.22±0.48^{d}	53.50±3.21^{d}	58.78±1.98^{c}	65.72±0.67^{a}	66.39±1.35^{a}	62.22±0.34^{b}
Root length (cm)	11.67±0.16^{c}	13.72±0.91^{b}	13.22±0.25^{b}	15.06±0.34^{a}	14.11±0.67^{b}	13.89±0.38^{b}
Leaf area (mm^2)	55.87±0.72^{c}	55.05±1.89^{c}	61.15±6.03^{b}	67.61±1.97^{a}	65.90±0.88^{a}	61.40±1.27^{b}
Fresh weight (mg)	4.50±0.09^{c}	3.20±0.17^{d}	6.03±0.07^{b}	6.75±0.15^{a}	6.08±0.07^{b}	5.93±0.15^{b}
Dry weight (mg)	0.71±0.03^{c}	0.70±0.04^{c}	0.81±0.03^{bc}	1.00±0.03^{a}	0.87±0.02^{b}	0.84±0.01^{bc}
Leaf number	4.67±0.06^{a}	5.11±0.04^{a}	4.89±0.10^{a}	5.11±0.23^{a}	5.11±0.11^{a}	5.00±0.34^{a}
Stem diameter (cm)	0.37±0.00^{a}	0.41±0.02^{a}	0.44±0.03^{a}	0.47±0.00^{a}	0.45±0.03^{a}	0.42±0.02^{a}

The values represent the average (n=3) ± standard error. For each parameter, means having the same ending letter do not differ significantly at 5% by Newman-Keuls test

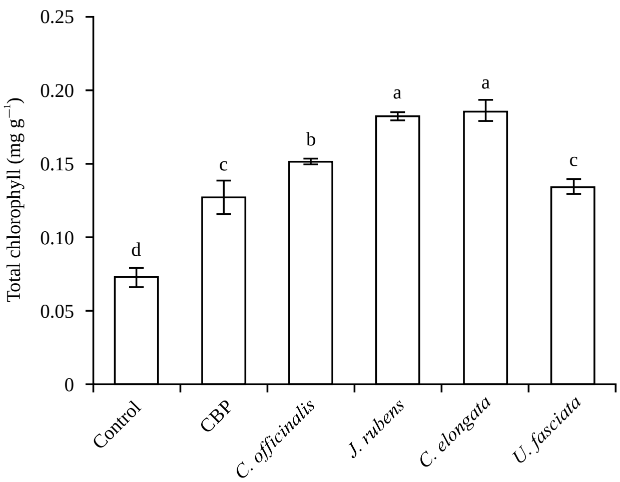

Fig. 4: Effect of applying different seaweed aqueous extracts and commercial biostimulant product (CBP) as foliar spray on total leaf chlorophyll of maize plants

Means having identical letter do not differ significantly at 5% by Newman-Keuls test

effect, chiefly on fresh weight was observed when using the four macroalgae extracts as a foliar spray. Hence, the rise in shoot fresh weight was higher compared to root weight. The greatest enhancement in corn plant fresh weight was found in the treatment of *Jania rubens* where fresh weight reached an average of 6.75 g with a percentage increase of 53% compared to the control (Table 3). Whereas, this parameter attained only about 33% for *Corallina officinalis*, *Corallina elongata* and *Ulva fasciata* treatment but it was much less pronounced than the commercial liquid extract with the recommended dose. Results also showed clearly that leaf area was improved significantly when using the aqueous seaweed extracts (Table 3). Among the five treatments, *Jania rubens* and *Corallina elongata* had the most pronounced effects: leaf area increase was estimated at 15 and 10% respectively. Whereas, there was a slight improvement noticed when spraying maize plants with the rest of other seaweed extracts. For stem diameter and leaf number, it appeared that both the parameters were the least affected by a foliar spray treatment of seaweed liquid extracts (Table 3). On the other hand, plants receiving the commercial biostimulant product displayed no significant differences in the studied growth parameters, since these measures were statistically similar to the distilled water control, except for fresh plant weight.

Photosynthetic pigments: Seaweed extracts applications as foliar spray resulted in much greener leaves of *Zea mays* plants, visible to the naked eye. Photosynthetic pigment content, determined in the greenhouse experiment revealed that the concentration of total Chlorophyll was found to be increased when compared to the control value (Fig. 4). The plant treated with *Jania rubens* and *Corallina elongata* as foliar spray showed a maximum total leaf chlorophyll content of 0.18 mg g^{-1} fresh weight matter compared to control, which was 0.07 mg g^{-1}. The other seaweed extracts also increased the chlorophyll contents but at a lesser extent.

DISCUSSION

Previous studies reported that seaweed extracts contained higher amounts of many essential minerals and trace elements such as N, K, Mg, P, Ca and Fe required for plant growth[19,20]. They should represent more than 20-50% of their dry weight which expresses a much higher level than in terrestrial plants[21]. The content of minerals in the benthic marine algae used in this study was in general agreement with the above researches. However, the quantitative ranges of mineral compounds in seaweeds can fluctuate widely according to the season, environmental conditions and analytical methods[15]. Among the major elements studied, calcium was the most abundant element in *Corallina elongata*, *Corallina officinalis* and *Jania rubens*. This affinity for calcium might be related to the ability of these benthic calcareous algae to accumulate this element in their thalli and depositing it in the form of a calcareous skeleton mainly as calcium carbonate[22]. Generally, the high mineral content of seaweeds is attributed to their marine habitat and their ability to accumulate a wide range of mineral marine substances due to the characteristics of their cell wall sulphated polysaccharides[23].

The current study also showed that the application of aqueous seaweed extracts had a greater effect on early seedlings growth rather than on final germination. Similar results were obtained by treating transgenic corn seeds with other seaweed extracts from both *Gracilaria edulis* and *Kappaphycus alvarezii*. Further, Paungfoo-Lonhienne *et al.*[3] also noted that there was no statistical difference in the final germination percent of corn seeds soaked in an aqueous extract from red algae (*Ahnfeltia tobuchiensis*). Nevertheless, corn seeds emerged much faster following treatment with the four studied seaweeds, mostly *Jania rubens* extract. According to Sivasankari *et al.*[24], seeds soaked with algae extracts significantly increased α- and β-amylase activity and induced different metabolic processes at germination and early seedling stage. As an essential starch-degrading enzyme, β-amylase is synthesized in the starchy endosperm during seed maturation and have a pivotal role in embryo development and seedling emergence. Increase in activity of this enzyme during germination, contributes to rapid radicle emergence from the seed coat[25]. The enhanced level of amylase activity and acceleration of the metabolic response might be due to the presence of stimulatory influence of growth-promoting substances like gibberellins. Similar results were reported in black gram[26], in bean[27] and in sunflower seeds[28].

However, all aqueous extracts, chiefly *Jania rubens* and *Corallina officinalis* showed a significant stimulatory effect on plumule and radicle length, fresh and dry weight of corn seedlings and lateral root development in comparison with control. The presented results are in agreement with those found by many authors reporting that macroalgal extracts were highly efficient in promoting the seedling vigor at the early stage of various species, like tomato[15], maize[3], beans[29] and wheat[30]. Further, the efficiency of seaweed extracts might be attributed to the presence of plant growth regulators, vitamins and mineral contents, such as P, Na, K, Ca and Mg[31]. For example, exogenous calcium, applied directly to the root cap, significantly stimulated root elongation in pea (*Pisum sativum* L.) and corn (*Zea mays* L.) seedlings[32]. Kumar and Sahoo[33] noticed that the seaweed liquid extracts of *Sargassum wightii* also enhanced deep root development through improving lateral root formation by 63.38%, compared to control. Auxins, which reported to be present in seaweed extracts, were also found to stimulate markedly initiation, as well as growth and branching of root systems[34].

Results from the greenhouse experiment indicated a positive correlation between leaf spray treatments and greater maize plant growth compared to the commercial biostimulant and the control. Among the five treatments, *Jania rubens* and *Corallina elongata* had the most marked effects on the examined vegetative growth parameters, as well as total leaf chlorophyll content. Such results are in agreement with those obtained by Rengasamy *et al.*[35], who observed better plant growth on foliar sprays of seaweed extracts. Chlorophyll content increase may be due to increased availability of algal nutrients, especially nitrogen and magnesium, which are the fundamental components of chlorophyll forming[36]. Furthermore, chlorophyll content increase might also be explained by the decrease in degradation of this molecule, caused in part by cytokinins and betaines, known to be present in seaweed extracts[37].

Enhancing growth characters in response to the foliar spray of aqueous marine algae extracts may be due to their positive action on increasing cell division and elongation, which aims to promote shoot growth, leaf area and plant dry weight[38]. Other researchers have reported that improved overall plant growth and vigor was also attributed to greater uptake of nutrients and water[39]. Similarly, the positive effect of seaweed foliar sprays was observed in wheat[33], tomato[40] and green gram[41]. This came in agreement with findings in this study, which showed a positive effect on most vegetative characters of maize plants. In this context, several reports suggested that beneficial effects of seaweeds and their extracts might be attributed largely to the presence of more than one group of plant growth-promoting substances such as auxins, cytokinins, gibberellins, micronutrients, vitamins and amino acids[39]. Thereby, cytokinins detected in seaweed extracts have been found containing trans-zeatin, trans-zeatin riboside and dihydro derivatives of these two forms[42]. Auxins and cytokinins have been reported in many intertidal macroalgal species like *Sargassum muticum*, *Caulerpa paspaloides*, *Porphyra perforata*, *Laminaria japonica*, *Dictyota humifusa*, *Undaria pinnatifida* and *Ulva fasciata*. They may play different roles in regulating plant growth and development including plant cell enlargement, stimulating cell divisions, leaf and root differentiation[43]. However, the mechanical action of seaweed extract is still unknown, although it is assumed that the beneficial effects of these extracts are mainly attributed to the synergetic effect of plant growth-promoting substances present in seaweeds[44]. Previous research on the mechanisms of foliar application mentioned that macro and microelements in liquid fertilizer can be readily absorbed by leaf tissue via the stomatal pores or directly through the leaf cuticle[45].

CONCLUSION

This study showed clearly that seaweed aqueous extracts derived from *Corallina elongata*, *Corallina officinalis*, *Jania rubens* and *Ulva fasciata* had potential growth-promoting substances, which significantly enhanced seed germination, seedling vigor and plant growth, as well as photosynthetic pigments of maize compared to the control. The presence of high mineral content in these Moroccan seaweed resources makes them an excellent choice as a potential source of natural fertilizers or biostimulants to improve plant performance in agriculture. More importantly, it will further help in reducing the use of chemical fertilizers for promoting sustainable agricultural systems and developing more eco-friendly approach to organic farming. Therefore, it will be necessary to conduct additional experiments to identify the algae-derived compounds with plant biostimulant activity.

SIGNIFICANCE STATEMENT

This study discovered the potential of aqueous extracts from Moroccan seaweeds to be used as biostimulants for improving seed germination, chlorophyll content and growth of maize plants under laboratory and in pot studies that can be beneficial for researchers and farmers. This study will help the researchers to uncover the critical areas of natural product and plant resources that many researchers were not able to explore. Thus a new theory on enhancing sustainable corn production using seaweeds and their products may be arrived at.

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