Role of *Cystoseira mediterranea* extracts (Sauv.) in the Alleviation of salt stress adverse effect and enhancement of some *Hordeum vulgare* L. (barley) growth parameters

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Abstract

Cystoseira mediterranea (Sauv.) extract was tested for its ability to restore barley (*Hordeum vulgare*) growth under salt stress (350 mM NaCl), shoot growth; membrane integrity; lipid peroxidation and hydrogen peroxide determination were performed. In normal conditions, the obtained data revealed the ability of the extract to stimulate most of barley growth parameters. However, it showed significant effect on most of barley growth parameters (plant height, fresh and dry weight of shoots and roots) and chlorophyll content, under salt stress. The measurement of stress parameters (membrane integrity, lipid peroxidation and hydrogen peroxide) revealed significant effect of *C. mediterranea* extract on reducing the deleterious impact of salt stress on barley seedlings.

Keywords *Cystoseira mediterranea* · Salt stress · Barley · Membrane integrity · Lipid peroxidation · Hydrogen peroxide

1 Introduction

The human population is expected to reach 9.7 billion by the end of 2050 and could peak at nearly 11 billion around 2100 [1]. Such growth inevitably will require more food to ensure food security. Thereby, a significant increase in agricultural land devoted to food production seems inevitable [2]. Salinity is one of the major factors affecting plant growth and development, consequently reduces crop yields and production. Desertification and high rate of evaporation in arid and semi-arid regions apply great pressure to the irrigated agriculture, owing to rapid rate of salinization of soil and water causing, arable land productive agricultural potential, reduction. Irrigation used in arid and semi-arid areas insures the development of agriculture and meets nutritional needs [3]; however, the poor quality of available water often affects soil and crops. The risk of the land loss by salinization has increased sharply in recent years, as a result of the intensified irrigation.

Additionally, the presence of soluble salts in irrigation water and evaporating power of the air in arid and semi-arid zones frequently leads to secondary salinization of soils in irrigated areas [4].

Salinity and population growth are increasing rapidly and simultaneously at the same rate, which further exacerbates food insecurity [5]. In fact, the pressure resulting from the combination of these two natural and human factors inexorably decreases agricultural lands availability and consequently reduces global food.

In recent years, several biological inputs have been developed and commercialized in order to alleviate the drastic effects of biotic and abiotic stress and to improve plant growth and health. Likewise, these products improve soil structure and quality, they named stimulating products or bio-stimulants habitually provide innovative solutions for soil fertilization and crop protection [6], and these biological molecules are mainly macroalgae and their derivative products.

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Marine algae and their derivative products are of great scientific and agronomic interest, since they have an important role in soil quality and plant development enhancement. The crude extracts of algae includes several compounds involved in several mechanisms of plant growth. Which may explain the biostimulant effects. Numerous studies have revealed the benefits effects of algal extracts on plants such as improvement of crop performance, yield and plant resistance to biotic and abiotic stress [7, 8]. Algal extracts could also improve nutrient availability and productivity. In stressed environment, alga and their products constitute the major source for compatible solutes like betaines, amino acids and 3-dimethyl-sulfoniopropionate (DMSP) [9]. *Cystoseira mediterranea* is a brown marine algae (*Fucales*, *Phaeophyceae*), endemic species of the Mediterranean Sea growing on littoral rocky shores of the Northwestern Coast [10].

The Algerian coast has an unusually rich diversity of seaweeds; however, there are only few studies on their biostimulant properties. The current investigation mainly focuses on the determination of *C. mediterranea* extract capability to restore barley growth under salt stress.

2 Material and methods

2.1 Seaweeds collection

Seaweed *C. mediterranea* (Sauv.) used in this experiment was collected from the coastal area of Bejaia-Algeria (Boulimat 36°48'42.1"N 4°58'53.9"E). The collected seaweed samples were handpicked washed thoroughly with a seawater to remove all the impurities. Samples were then brought to the laboratory and washed with tap water to remove epiphytes and adhering sand particles. Samples were air-dried and powdered using electric blender then stored in smoked glass jars.

2.2 Seaweed extract preparation

Algal powder (10 g) was homogenized in 100 ml of distilled water. The solution was autoclaved for 20 min/120 °C/15psi to release the constituents. The supernatant was finally, transferred in sterile flasks. Different concentrations of 100, 50% and 20% were prepared by extract dilution in distilled water, then stored at 4 °C for further applications.

2.3 Surface sterilization of barley seeds

Barley seeds (*Hordeum vulgare* L.) were surface-sterilized as described by Götz et al. [11]. First, seeds are treated with 70% ethanol for 1 min, and then with 12% acidified

hypochlorite for 15 min. Sterilized seeds were finally, washed thoroughly in sterile water.

2.4 Halotolerance of baley seeds

Before proceeding to this experiment, the halotolerance of barley seeds was studied in order to determine which NaCl concentration should be used.

Seeds imbibed in tap water for 1 h at room temperature were placed in Petri dishes layered with sterile filter paper and soaked with 6 mL per Petri dish of water (control) or various NaCl solutions (50 mM; 100 mM; 150 mM; 200 mM; 250 mM; 300 mM; 350 mM and 400 mM). All tests were repeated in triplicate (13 seeds per Petri dish) [12]. The experiment was conducted in darkness at room temperature 25° C. Germination counts were made every day during 15 days, and the final germination percentage was determined at the end of the experiment.

2.5 Barley germination under salt stress

The halotolerance test showed that 350 mM of NaCl is stressful. The protocol was similar to the experimental protocol in Sect. 2.4. In this test, filter paper was soaked with tap water (Control), salt solution 350 Mm NaCl, *Cystoseira* extracts (20% and 50%) and the solution test (*Cystoseira* extracts + salt solution). Seeds germination carried out for 15 days by counting the germinated seeds in each box every day. At the end of the experiment, the percentage of germination in each box was determined. All tests were repeated in triplicate (13 seeds per Petri dish).

2.6 Barley growth under salt stress

After 1 h in tap water, barley seeds were sown in soil. The experiment consists of nine pots (3 seeds per pot at a depth of 1 cm). Six experiments were prepared: Experiment 1: Control, seeds were watered with tap water (5 ml/pot); Experiment 2 and 3: Seeds were watered with *Cystoseira* extract 20% and 50%, respectively. Experiment 4, 5 and 6: Seeds were sown in saline soil and watered with tap water, cys. extract 20% and cys. extract 50%, respectively. All experiments were conducted under natural conditions at temperature 23–28 °C/15 days. Growth parameters: plant height, fresh weight, dry weight of shoots and roots as well as chlorophyll a, b and total, were measured.

2.7 Chlorophyll contents

The photosynthetic pigment content was determined as described by Hiscox and Tsraelstam [13]. Barley fresh matter (100 mg) was cut and mixed in test tube containing 7 ml of Dimethyl sulfoxide. The mixture was incubated at

65 °C for 30 min. After incubation, the sample was transferred into a 25 ml graduated cylinder and the volume was adjusted to 10 ml with DMSO. The absorbance was measured immediately at 645 and 663 nm. Chlorophyll a, b and total were determined according to the equations established by Arnon [14].

$$Chla(g\ l^{-1}) = 0.0127 \times A_{663} - 0.00269 \times A_{645};$$

$$Chlb(g\ l^{-1}) = 0.0229 \times A_{645} - 0.00468 \times A_{663};$$

$$\text{Total } Chl(g\ l^{-1}) = 0.0202 \times A_{645} - 0.00802 \times A_{663};$$

where *Chla* is the chlorophyll a content; *Chlb* is the chlorophyll b content; *Total Chl* is the total chlorophyll; *A* is the absorbance.

2.8 Measurement of stress parameters

2.8.1 Membrane integrity

The study was performed following Radoglou et al. [15] modified [16, 17]. Barley leaves (20 g) were washed with distilled water, then cut into small pieces and taken in test tubes containing 20 ml of distilled water and incubated at 25 °C for 2 h. Electrical conductivity (C1) of the solution was measured using an electrical conductivity meter. Samples were autoclaved at 120 °C/20 min and then cooled at room temperature. The second conductivity (C2) measurement was obtained after stabilization at 25 °C. So, a maximum electrolytes leakage amount was determined by the following formula:

$$\text{Membrane integrity (\%)} = (C1/C2) \times 100$$

where C1 is the electrical conductivity of the solution before autoclaving, C2 is the electrical conductivity of the solution after autoclaving.

2.8.2 Estimation of lipid peroxidation

Lipid peroxidation was determined by malondialdehyde (MDA) content evaluation, which is a product of oxidative degradation of lipids and unsaturated fatty acids. MDA content is determined according to Heath and Packer [18].

Plant materials (50 mg) were grinded and diluted in 4 ml of 20% trichloroacetic acid (TCA). This procedure was used to reveal free radicals present in the sample. The level of MDA serves as an index of lipid peroxidation, and the result was therefore, expressed in mg of MDA. The extract (1 ml) was centrifuged at 10,000 rpm for 10 min at 4 °C. Supernatant (0.5 ml) was added to 2 ml of 0.5% thiobarbituric acid (TBA). The mixture was finally, heated at 95 °C

for 30 min. After cooling, the mixture was centrifuged at 10,000 g/10 min and the absorbance of the supernatant was measured at 532 nm. The MDA content was calculated by the Beer–Lambert law: $OD = \epsilon \cdot C \cdot l$, using the molar extinction coefficient of MDA ($\epsilon = 155\text{ Mmol}^{-1}\text{ cm}^{-1}$).

2.8.3 Determination of H₂O₂ content

The experiment was performed according to method of Sergiev et al. [19] modified. Leaf tissues (50 mg instead 500 mg) were homogenized in ice bath with 2.5 ml (instead 5 ml) 0.1% (w/v) Trichloroacetic acid. The homogenate (1 ml) was centrifuged at 12,000 × rpm for 15 min, and 0.5 ml of the supernatant was added to 0.5 ml 10 mM potassium phosphate buffer (pH 7.0) and 1 ml 1 M KI. The OD of supernatant was recorded at 390 nm. H₂O₂ content was determined using the extinction coefficient $0.28\text{ }\mu\text{M}^{-1}\text{ cm}^{-1}$.

2.9 Statistics

Statistical analyzes were performed by analysis of variance (One Way ANOVA) using the GraphPad PRISM software. Differences between treatments were separated by the least significant difference test at a 0.05 probability level.

3 Results and discussion

3.1 Seeds germination and barley growth

The results show that NaCl has significantly affected seed germination. The algae extracts (Cys 20% and 50%), promoted barley seeds germination under stress conditions, and the germination kinetics is similar to the control. These results showed clearly the deleterious effect of salt stress as well as the remarkable ability of *Cystoseira* extract to restore seeds germination affected by salt (Fig. 1).

Plant growth parameters measurement displayed that both algal extract concentrations (20% and 50%) stimulated the most of parameters plant height ($15.87 \pm 1.12\text{ cm}$; $14.37 \pm 0.62\text{ cm}$), root length ($39.83 \pm 1.77\text{ cm}$; $40.66 \pm 0.88\text{ cm}$), shoots fresh weight of ($1.49 \pm 0.11\text{ g}$; $1.42 \pm 0.06\text{ g}$), roots fresh weight of ($1.45 \pm 0.08\text{ g}$; $1.73 \pm 0.18\text{ g}$) as well as the dry weight of shoots ($0.37 \pm 0.03\text{ g}$; $0.31 \pm 0.05\text{ g}$) and roots ($0.28 \pm 0.02\text{ g}$; $0.29 \pm 0.02\text{ g}$), compared to the untreated control ($13.62 \pm 0.62\text{ cm}$; $31.33 \pm 1.11\text{ cm}$; $1.04 \pm 0.08\text{ g}$ and $1.25 \pm 0.06\text{ g}$; $0.26 \pm 0.03\text{ g}$; $0.28 \pm 0.01\text{ g}$, respectively) (Figs. 2, 3).

Salt stress affected significantly all barley growth parameters. The addition of algal extract (20% and 50%) in the soil restored significantly all growth parameters. According

Fig. 1 Effect of *Cystoseira mediterranea* extracts on barley seeds germination percentage under normal and salt stress conditions

Fig. 2 Effect of *Cystoseira mediterranea* extract on barley growth under normal and salt stress conditions. **a** Shoot length; **b** root length; **c** fresh weight of shoots; **d** fresh weight of roots; **e** dry weight of shoots; **f** dry weight of roots; 350 mM: 350 mM NaCl; cys: *Cystoseira mediterranea*; ns: Not significant ($p \geq 0.05$); *significant $p \leq 0.05$; **significant $p \leq 0.01$; ***significant $p \leq 0.005$; ****significant; $p \leq 0.001$

Fig. 3 Effect of *Cystoseira mediterranea* extracts on barley growth under saline and non-saline conditions

to Sharif et al. [20], the degree of sensitivity to salt stress depends on vegetative stage during stress exerted. For example, cotton is more sensitive at the seedling stage than at the maturity [21]. To evaluate salt tolerance at the germination stage, several germination indicators could be used [22]. Singh et al. [23] found that the tomato seeds germination rate decreased with salt stress increasing. They also demonstrated that the dry weight ratio (roots/shoots) of seedlings and the Na^+ content increase, while the K^+ concentration decreases.

Seaweeds constitute an important source of nutrients for the seeds and retain water in its external environment, which reduces the rate of dehydration [24]. Seaweed extracts have the ability to increase the concentration of antioxidants in stressed plants [25]. Zhu et al. [26] mentioned that salinity negatively affects the length of the coleoptile and the development of plant roots. Amira et al. [27] reported that seaweed extracts could completely decrease the aggressive effect of low concentration of salt stress and partially the effect of high concentration of stress. Sivasankari et al. [28] discovered that *Caulerpa chemnitzia* and *Sargassum wightii* extracts increase the percentage of vine seeds germination. The germination rate is proportional to the concentration of the extract between 5 and 20% (v/v) and then decreases for the concentrations between 20 and 50%. Above a 50% algal extract concentration, germination is inhibited. Kumar and Sahoo [29] reported that the 20% dilution of *Sargassum wightii* extract significantly stimulated germination of *Triticum aestivum* seeds.

The ability of studied extracts to restore germination and growth of barley may be explained by the fact that seaweed extracts are rich in osmoprotective compounds, particularly free amino acid molecules. According to Ghoul et al. [9], the restoration of wheat plant growth under salt stress is due to the compatible solutes contained in the algae (various betaines, proline, amino acids and dimethylsulfoniopropionate). These compounds reduce the effect

of stress on plants and provide nitrogen and energy for the plant. Compared to plants stressed, the treatments with algae extracts allow a better production of biomass of plants cultivated under saline conditions. However, it should be noted that the biomass of plants stressed and treated with algae extracts always remains significantly lower than those of unstressed plants. These results suggest that the presence of the extracts, although beneficial, does not provide total protection against salt stress [30].

3.2 Chlorophyll contents

Salinity stress causes a perturbation in photosynthesis and therefore reduces plant growth and production. In this study, the chlorophyll content quantification carried out in order to verify the ability of *C. mediterranea* extract to alleviate salt stress impact. Results of this study showed that salt stress significantly reduced the chlorophyll content. Both concentrations of *C. mediterranea* under saline stress (Cys 20% + 350 mM NaCl and Cys 50% + 350 mM NaCl) improve the content of barley seedlings in chlorophyll a, and total compared to the control untreated (350 mM NaCl). In the absence of stress, *C. mediterranea* extract slightly improved chlorophyll content (Fig. 4).

It has been stated by Shaheen et al. [31] that salinity stress causes perturbation in gaseous exchange in plant processes like photosynthesis, substomatal CO_2 concentration, and net CO_2 assimilation and transpiration rate. Under salt stress, as a response to osmotic stress, plant reduce leaf area and chlorophyll content, defoliation, and carbon assimilation [32]. Salinity reduces the chlorophyll content, and this reduction is dependent on the intensity of stress and the degree of plant tolerance [33]. This reduction in chlorophyll contents could be related to the suppression of the enzymes responsible for chlorophyll synthesis [34]. Zhang et al. [35] reported that the increase in salinity levels reduces the chlorophyll a and b contents in cotton.

Fig. 4 Chlorophyll content of barley grown under salt stress in the presence of different concentrations of *Cystoseira mediterranea* extract. cys: *Cystoseira mediterranea*; ns: Not significant ($p \geq 0.05$); **:significant $p \leq 0.01$; ***: significant $p \leq 0.005$

In this investigation, *C. mediterranea* increased the amount of chlorophyll content of barley under salt stress. Results obtained with stressed barley plants treated with *C. mediterranea* extracts revealed a higher chlorophyll contents than unstressed barley plants. Bozorgi [36] and Ramarajan et al. [37] showed that the application of algae to the bean plant as a foliar spray or incorporated into the growing medium increases the pigmentation of the leaves and shoots (especially Chl a). Likewise, the application of seaweed extract to eggplant significantly increases the chlorophyll content in two levels of salt stress (54.76 mM and 82.14 mM). However, stressed plants show significantly higher chlorophyll contents than unstressed plants.

3.3 Stress parameters

3.3.1 Membrane integrity

The electrolyte leakage was estimated by measuring the electrical conductivity of the external medium. The

obtained data showed that the extract Cyst 20% and Cyst 50% reduced the leakage of electrolytes and therefore protected the membrane integrity of barley seedlings. Compared to the control, both concentrations of *C. mediterranea* extract displayed almost the same results; this means that these extracts can reduced the negative effect of NaCl (Fig. 4).

3.3.2 Lipid peroxidation

MDA was evaluated to determine the ability of *C. mediterranea* extract lipid peroxidation decrease in barley cell membranes. Salt stress caused a significant increase in MDA content in plants. A significant reduction ($p < 0.05$) of MDA was obtained with plants treated by cys 20% seaweed extract, whereas the cys 50% + extract reduced it slightly (Fig. 5).

Fig. 5 Effect of *Cystoseira mediterranea* extract on the membrane integrity of barley seedlings in the presence and absence of salt stress. **a** Membrane integrity; **b** Lipid peroxidation; Determination

of H₂O₂; **c** H₂O₂ content; cys: *Cystoseira mediterranea*; ns: Not significant ($p \geq 0.05$); *significant $p \leq 0.05$; **significant $p \leq 0.01$; *** significant $p \leq 0.005$; ****significant $p \leq 0.001$

3.3.3 Determination of H₂O₂ content

Salt stress increased markedly the level of hydrogen peroxide ($2.07 \mu\text{m}^{-1} \text{cm}^{-1}$) compared to the control ($1.18 \mu\text{m}^{-1} \text{cm}^{-1}$). In comparison with the stressed control, the treatment with Cys 20% and 50% extracts reduced significantly H₂O₂ level of ($p < 0.0001$) (Fig. 5).

Reactive oxygen species generated by salt stress causes considerable damage to lipids and proteins and other biomolecules. This damage can lead to plants death [38]. The activation of the plant antioxidant system can adjust the disruption of cellular redox state [39, 40]. Recently, many reports have announced the ability of algae to activate cellular antioxidant machinery in plants under stress [41–43]. The evaluation of these three parameters (hydrogen peroxide, membrane integrity and lipid peroxidation) showed clearly the ability of *C. mediterranea* extract to mitigate the deleterious effect of salinity on barley seedlings.

Evaluating the level of hydrogen peroxide is a main step in stressed plants, as it is the important generator of reactive oxygen compounds, which cause oxidative stress. Several studies have confirmed the involvement of abiotic stresses in reactive oxygen species generation. Mezghani et al. [41] reported that *Ulva rigida* extracts possess strong radical scavenging activity; they suggest that the richness of these extracts in bioactive molecules will provide alga with strong protection for plant cells against oxidative stress. Sadasivam et al. [42] showed that the level of the accumulated hydrogen peroxide in tomato plants as well as the amount of brown spots on leaves increased considerably under salt stress. They suggested that these effects are due to the 3,3' diaminobenzidine (DAB) with peroxidases reaction. Recently, several algae compounds, including polyphenols, polysaccharides, and proteins, have been classified as potent antioxidants that protect cells against free radicals and reduce the progression of many chronic diseases [43].

Lipid peroxidation is a biochemical indicator of alterations induced by reactive oxygen species [44]; it takes place through the oxidation of unsaturated fatty acids, thus causing cell membrane and electrolytes leakage alteration [45]. The determination of the impact of salt stress on plants carried out by measuring the MDA amount and the lipid peroxidation intensity [46]. Lipid peroxidation expressed by MDA concentration is closely related to the disruption of the antioxidant machinery of stressed plants [47]; in our study, the treatment with *C. mediterranea* extract decreased significantly the MDA level that allows us to suppose that the cellular antioxidant machinery in barley was activated and the production of antioxidative enzymes increased by our seaweed extract.

The varied and rich composition of algae and their products are the source of its protective potential of plants

in normal and stressed environments. Besides, they are the major source for compatible solutes for plant and bacteria in stressful environment [48]. Algae, by their composition in compatible solutes, restore plant growth in a stressful environment and enhance the potential of beneficial soil bacteria such as plant growth promoting rhizobacteria (PGPR). *Ulva lactuca* extracts enhanced *Azospirillum brasilense* ability to restore wheat growth under salt stress [49] and restored the germination, protein and chlorophyll contents of wheat inoculated by *P. fluorescens* [50].

4 Conclusion

Cystoseira mediterranea (Sauv.) extract showed a protective mechanism for barley under saline conditions. In normal conditions, *C. mediterranea* extract stimulated most of barley parameters. Under salt stress, both concentrations (20% and 50%) showed a significant effect, on chlorophyll content. This extract reduced significantly the deleterious effect of salt stress on barley seedlings. The results of this investigation encourage the transition towards a healthy culture “Bio-agriculture” beneficial to human health and the worldwide economy. Algal extracts utilization as biostimulants is emerging as a promising alternative to chemicals (fertilizers and pesticides) that are both harmful to the environment and to public health, and as a promising protective mechanism of stressed plants.

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Author contributions The first author carried out all the experimentation and wrote the article. The second author revised and corrected the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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