Acta Biologica Turcica, 36(3), J5:1-8, 2023 Received 16 Feb. 2023; Accepted 23 Aug. 2023; Published Online 01 Oct. 2023

ACTA BIOLOGICA TURCICA

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E-ISSN: 2458-7893, http://www.actabiologicaturcica.com

Review article

A review on the utilization of macroalgae in agriculture within the concept of sustainable development goals

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Abstract: Mitigating climate change and global warming require some transitions to adapt more sustainable approaches. Global population increase also challenges humanity for adequate food supply and as-related climate change confronts some undesired stress conditions such as drought and temperature anomalies in agriculture. Therefore, increasing agricultural yields in a sustainable manner is gaining importance. Introducing organic-derived inputs in agriculture would be an effective approach, since the growth promoting effect of these organic substances would enhance the efficiency of mineral fertilizers, which are indispensable in agriculture. Seaweeds are macroscopic algae, and they are promising candidates to provide the organic sourced- nutrients and utilized as organic-based fertilizers in agriculture. This study provides a brief review on the extraction methods of seaweeds and their utilization in agriculture in terms of effects on growth, yield, enhancement in the tolerance for stress conditions and their soil- improving effect.

Keywords: sustainable agriculture, seaweed, macroalgae, agronomic yield, sustainable development.

Citing: Avşar, C. (2023). A review on the utilization of macroalgae in agriculture within the concept of sustainable development goals. *Acta Biologica Turcica,* 36(3), J5:1-8.

Introduction

Continuous increase in the global population and the demand to supply the populations' required food and energy are directly proportional with each other. Thus, production of adequate food and energy is of importance. Agricultural applications have been playing an important role to overcome with the pressure on the food demand. Thus, demand to increase product yield together with increase in mineral fertilizer application and the demand increase to mineral fertilizer, resulting with the production capacity increase are all related to each other (Avşar, 2022).

Today, fossil fuel-based resource consumption to provide energy demand as well as limited global resource consumption in production processes has resulted a challenge in terms of sustainability. Thus, conventional production strategies should undergo a change to provide a transition to reach the Sustainable Development and Green Deal goals. Fertilizer industry conducts this transition by introducing sustainable inputs as fertilizer products to enrich the formulations of currently available mineral fertilizers, resulting new generation fertilizer products as organo-mineral, bio or microbial fertilizers, or provides auxiliaries such as biostimulants to boost the development of plants on which the fertilizers are applied on. Today, there are viable commercial alternatives as organic inputs in agriculture, and their agricultural efficiency are being investigated intensively. Thus, sustainable agriculture is a specialty field to provide a problem-solving approach to meet the consumption of resources in a sustainable manner.

Seaweeds are macroscopic algae, and they are promising candidates to provide the organic sourced-nutrients and utilized as organic-based fertilizers in agriculture. Seaweeds sustain ecological and economical importance, and their phytochemical bioactive compound-rich structure enables their utilization as antioxidants, plant hormones, nutrients, or bioactive metabolites (Raghunandan et al., 2019; Alprol et al., 2021; Mansour et al., 2022). However, industrial or anthropogenic factors such as coastal development, aquatic environment pollution, water quality decrease, ocean acidification, microplastic pollution, and invasive species play as a disturbance and put a threat pressure on seaweed ecosystems. Climate change and global warming are also primary risks, threatening not only seaweed ecosystems, but also marine ecosystem as a whole (Cotas et al., 2023; Pacheco et al., 2020; Filbee-Dexter, and Wernberg, 2018; Baraket et al., 2021; Senousy et al., 2023).

Seaweeds as Organic Inputs in Agriculture

Metobolic effects in plants upon seaweed application

Biologically derived organic inputs play a stimulating effect on natural plant processes. These inputs can be applied via roots, foliar spraying, or both, and have boosting effect on efficient nutrient uptake, healthy growth and gaining durability against biotic and abiotic stress conditions by increasing enzymatic and non-enzymatic antioxidant defense mechanism (Ali et al., 2021; Kasim et al., 2015). Seaweeds are being categorized as bioproducts and the bioactive substances extracted from seaweeds can be used as supplements and fertilizers to improve the crop yield and quality. Seaweeds have been utilized as organic fertilizers or biostimulants in agricultural applications for a long time however, there have been a diverse focus on seaweeds over 15-20 years with the wide spreading of organic agriculture point of view (Ali et al., 2021)

Seaweeds are composed of essential macro and micro-elements (N, P, K, Ca and Mg) together with amino acids and hormones such as cytokinin, gibberellin, alginic acid, fatty acids and growth promoting substances. N, P, and K are the primary nutrients for a healthy plant growth, seaweed application results significant nutrient content increase, which is directly related to the overall yield (Shah et al., 2013). These wide range of nutrients and biomolecules provided by seaweeds not only promote plants, but also improve the physical structure of soil. These modifying effect on both plant and soil boost the mineral uptake, growth on both roots and fruit, performance, yield, biomass together with reducing seed dormancy and accelerate the seed germination (Ali et al., 2019).

Seaweed application have a significant effect on the growth mechanism in terms of photosynthetic pigment development and photosynthetic activity. Once applied, seaweed extracts release metabolites, which promote chlorophyll synthesis rate, resulting the acceleration in the photosynthesis rate of crops, and improving the harvest quality (Gonzales et al., 2015). Seaweed application during early development stage significantly increase the chlorophyll content, possibly due to disabling chlorophyll degradation and increasing the rate of photosynthesis.

Seaweed extracts have a biostimulator effect to increase fruit yield and post-harvest shelf lives. These extracts can be classified into two groups according to their molecular weights. Low molecular weight extracts are effective in plant growth, whereas high molecular weight extracts enhance the resistance against biotic and abiotic stress conditions. Extracted and purified polysaccharides and oligosaccharides triggers the plant growth. Genetic characterization upon seaweed application report that the total contents of soluble proteins, phenols, flavonoids and antioxidants also tend to increase (Fan et al., 2013; Gonzales et al., 2013; Mukherjee and Patel, 2020. Some macroalgae species can possess high amounts of tocopherols, which are lipid-soluble antioxidants and act as a protective substance for membrane lipids against oxidative damage (Durmaz et al., 2007).

Theoretical studies on the extraction procedures

Although seaweed extracts have been utilized for a long time, the extraction procedures for agricultural applications have not been comprehensively explained. The application on agricultural basis is mostly commercial-intended, and the lack of comprehensive and detailed data or document about extraction protocols is possibly due to commercial confidentiality. Generally, the main concern in extraction procedures is obtaining high yield and purity. There are some studies regarding to the extraction procedures in aqueous, acidic, alkali media or via physical disruption by low temperature milling, giving different yield and purity on extracted substances (Sharma et al., 2014; Lim and Aida, 2017).

Wever et al., studied the isolation procedure of bromoperoxidase enzyme from the seaweed *Ascophyllum nodosum* via polyacrylamide gel electrophoresis in sodium dodecyl sulfate media. Enzyme activity by monochloridimedone bromination was studied, in which the reaction rate was reported to be on its optimum level in pH 4.5-6.5 range. Extracted enzyme was also reported to be thermostable and showed high resistance against organic solvents such as methanol, ethanol and n-propanol (Wever et al., 1985).

Fleurence et al. conducted protein extraction from *Ulva rigida* and *Ulva rodundata* via classical and enzymatic procedures. One of the procedures the authors utilized was utilizing NaOH under reductive conditions and the other was PEG- K_2CO_3 two-phase system. After extraction was conducted, protein fractions were characterized by SDS PAGE. In both cases, extracted protein fractions were rich in aspartic and glutamic acids, alanine, glycine and hydroxyproline residues. In the case of enzymatic procedure, utilization of cellulase showed no significant effect on the extraction yield of algal proteins, this might be due to the inadequate accessibility between the substrate and cell wall. Moreover, polysaccharidase mixture of β-glucanase, hemicellulose and cellulase utilization enhanced the protein yield (Fleurence et al., 1995).

Ponce et al. reported an extraction procedure for brown seaweed *Adenocystis utricularis* in different extraction media, i.e. distilled water, calcium chloride solution (2 wt%) and hydrochloric acid solution (pH:2) at room temperature and at 70 °C. They reported that there were minor differences between extraction yield and extraction product characteristics, which show that there are two different types of fucoidan, galactofucan and uronofucoidan, in the structure. Authors also reported that the fractionation with cationic detergent resulted a better galactofucan and uronofucoidan components. Galactofucan component, which is composed of L-fucose, D-galactose and ester sulfate, is better extracted at room temperature, whereas uronofucoidan extraction is better conducted at 70 °C (Ponce et al., 2003).

Rioux et al., studied polysaccharide extraction from *Ascophyllum nodosum*, *Fucus vesiculosus* and *Saccharina longicruris*. Seaweeds were treated with selective solvents to extract laminaran, fucoidan and alginate and their content analysis was determined in sulphate, total sugar and uronic acid. Laminaran content of *S. longicruris* was determined to be highest as 99.1%, followed by *F. vesiculosus* and *A. nodosum* as 89.6% and 84.1%, respectively. *F. vesiculosus* and *S. longicruris* had significant variations in their total sugar, uronic acid and polysaccharides' molecular weight. Among these three species, *A. nodosum* had more stable chemical composition in terms of polysaccharide content (Rioux et al., 2007).

Ale and Meyer studied fucoidan extraction from different brown seaweed species and reported that the structural details are dependent on the seaweed type, and fucoidanases might be helpful in determining the detailed fucoidan structure from various seaweed species. Extraction route also had an effect on the composition and structural features on fucoidan components. Among the extraction methods, acid treatment had the most degrading effect on fucoidan structure. Thus, milder conditions are required to preserve the natural fucoidan structure. Thus, extraction method plays an important role on the biological activity of the extracted fucoidan substances (Ale and Meyer, 2013).

Uslu et al. evaluated the proximate analysis and fatty acid profile of brown macroalgae (*Stypopadium schimperi, Halopteris scoparia, Cystoseira compressa, Padina pavonica, Sargassum vulgare*). *Halopteris scoparia* and *Cystoseira compressa* species had the highest and lowest ash content by 28% and 21%, respectively. *Cystoseira compressa* species had the lowest lipid content by 2%, whereas *Stypopadium schimperi* species had the highest lipid amount by 6.36%. Protein content of *Halopteris scoparia* and *Cystoseira compressa* were approximately around 9.5%, wheras *Padina pavonica* species had the lowest protein content around 4%. Results indicate the utilization of brown macroalgae species is promising especially in the nutraceutical and food industries (Uslu et al., 2021).

Lopez-Hortas et al. studied dehydration of *Rugulopteyx okamurae* by employing solid-liquid extraction in ethanol media and microwave hydrodiffusion and gravity (MHG) methods to make comparison between them. Conventional solid-liquid extraction in ethanol media showed poor recovery of liquid fractions and lower yield and antioxidant potential when compared with novel MHG method. Solid phases showed lower mineral content after MHG treatment. Alginates obtained in the MHG liquid phase possessed similar structural characteristics to those of commercially available products (Lopez-Hortas et al., 2023).

Chen et al. studied the comparison of phytosterol extraction methods from brown seaweeds and optimized via one factor at a time (OFAT) and response surface methodology (RSM) and reported that the optimized parameters were ultrasound assisted extraction with chloroform-methanol mixture (2:3 w/w) for 15 minutes followed by saponification step with 1.65 ml of 1.85 M KOH solution during 14.5 h. Since phytosterol extraction studies are limited in the literature, this phytosterol extraction study might help the investigation of the nutritional content and functional nutrient extraction from seaweeds (Chen et al., 2023).

Among the nutrition-extraction studies discussed above, Moreda-Pineiro et al. employed extraction study for major and trace element from red, green, and brown edible seaweed species. Acetic acid- pressurized liquid extraction method was utilized in simultaneous extraction of major elements such as Ca, K, Mg and Na, and trace elements such as Cd, As, Co, Cr, Mn, Pb and Zn, followed by ICP-OES (Inductively coupled plasma atomic emission spectroscopy) analysis. The effect of extraction route employed such as temperature, time, pressure, number of cycles, and particle size on metal leaching efficiency was determined. Extraction procedures were evaluated in terms of limits of detection, quantification, and repeatability. The novelty of this study is the extraction of heavy metals in seaweeds, which might be useful when a prior content evaluation is required prior being utilized in agriculture (Moreda-Pineiro et al., 2007).

Chronologically listed seaweed extraction studies report that former studies were conducted mostly based on OFAT strategy, whereas up-to-date studies introduce statistical and mathematical techniques to run a set of factors and levels in one experiment, which helps to eliminate the time-consuming disadvantage of OFAT experiments. Additionally, major and trace element extraction studies have been also conducted apart from nutrition extraction studies, which might leave an opinion about the trace element content of seaweeds and whether these trace elements might possess a risk upon agricultural application.

Theoretical studies on the application of seaweeds in agriculture

Various studies have been reported on the application of seaweed extracts in agricultural activities and the effects of seaweed extracts on the growth mechanism, yield and tolerance against biotic and abiotic stress conditions. Studies conducted on this field have been intensified especially in the last 10-15 years. Therefore, studies discussed below examine the experimental details of the application of seaweeds in agriculture to increase yield and tolerance against stress conditions or in soil amendment carried out in the last 5 years.

de Soza et al. tested the effect of composted materials prepared from seaweeds and pruning residue in soil amendment study. Application of the prepared samples in different mass ratio amounts resulted an increase in soil organic matter and enhanced the nutrient composition of the soil by increasing phosphorus (P) and potassium (K) content. Nitrogen (N) increase of soil structure was reported to be around 20%. Leaf characterizations reported elevated NPK concentrations during the 1st year of seaweed application. Results of the study underlines that the long-term effect of seaweed application should be investigated, however the seaweed application could provide a cost-effective approach for soil amendment in terms of increasing soil organic matter and NPK concentrations (de Soza et al., 2023).

Ashour et al. investigated the effect of True-Algae-Max (TAM) on the yield and nutritional contents of strawberry plant by the applications of 0, 50 and 100 wt% TAM together with inorganic NPK fertilizer via foliar spraying application. Yield, growth, chlorophyll, and nutrient content in the strawberry plants were significantly enhanced upon TAM application. Physical characteristics of the plants such as root length, leaf area, individual fresh weight and fruit weight increase of the strawberry plants were ranging from 10-110% in comparison with the control. Results show promising physical characteristics enhancement upon TAM treatment. Apart from agricultural applications, this study also investigated utilization of seaweed biomass after extraction and TAM residues after application in bioethanol production. Results indicate a novel application area of seaweeds, i.e. in biofuel production (Ashour et al., 2023).

Ma et al. reviewed the potential of macroalgae species in agriculture in terms of nutrient uptake in plants and soil amendment application. They report that seaweed utilization in agriculture would be cost-effective auxiliary for conventional mineral fertilizer application, by providing an increase in soil organic content and boost crop growth. They also reported soil-plant system mechanisms for more efficient nutrient uptake, discuss the current situation and make a projection for afterwards (Ma et al., 2022).

Atzori et al. evaluated the potential of macroalgae (*Chaetomorpha* sp., and *Cystoseria* sp.), microalga (Chlorella) and bioguano (macroalgae, spiriluna and guano mixture) utilization as organic fertilizer on barley as the model plant. Among these species, bioguano mixture had a significant effect on the growth by total biomass yield, and high nutrient uptake efficiency. Nitrogen (N) and potassium (K) uptake efficiency was reported to be 60% and 41%, respectively. Bioguano show a great potential as organic fertilizer by providing growth promoters required for growth (Atzori et al., 2020).

Sunarpi et al. studied the effect of both solid and liquid brown macroalgae extracts (*Sargasum crassifolium, Sargasum cristaefolium, Sargasum aquifolium and Turbinaria murayana*) on rice plants in terms of growth and yield. Mixtures of the extracts composed of all macroalgae species were applied in solid and liquid form for 8 weeks and the evaluations were conducted based on the vegetative growth and yield measurement. Results indicate that application of seaweed extracts in solid or liquid form had different effects, solid form application triggered vegetative growth, whereas liquid form application promoted yield based on shoot and root ratio (Sunarpi et al., 2019).

Hashem et al. evaluated the utilization of seaweeds of different algal taxa as biofertilizers and investigated their growth and yield effects on canola, followed by the behavior of canola under salt stress. *Ulva lactuca* (green), *Cystoseira* (brown) and *Gelidium crinale* (red) species were investigated, and results indicate the application of these species had improved salt stress tolerance of canola plant. This promoting effect might be due to the rich chemical composition of growth promoters such as hormones, cytokinins, total carbohydrates, and phenolic compounds (Hashem et al., 2019).

Uthirapandi et al. evaluated the effect of *Sargassum wightii, Turbinaria ornata* and *Caulerpa racemosa* application on the growth and biochemical characteristics of *Ocimum sanctum*. Extracts of macroalgae were applied in liquid form via foliar spraying. After a 60-days growth period, growth parameters (shoot and root length, total plant height, leaf number and leaf surface area, fresh and dry weight) together with biochemical composition (starch, glucose, protein, chlorophyll content) were evaluated. Results indicate the individual application of the seaweed extracts has an enhancing effect on the growth parameters and biochemical composition of *Ocimum sanctum*, however in case of seaweed extract mixture application, the results were reported to be enhanced. This might be due to the synergistic and cumulative effect of the nutrient and growth promoters in the seaweed extract mixture (Uthirapandi et al., 2018).

Duarte et al. reported the activity of *Ulva fasciata* and *Palisada perforata* in the form of fragments and of silage in liquid on *Pisum sativum* plant for the first time. apart from these species, seven different species were also included in the study together with two control groups, hormones and water, respectively. Ensiling treatment of *Ulva fasciata* and *Ulva lactuca*, and fragment treatment of *Gracilaria caudata* and *Palisada perforate* showed enhancement on growth when compared to control groups. Results show that the release of algae components play an important role on the growth, but they do not affect the hormone mimetics (Duarte et al., 2018).

Jung et al. prepared biochar derived from *Undaria pinnatifida* roots via pyrolysis at 200 to 800 °C temperature range. They evaluated the temperature effect on biochar properties and phosphate adsorption capacity and reported that the increase in temperature reduced biochar yield. Phosphate adsorption capacity was enhanced when the temperature was increased up to 400 °C, further increase in temperature had an adverse effect on phosphate adsorption yield. They also conducted a pot experiment to evaluate biochar derived from *Undaria pinnatifida* roots, and results indicated that the prepared biochar had a potential for utilizing as fertilizer, however prior phosphate adsorption was required (Jung et al., 2016).

There are many studies in the literature on the agricultural use of seaweeds. The theoretical studies given as examples above have been selected by filtering for the last 5 years upon particular purposes such as investigating the effects of seaweeds on physical functions such as growth, development and yield on different plant species, evaluating seaweeds as soil conditioners or using waste seaweed residues in biochar production and utilizing them in agricultural activities.

Green Deal and Sustainable Development point of view

The effects of climate change and global warming is continuously putting pressure on environmental and societal issues and have become one of the most critical problems of 21st century. Changes in the environment on global scale upon limited resource consumption and fossil fuel utilization for energy demand have been incrementally affecting the ecosystem and humanity. Economic development, urbanization and industrialization result the generation of wastes (Borowski and Barwicki, 2022. Former linear economy model approach has been undergone a transition to circular economy approach, in which waste utilization is required. Thus, circular economy strategy favors sustainable approaches especially in decarbonization precautions, which are both related to the Green Deal and Sustainable Development goals.

European Union (EU) Green Deal framework urgently promote a commitment to sustainable agriculture and food production and determine EU Common Agricultural Policy (CAP) objectives to support “Farm to Fork” strategy (Biro and Csete, 2022). Transition to sustainable approaches within the framework of decarbonization concepts would provide a climate-resilient society. Climate-innovative efforts and measurement implementations would help improvements in the agricultural economy.

Carbon dioxide is the main contributor of climate change together with other greenhouse gases (GHGs), thus decarbonization approaches are significantly important to mitigate the negative effects of climate change. Limiting these GHG emissions from agriculture could assist the adaptation against the challenges of climate change. Mineral fertilizers are indispensable for achieving agricultural yield, and organic/inorganic inputs to boost the growth and development of plants are as important as mineral fertilizers. Combining the nutritional effects of mineral fertilizers with a sustainable raw material source would relieve the pressure on mineral fertilizers and utilizing organic inputs as co-fertilizing products would be a promising approach to sustainable agriculture. In this manner, seaweeds or seaweed wastes are one of the organic inputs in agriculture. Utilizing these organic materials would promote soil physiology and act as a growth promoter to plants together with the nutritional facts of mineral fertilizers. Utilizing seaweeds in agriculture as organic input enable a sustainable and continuous raw material supply chain. Introducing seaweeds in agriculture as solid/liquid extract or as in biochar form in co-operation with mineral fertilizers would be a promising approach in terms of achieving Sustainable Development goals.

Conclusion

Projections indicate that the increase in the population growth related food demand will show an increasing trend in the next years. The negative effects of global warming and climate change on the environment have begun to manifest themselves with anomalies such as drought and sudden temperature changes, both stress conditions are not desired in agriculture. The climate change-related changes will have an adverse effect on the natural resource systems. Agriculture as an industrial field is one of the largest consumers of resources. Therefore, it is important to improve the agricultural yield without compromising the environment, and this issue will challenge and require adaptation in the next decades. Sustainable agriculture is an important tool to mitigate the climate change effects and introducing organic inputs to agriculture are gaining attention since they offer high bioavailability and cost-effective applications, and it is of importance to strategically integrate food and energy to increase mass productivity while reducing production costs and negative environmental effects. Seaweed- based agricultural inputs will be cost-effective and environmental-friendly substances, since these organic inputs provide a wide range of potential feedstocks necessary for plant growth such as pigments, proteins, polymers, lipids, sugars etc. Although there is vast amount of studies conducted in this field, further long-term evaluation of the effect of seaweed-based organic inputs on the growth mechanism and yield in agriculture is required.

Acknowledgement

The author appreciates her beloved father, Prof. Dr. Dursun Avşar, for providing the ever lasting inspiration throughout her education life.

Ethical Approval

The author doesnt declare ethical approval.

Conflicts of Interest

The author declares that no conflict of interest.

Funding Statement

The author doesnt declare any fund.

References

Ale, M. T., Meyer, A.S. (2013). Fucoidans from brown seaweeds: an update on structures, extraction techniques and use of enzymes as tools for structural elucidation, *RSC Advances*, *3*, 8131.

Ali, O., Ramsubhag, A., Jayamaran, J. (2021). Biostimulant properties of seaweed extracts in plants: implications towards sustainable crop production, *Plants*, *10*(3), 531.

Ali, O., Ramsubhag, A., & Jayamaran, J. (2019). Biostimulatory activities of Ascophyllum Nodosum extract on tomato and sweet pepper crops in an tropical environment, *PLOS ONE*, *14*(5), e0216710.

Alprol, A. E., Ashour, M., Mansour, A. T., Alzahrani, O. M., Mahmoud, S. F., & Gharib, S. M. (2021). Assestment of water quality and phytoplankton structure of eight Alexandria beaches, Southeastern Mediterranean Sea, Egypt, *Journal of Marine Science and Engineering*, *9*(12), 1328.

Ashour, M., Al-souti, A. S., Hassan, S. M., Ammar, G. A. G., Goda, A.M. A. S., El-Shenody, R., Abomohra, A. E. F., El-Haroun, E., & Elshobary, M. E. (2023). Commercial seaweed liquid extract as strawberry biostimulants abd bioethanol production, *Life*, *13*, 85.

Atzori, G., Nissim, W. G., Rodolfi, L., Niccolai, A., Biondi, N., Mancuso, S., & Tredici, M. R. (2020). Algae and bioguano as promising source of organic fertilizers, *Journal of Applied Phycology*, *32*, 3971-3981.

Avşar, C. 2022. A novel assesment strategy for nanotechnology in agriculture: evaluation of nano-hydroxyapatite as an alternative phosphorus fertilizer, Kemija u Industriji, *71*(5-6), 327-334.

Barakat, K. M., El-Sayed, H. S., Khairy, H. M., El-Sheikh, M. A., Al-Rashed, S. A., Arif, I. A., & Elshobary, M. E. (2021). Effects of ocean acidificatin on the growth and biochemical composition of a green alga (Ulva fasciata) and its associated microbiota. *Saudi Journal of Biological Sciences*, *28*(9), 5106-5114.

Biro, K., & Csete, M. S. (2023). How can development strategies foster agri-digitalisation in the era of climate change? A common ahriculture policy based consistency analysis in Hungary. *Periodica Polytechnica Social and Management Sciences*, *31*(1), 9-18.

Borowski, P. F., Barwicki, J. 2022. Efficiency of utilization of wastes for green energy production and reduction of pollution in rural areas. *Energies*, *16*(1), 13.

Chen, Z., Shen, N., Wu, X., Jia, J., Wu, Y., Chiba, H., & Hui, S. (2023). Extraction and quantitation of phytosterols from edible brown seaweeds: optimization, validation, and application. *Foods*, *12*(2), 244.

Cotas, J., Gomes, L., Pacheco, D., Pereira, L. (2023). Ecosystem services provided by seaweeds, Hydrobiology, 2(1):75-96.

de Soza, L. L., Navarro-Fernandez, C. M., Panettieri, M., Madejon, P., Perez-de-Mora, A., & Madejon, E. (2023). Application of seaweed and pruning residue as organic fertilizer to increase soil fertility and vine productivity. *Soil Use and Management*, 12882.

Duarte, I. J., Alvares-Hernandez, S. H., Ibanez, A. L., & Canto, A. R. (2018). Macroalgae as soil conditioners or growth promoters of Pisum sativum (L). *Annual Research & Review in Biology*, *26*(6), 1-8.

Durmaz, Y., Monteiro, M., Bandarra, N., Gökpinar, Ş., & Işik, O. (2007). The effect of low temperature on fatty acid composition and tocopherols of the red microalga, *Porphyridium cruentum*. *Journal of Applied Phycology*, *19*, 223-227.

Fan, D., Hodges, M., Critchley, A. T., & Prithiviraj, B. (2013). A commercial extract of brown macroalga (Ascophyllum nodosum) affects yield and the nutritional quality of spinach in vitro. *Communications in Soil Science and Plant Analysis*, *44*(12), 1873-1884.

Filbee-Dexter, K., & Wernberg, T. (2018). Rise of turfs: a new battlefront for globally declining kelp forests. *Bioscience*, *68*(2), 64-76.

Fleurence, J., Le Coeur, C., Mabeau, S., Maurice, M., & Landrein, A. (1995). Comparison of different extractive procedures for proteins from the edible seaweeds *Ulva rigida* and *Ulva rotundata*. *Journal of Applied Phycology*, *7*, 577-582.

Gonzales, A., Castro, J., Vera, J., & Moenne, A. (2013). Seaweed oligosaccharides stimulate plant growth by enhancing carbon and nitrogen assimilation, basal metobolism, and cell division. *Journal of Plant Growth Regulation*, *32*, 443-448.

Gonzales, A. Z., Rodrigues, B. R. L., Alvarez, A. I. M., Rodriguez, H. R., Palomo, J. O. C., & Lopez, J. P. M. (2015). Seaweed extracts and its relation to photosynthesis and yield of a grapevine plantation. *Revista Mexicana de Ciencias Agricolas*, 2437-2446.

Hashem, H. A., Mansour, H. A., El-Khawas, S. A., & Hassanein, R. A. (2019). The potentiality of marine macro-algae as bio-fertilizers to improve the productivity and salt stress tolerance of canola (*Brassica napus* L.) plants. *Agronomy*, *9*(3), 146.

Kasim, W. A., Hamada, E. A. M., El-Din, N. G. S., & Eskander, S. (2015). Influence of seaweed extracts on the growth, some metobolic activities and yield of wheat grown under drought stress. *International journal of Agronomy and Agricultural Research*, *7*(2), 173-189.

Jung, K. W., Kim, K., Jeong, T., & Ahn, K. (2016). Influence of pyrolysis temperature on characteristics and phosphate adsorption capability of biochar derived from waste-marine macroalgae (*Undaria pinnatifida* roots). *Bioresource Technology*, *200*, 1024-1028.

Lim, S. J., & Wan Aida, W. M. (2017). Extraction of sulfated polysaccharides (fucoidan) from brown seaweed, In: Seaweed Polysaccharides, Venkatesan, J., anil, S., Kim, S.K. (eds) Elsevier, pp 27-46.

Lopez-Hortas, L., Florez-Fernandez, N., MAzon, J., Dominguez, H., & Dolores torres, M. (2023). Relevance of drying treatment on the extraction of high valuable compounds from invasive brown seaweed *Rugulopteryx okamurae*. *Algal Research*, *69*, 102917.

Ma, C., Song, W., Yang, J., Ren, C., Du, H., Tang, T., Qin, S., Liu, Z., & Cui, H. (2022). The role and mechanism of commercial macroalgae for soil conditioner and nutrient uptake catalyzer. *Plant Growth Regulation*, *97*,455-476.

Mansour A. T., Alprol, A. E., Abualnaja, K. M., El-Beltagi, H. S., Ramadan, K. M. A., & Ashour, M. (2022). Dried brown seaweed's phytoremediation potential for methylene blue dye removal from aquatic environments. *Polymers*, *14*(7), 1375.

Mukherjee, A., & Patel, J. S. (2020). Seaweed extract: biostimulator of plant defence and plant productivity. *International Journal of Environmental Science and Technology*, *17*, 553-558.

Moreda-Pineiro, J., Alonso-Rodrigues, E., Lopez-Mahia, P., Muniategui-Lorenzo, S., Prada-Rodrigues, D., Moreda-Pineiro, A., & Bermejo-Barrera, P. (2007). Development of a new sample pre-treatment procedure based on pressurized liquid extraction for the determination of metals in edible seaweed. *Analytica Chimica Acta*, *598*(1), 95-102.

Pacheco, D., Araujo, G. S., Cotas, J., Gaspar, R., Neto, J. M., & Pereira, L. (2020). Invasive seaweeds in the Iberian Peninsula: A Contribution for food supply. *Marine Drugs*, *18*(11), 560.

Ponce, N. M. A., Pujol, C. A., Damonte, E. B., Flores, M., & Stortz, C. A. (2003). Fucoidans from the brown seaweed *Adenocyctis utricularis*: extraction methods, antiviral activity and structural studies. *Carbohydrate Research*, *338*(2): 153-165.

Raghunandan, B. L., Vyas, R. V., Patel, H. K., & Jhala, Y. K. (2019). Perspectives of seaweed as organic fertilizer in agriculture, in: Soil Fertility Management for Sustainable Development, Panpatte, D., Jhala, Y. (eds), Springer, Singapore, pp 267-289.

Rioux, L. E., Turgeon, S., L., & Beaulieu, M. (2007). Characterization of polysaccharides extracted from brown seaweeds. *Carbohydrate Polymers*, *69*(3), 530-537.

Senousy, H. H., Khairy, H. M., El-Sayed, H., Sallam, E. R., El-Sheikh, M. A., & Elshobary, M. E. (2023). Interactive adverse effects of low-density polyethylene microplastics on marine microalga *Chaetoceros calcitrans*. *Chemosphere*, *311*(2), 137182.

Shah, M. T., Zodape, S. T., Chaudhary, D. R., Eswaran, K., & Chikara, J. 2013. Seaweed sap as an alternative liquid fertilizer for yield and quality improvement of wheat. *Journal of Plant Nutrition*, *36*(2), 192-200.

Shekhar Sharma, H. S., Fleming, C., Selby, C., Rao, J. R., & Martin, T. 2014. Plant biostimulants: a review on the processing of macroalgae and use of extracts for crop management to reduce abiotic and biotic stresses. *Journal of Applied Phycology*, *26*, 465-490.

Sunarpi, H., Ansyarif, F., Putri, F. E., Azmiati, S., Nufus, N. H., Suparman, W., & Prasedya, E. S. (2019). Effect of Indonesian macroalgae based solid and liquid fertilizers on the growth and yield of rice (*Oryza sativa*). *Asian Journal of Plant Sciences*, *18*(1), 15-20.

Uslu, L., Sayin, S., Naz, M., Taskin, E., Soyler, O., Saygili, I., Cetin, Z., Dinler, Z. M., & Isik, O. (2021). Proximate analysis and fatty acid profile of some brown macroalgae collected from the Northeastern Mediterranean coast. *Fresenius Environmental Bulletin*, *30*, 9426-9430.

Uthirapandi, V., Suriya, S., Boomibalagan, P., Eswaran, S., Ramya, S. S., Vijayanand, N., & Kathiresan, D. (2018). Biofertilizing potential of seaweed liquid extracts of marine macro algae on growth and biochemical parameters of *Ocimum sanctum*. *Journal of Pharmacognosy and Phytochemistry*, *7*(3), 3528-3532.

Wever, R., Plat, H., & de Boer, E. (1985). Isolation procedure and some properties of the bromoperoxidase from the seaweed Ascophyllum nodosum. *Biochimica et Biophysica Acta (BBA)*, *830*(2): 181-186.