

Seaweed extracts as biostimulants of plant growth: review

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Seaweeds

Seaweed extracts are the new type of products currently used in plant cultivation. The sources of seaweed extracts are different species of marine algae which seem to be valuable and not wholly discovered biological material [1]. For ages, extracts obtained from algae have been used as feed additives for animals nutrition improvement [2]. Furthermore, they have been used as industrial raw material or in production of natural cosmetics. Nowadays, seaweeds and products obtained from marine algae constitute the subject of interest in agriculture with emphasis on its application in sustainable agriculture [1]. Marine algae are classified by the researchers as the most important group of organisms which can be widely used in plants nutrition.

Biologically active compounds

Seaweed extracts act as biostimulants mainly due to the presence of plant hormones [3]. Main phytohormones identified in seaweed extracts are: auxins, cytokinins, gibberelins, abscisic acid and ethylene [3,4]. Auxins are responsible for elongational growth of plant tissues and apical dominance, cell division, plant movements and plant aging [3, 5, 6]. Cytokinins are involved in cell division regulation affecting plant growth and rest period. Moreover, they inhibit aging of plant tissues and play crucial role in transport of nutrients [3,6]. One of the basic functions of gibberellins are initiation of seed germination, growth regulation, breaking bud dormancy, florescence and fruits development [3, 5, 6]. Abscisic acid and ethylene are responsible for response to stress factors, inhibition of cell growth, acceleration of plant aging [3, 5, 6]. Furthermore, abscisic acid participates in regulation of seed germination.

Seaweeds the most widely used in agriculture due to their good biostimulant activity are red algae: *Corralina mediterranea*, *Jania rubens*, *Pterocladia pinnata*, green algae: *Cladophora dalmatica*, *Enteromorpha intestinalis*, *Ulva lactuca* and brown algae: *Ascophyllum nodosum*, *Ecklonia maxima*, *Saragassum* spp [7].

The methods of seaweed extracts production

It is over 60 years since first commercial seaweed extract was used in agriculture. Preparation of first extract allowed its direct application to specific parts of plants (leaves, roots) [2]. The application of algal extracts results in soil enrichment with trace elements, contributes to plant growth and improves crop yields [8].

Different extraction methods can be used for seaweed extracts preparation i.e. water extraction under high pressure, alcohol extraction, alkaline extraction, microwave-assisted extraction (MAE) and supercritical CO₂ extraction. Conditions of the process depend on the active substances of interest [9 ÷ 13].

Extracts rich in auxins can be produced by alkaline extraction. The process is carried out under low pressure. Previously dried probes are extracted with the use of sodium hydroxide [9]. By Microwave Assisted Extraction (MAE) combined with water extraction under high pressure, fucoidan can be extracted. For the highest efficiency, adequate temperature and pressure should be applied. Duration of the process is at most 30 min and the pressure varies from

0.21 to 0.83 MPa. The biomass is dispersed in water in the concentration 0.04–0.20 g/ml. High temperature is not required and mild solvents are used in the process what allows to reduce costs and makes process environmentally friendly [10]. Cytokinins can be extracted using chilled 70% ethanol. Deuterium is used as cosolvent in this process [11, 14]. Extraction in 85% methanol leads to obtainment of algae extract rich in gibberelins. Biomass should be previously homogenized. The temperature of the process is 4°C [12].

Production of seaweed extracts by supercritical CO₂ extraction seems to be the most beneficial solution due to the low invasiveness of the method. Biomass pretreatment is very important in this case. The first step involves centrifugation of algae and filtration to eliminate water from the probe. After biomass pretreatment, homogenized biomass underwent extraction by supercritical CO₂ extraction. The composition of seaweed extract strongly depends on the algal species. Among many biologically active substances found in extracts produced under supercritical conditions, lipids, volatile metabolites, pigments, aliphatic hydrocarbons, antioxidants, lutein, carotenoids, chlorophyll, vitamin E, γ -linolenic acid can be found [13, 15].

Supercritical extraction has been used in nutraceutical and pharmaceutical industry where low invasiveness is very important [13].

Seaweed extracts in plant cultivation

Some research show that the application of seaweed extracts in plant cultivation exhibits positive effect on cultivated plants [7]. Algae extracts improve plant resistance to frost and drought and increase crop yields. Plants sprayed with the use of seaweed extracts are also characterized by higher resistance to pests and pathogens and more efficient consumption of nutrients from soil [7]. Seaweed extracts contribute to the recovery of damages caused by insects and bacterial or fungal diseases [2].

Formulations basing on algal extracts are rich in phytohormones (gibberelins, auxins, cytokinins), amino acids and fatty acids which are responsible for plant growth, development and resistance to pathogens [8]. Biostimulant activity of extracts obtained from marine algae is connected with the presence of plant growth regulators, particularly cytokinins mainly responsible for plant aging delay, mitosis induction, stimulation of chloroplast maturation, growth of shoot and lateral buds [7, 16]. The amount of cytokinins changes and their ratio to other plant growth hormones depends on the species of algae resulting in different effects of seaweed extracts on plant cultivation [7].

Seaweed extracts can be delivered to plants in many ways. Soaking of seeds in algal extracts is one of the methods. This way of treatment can affect seeds germination [8]. Foliar and classical soil application can be used as well [2, 7]. In addition to application methods, also the concentration of seaweed extract, species of algal, plant variety affects the efficiency of seaweed extracts as plant biostimulants [7].

Both, micro- and macroalgae extracts have been used to increase crop yields and food production in various regions of the world. It is due to beneficial effect of seaweed extracts on the soil which is dependent on the type of crop and environmental conditions [2].

The application of seaweed extracts in plants cultivation is beneficial. Craigie (2010) carried out experiments on different plant species which proved that algae extracts improved germination and root development. Improved quality of leaves, plant vigor and pathogen resistance were also found [2].

The higher content of nutrients in leaves causing more intense growth was shown in grapes treated with seaweed extracts. Increased drought resistance was also observed [17]. Beneficial effect of foliar application of extract obtained from *Ascophyllum nodosum* (as a support to nitrogen and boron fertilization) on olive trees was also investigated. Extract application caused increase of olives size and improved the quality of olive oil [18]. Foliar application of extracts on fruit trees (such as apple) resulted in more intense leaves and shoot growth. Fruits were usually larger and crops were better [19].

Beneficial effects of extract obtained from some algal species on the growth and productivity of rice was also investigated. Application of seaweed extracts allows to decrease doses of inorganic fertilizers used in rice cultivation [20]. The impact of algal extracts on *Brassica napus* was tested. The influence of extracts from marine algae on germination and initial growth of this plant was evaluated. It was shown that the application of seaweed extracts stimulated seeds germination of *Brassica napus*. Plants germinated from seeds soaked in extracts were characterized by higher shoot mass [7].

The positive effect of seaweed extracts application on soya yield was also investigated. Foliar application of extracts in different concentrations resulted in higher yield, more intensive growth and better nutrients absorption of soya [21]. Crouch and van Staden [22] were spraying shoots of tomato with seaweed extracts during vegetative phase. They investigated 30% increase of fruit mass. The response of carrot and parsley on seaweed extracts fertilization constitute another example of its positive effect on plant condition. It was shown, that seeds soaking in algal extracts improved germination ability and had positive impact on chemical content of carrot roots [8]. Advantages of seaweed extracts application were also proved by Pise and Sabale [23]. They showed that extracts obtained from marine algae stimulated shoots growth and increase mass of *Trigonella foenum-graecum*. Increase in carbohydrates, proteins, free amino acids, polyphenols and nitrogen content was also found [23].

Conclusions

Seaweed extracts are well-known biostimulants. They are characterized by high efficiency in plants cultivation what was proved by many papers, besides they are environmentally friendly due to biological origin of material. Therefore, algal extracts can constitute an alternative to synthetic plant stimulants, the application of which very often causes environmental pollution, and support to traditional fertilizers. The use of extracts from marine algae gives an opportunity to choose any method of application suitable for a particular plant and expected effects.

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