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The Economic Importance of Macroalgae

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ABSTRACT

In this study, we discussed algae with economic importance. Information was given about the use of macroalgae in the food industry, medicine and pharmacy, additives, organic agriculture, wastewater treatment, and bioplastic production, which are the areas of use in the economy. The taxa and species used in these areas were investigated. Macroalgae in the seas of our country were examined, and information was given about how they can contribute to the economy.

1. INTRODUCTION

Algae are primary producers in the aquatic environment and form an essential part of the food chain (Aktar and Cebe, 2010). Industrial uses of algae differ in terms of micro and macroalgae. Marine macroalgae are mostly preferred as raw materials in the industry due to the risk of contamination in the production of microalgae (as in bacterial sources) and the difficulties experienced in their harvest (Oğur, 2016).

Algae are used in almost every field of industry. Algae, which are used as food in the Far East and South Asian countries, also have wide use in medicine, pharmacy and cosmetics industries, in agriculture, and in fertilizer production. In addition to collecting algae from nature, they are also cultured (Oğur, 2016). Macroalgae are used as food in Japan, China, Korea, the Philippines, and similar places, and as raw materials in many areas of industry in Europe and America. For this reason, macroalgae stand before us as organisms worth examining and focusing on in all aspects (Yazıcı and Kaynak, 2012).

1.1. Ecology of Algae

Algae, which perform the first production by photosynthesis, have a very important role in the marine ecosystem as they form the first link of the food chain (Aktar and Cebe, 2010). Algae show a geographical distribution depending on the physical and chemical changes of the environment. Human activities, domestic, industrial, and agricultural wastes have had a direct impact on eutrophication in recent years. In addition, nitrogen mixing with the water from the atmosphere, nutrients carried by rainwater, and substances carried to the environment through drainage are natural developments that accelerate the pollution process. One of the most obvious consequences of eutrophication is the occurrence of excessive algal blooms. The increase in phytoplankton populations causes the color, smell, and ecological balance of the water to deteriorate. In addition, the excessive growth of algae causes toxic effects for many living things in the aquatic environment and causes death (Aktar and Cebe, 2010; McHugh, 2003).

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1.2. Ecological Factors Affecting the Distribution of Algae

The factors affecting the distribution of algae are grouped under three groups (Aktar and Cebe, 2010):

1.2.1. Physical Factors

Substrate: The physical structure of the substrate is important for the adhesion and development of algae. Algae living in the substrate are called “endolytic algae” and algae living on the substrate are called “epiphytic algae”.

Temperature: In seas, the seasonal temperature difference decreases as the depth increases. For this reason, some algae are not resistant to temperature changes in the depths. On the other hand, since the temperature changes are very high in the water bodies in the mediolittoral zone, only algae resistant to temperature changes such as Ulva sp. and Enteromorpha sp. are encountered. In the Mediterranean, cold sea species such as Bangia sp., Nemalion sp., Ulothrix sp. are found in winter, and warm sea species such as Acetabularia sp., Anadyomene sp., Halimeda sp., and Digenea sp. are seen in summer.

Light: The wavelength and amount of light is a limiting factor in the deep distribution of algae. Non-living particles and planktonic organisms in seawater cause a decrease in the light transmittance of seawater. Blue and violet light are the rays that can reach the deepest the most. According to their tolerance to light, marine algae are divided into two groups: "light-loving algae" and "dark-loving algae".

Turbidity: Suspended solid matter causes the water to lose its clarity. This is called “turbidity of waters”. Turbidity limits the intensity and spread of light. As a result, photophilous organisms move away from the environment as primary production efficiency decreases.

1.2.2. Chemical Factors

Salinity: Salinity is one of the most important factors in the distribution of marine organisms. NaCl, which is dominant in seawater, regulates the osmotic pressure in living things. Oligo-elements such as N, P, S, K, Ca, Mg, Si is also important in the physiological activities of living things. Elements such as I and Br, which accumulate in large amounts in various algae species such as Laminaria sp., increase the economic value of these plants (Aktar and Cebe, 2010; Cirik and Cirik, 2011).

pH: Seawater is generally basic and its pH varies between 8.1 and 8.3. Eurichalin, euritherm, and eurionic green algae species, Ulva sp. and Enteremorpha sp., are seen to grow abundantly in environments in the supralittoral and mediolittoral zones with little contact with the sea (Casal et al., 2009).

As a result of the photosynthesis activity of these algae and the excessive use of CO_2, the bicarbonate in the environment decomposes and turns into neutral carbonate. This event causes the alkalinity in the environment to increase and the pH to reach 10. Therefore, stenoionic algae such as red algae cannot grow in such environments (Cirik and Cirik, 2011).

Dissolved Gases in Sea Water: O_2 has a limiting effect on the distribution of algae as well as in all sea creatures. The main factors that increase the amount of O_2 are photosynthesis, the contact of oxygen-poor surface waters with the atmosphere, the effect of currents and winds. Among the factors that reduce the amount of O_2, it can be said that the respiration of plants and animals, various chemical and biological events including oxidation, O_2 loss from surface waters that are in contact with the atmosphere and richer in oxygen. Algae are absent in oxygen-free zones (Aktar and Cebe, 2010; Cirik and Cirik, 2011).

Nutrient salts, oligo-elements, and vitamins: Lack of nutritive salts such as nitrate and phosphate limits the growth of phytoplankton, and excess causes the proliferation of nitrophilous algae such as Ulva sp. and Enteromorpha sp.. Some oligo-elements support the growth of algae. As a result of bacterial activities in seawater, various vitamins, especially B_{12}, occur. While some algae do not require vitamins for their growth, others require vitamins such as B_{12}, biotin, and thiamine. Some algae such as Corallina sp., Halimeda sp., Lagora sp., and Diatomae sp. store $CaCO_3$ and silica Cirik and Cirik, 2011; Casal Garcia et al.,2009; Farasat et al., 2014; Hassan and Ghareib, 2009).

1.2.3. Dynamic Factors

Sea Turbulence (Agitation): Although the algae in environments with high water movements such as Cytoseira fimbriata are unbranched, it has been observed that the algae in calm waters are more branched. The turbulence of the water is important for the ecological factors to become homogeneous. In the observations made on algae, it was observed that the intensity of photosynthesis and respiration change depending on the water movements (Aktar and Cebe, 2010; Cirik and Cirik, 2011).

Sea Level Change and Staying Out of Water (Emersion): Periodic changes in sea level are seen depending on the gravitational force of the moon, the effect of winds, air pressure, and the location of the coast. Although being out of the water is a requirement for some algae such as Fucus sp., Pelvetia sp., Ascophyllum sp., most of them cannot stay out of the water for a long time (Aktar and Cebe, 2010; Cirik and Cirik, 2011; Hassan and Ghareib, 2009).Water Movements (Currents, Waves): In the observations made on benthic algae, it was determined that thallus size is related to water movement. Water movements can affect the growth and development of algae in two ways. The first of these is the transport of reproductive cells to various places with water movements and the facilitation of their fertilization, and the other is the negative or positive effects of young individuals at the time of settling. It is accepted that the biogeographical distributions of planktonic algae are related to currents (Aktar and Cebe, 2010; Cirik and Cirik, 2011).

Pressure: In a study on the effect of hydrostatic pressure on algae distribution; Although the superficial forms of Codium bursa are a few cm in diameter, it has been observed that the forms living at 40-50 m depths are approximately 1 m in diameter (Aktar and Cebe, 2010; Cirik and Cirik, 2011).

1.3. Usage Areas of Algae

One of the most important living resources of the seas is algae. Algae are used in the fields of food, agriculture, medicine, pharmacy, cosmetics, and industry. In addition, algae are of great importance to other sea creatures.

1.3.1. Use of Algae in Medicine and Pharmacy

It is known that algae are used in injuries, heavy metal poisoning, balancing the immune system, reducing "high fever, regulating blood circulation, skin regeneration, removing vascular occlusions, and lowering cholesterol (Aktar and Cebe, 2010; Meenakshi ,et al.,2012). In some societies, Ulva species are used as a low-calorie diet for weight loss because of their rich fiber, mineral, protein, low fat and digestible carbohydrate content. There is information that algae are widely used in the treatment of goiter, in the treatment of various kidney diseases, and as an anthelmintic, especially in countries with a coastline. For example, in South America, Ulva lactuca is used to increase resistance to goiter because it is rich in vitamin A (Aktar and Cebe, 2010; Gümüş, 2006). Antimicrobial agents could be obtained from Fucus serratus species. In addition, it is rich in iodine and is used against goiter disease and obesity (Aktar and Cebe, 2010; Taşkın, et al., 2010).

S. vulgare, one of the Sargassum species found in our country, contains an antilipidemic substance in its structure. Other Sargassum species are also algae with anticoagulant and analgesic properties. Cyctoseria barbata is also one of the species that have an antilipidemic substance in its structure and spreads in our seas. Macrocystis pyrifera is used in anemia because it is rich in vitamin B12. Acanthopeltis japonica, one of the red algae, is used as a food and is also known to reduce the cholesterol ratio. Some red algae, such as Porphyra atropurpurea, are used as "poultice" (Aktar and Cebe, 2010; Devi,et al. 2008). Chondrus crispus species has been used as medicine and food in Europe for a long time (Taşkın, et al., 2010; El Baky,et al., 2008; Taşkın, et al., 2007).

The important uses of algae in pharmacy are mainly due to their phycocolloids (Brownlee, et al., 2005). It is known that phycocolloids affect drug absorption in the body due to their colloid-forming properties. Phyllophora nervosa found in the Black Sea is used as a source of phycocolloids in medicine and pharmacy (Aktar and Cebe, 2010).

Alginates obtained from algae are used as raw materials or auxiliary materials in the pharmaceutical industry. Alginates are used in injectable and oral drug forms of some active substances (such as insulin, antibiotics, hormones, vitamins); in aqueous solutions of oils and waxes; providing homogenization and stability of oily creams; It is used in making lotions, ointments, soaps, shampoos, tampons, toothpaste and coating drug forms that dissolve in the intestine. Alginates form the main material of plasters, dressings, and bandages (Aktar and Cebe, 2010; Gümüş, 2006).

Compounds responsible for antibiotic activity are common in macroalgae. The most important of them are; halogenated compounds were alcohols, aldehydes, terpenoids, hydroquinones, and ketones. These macroalgae used in antibiotic activity: Cystophora sp, Bryopsis sp., Ascophyllum nodosum, Jania rubens, Dictyopteris membranacea, Cystoseira barbata, Ulva rigida, Corallina officinalis.

Macroalgae used in anticancer and antitumor activities are Scytosiphon lomentaria, Lessonia nigricans, Laminaria japonica, Bryopsis sp., Ulva sp., Chondria atropurpurea, Caulerpa taxifolia, Cystoseira mediterranea, Cystophora usneoides species.

In recent studies, it has been found that algae can be effective in the treatment of diabetes, especially in TYPE2 diabetes. TYPE2 diabetes is the most common form of diabetes, a metabolic disorder in insulin resistance that accounts for more than 90% of all cases. In pharmacological studies, it has been shown that substances obtained from macroalgae as natural products affect the disorders in antidiabetic metabolism (Yan, et al.,2019).

1.3.2. Use of Macro Algae in Cosmetics

Algae products prepared in the form of various dough, flour, or powder are also preferred in Thalassotherapy centers due to minerals such as calcium, magnesium, sodium, potassium, trace elements such as iron, copper, zinc, and manganese, and vitamins (Turan, 2007). Agar gels are also used in various products such as perfumed underarm creams, sunscreens, and dermatological creams containing zinc oxide or penicillin. It has also been stated in the studies that the alginates used in the creams give a feeling of freshness and relaxation to the skin due to the rapid evaporation effect on the skin. It also provides economic advantages in the preparation of low-fat creams. In soaps and shaving foams, sodium alginate is used as a lubricant, to add an oily feature to non-foaming shaving creams, and to maintain the foam in foamy ones. In hair lotions, alginate spreads over the entire hair, giving the hair a shiny feature and making it easy to shape. Sodium alginate is also used in the production of band-aids due to its adhesive properties (Ak, 2015).

It holds most of the water in toothpaste and is one of the basic ingredients of suntan oils. They are used as fixatives in hair balms and as absorption enhancers in products such as face masks, preserving the foam in shampoos, shaving foams, and soaps. Underarm deodorants with carrageenan inhibit the growth of bacteria that cause undesirable sweat odors (Fitton, et al., 2007).

Macroalgae genera that can be used for these purposes in the field of cosmetics, Porphyra sp., Gelidium sp., Hypnea sp., Halopteris sp., Dictyopteris sp, Stilophora sp, Sargassum sp., Cystoseira sp., Ulva sp., Enteromorpha sp., Codium sp., Gigartina sp., Gracilaria sp., and their species are found in the seas of our country (Cirik and Cirik, 2011).

1.3.3. Use of Algae in Organic Agriculture

The oldest known usage area of algae is fertilizer and it was used mostly in the Far East. Although it is known that algae have been used as fertilizer since ancient times, it has been understood that the application of algae extracts by spraying the leaves for 40-50 years also increases the yield and product quality. Algae extracts are used more in organic agriculture, especially in developed countries, in areas such as increasing the amount of product, reducing fruit storage losses, increasing the uptake of inorganic nutrients from the soil, increasing seed germination, and increasing resistance to stress conditions.

As a result of the use of algae extracts in world agriculture; To increase germination, to provide better root development, to increase the storage life of fruits and vegetables, to provide darker and larger flowers and leaves, to provide resistance against diseases and pests, to increase resistance to stress conditions such as frost, drought and adverse soil conditions, and to increase the nutrient elements in the soil such as effects have been determined (Yazıcı and Kaynak, 2012).

1.3.4. Use of Algae in Food

About 160 species of algae are consumed by humans as food. Algae, which are widely used in Far East countries, especially in China, Korea, and Japan, are on the list of alternative foods against the danger of hunger predicted in the future (Ünver et al. 2017). While 800 thousand tons of 28 million tons of seaweed produced in 43 countries around the world are collected from nature, 94% is obtained through aquaculture. Although there are academic studies on macroalgae in our country, commercial cultivation has not yet started (Ak, 2015). Among marine macroalgae, red and green algae contain higher levels of protein than most brown algae. However, the reduction of nutrient salts in coastal waters during summer reduces the macroalgal protein levels and changes the relative ratios of amino acids. There is a need for better replication of proteins and amino acid profiles and for all nutritional components in macroalgae studies, as well as better commercial identification of the analyzed samples (Wells, et al., 2017).

Algae are the source of industrial polysaccharides such as carrageenan (Chondrus sp., Eucheuma sp., and Kappaphycus species), agar-agar (Gelidium sp., Gracilaria species), and alginate (Laminaria sp., Ascophyllum sp., and Macrocystis species) with a market size of approximately 1 billion USD (Ak, 2015).

Carrageenan: Among the red algae, Chondrus crispus contains 71% and Kappaphycus species up to 88% carrageenan (Ak, 2015). Carrageenan is used as a food additive in canned foods, salad dressing, filling material in pastry products, ice cream, and canned cat-dog foods (Kraan, 2012). The Gigartina species from which this substance is obtained are found in our seas and it is thought that it can be commercially cultivated.

Agar-agar: It is obtained from the red algae Gracilaria sp. and Gelidium species. 90% of the produced agar is used in food applications and 10% is used in microbiological and biotechnological applications (Kraan, 2012). Agar, which is mostly used as a coating gel in canned meat and fish in foods, is widely used in the field of pastry, such as cake fillings and creams, due to its high-temperature resistance (Cirik and Cirik, 2011). In addition, it is used in bakery products to control water activity and delay staling, in processed cheeses and fruit juices due to its stabilizing properties (Ak, 2015; Kraan, 2012).

Alginate: Alginate is obtained from brown algae such as Laminaria digitata. Only 20% of the produced alginate is used as a food additive and 80% is used in many industries (Kraan, 2012). Alginates, which are used at a rate of 0.3 - 0.5% in fruit cake coatings due to their film-forming and water-holding properties, prevent the formation of ice crystals as well as providing a smooth structure and volume increase during ice cream production. In addition, due to their rapid gelation and structural diversity, these stabilizers are widely used in cream cheese, whipped cream, cheese, and sour cream (Yılsay,et al., 2001). Alginates are used as film-forming agents to prevent oxidative rancidity of meat and fish products and to minimize evaporative losses during storage (Ak, 2015). It is possible to obtain alginate from algae called Cystoseira sp. and Sargassum sp. in our seas (Cirik and Cirik, 2011).

1.3.5. Use of Algae in Wastewater Treatment

It is known that algae have an important role in the process of self-purification of natural waters as a result of the continuous supply of oxygen to the environment by photosynthesis. However, it has been reported by many researchers that algae remove pollutants that are dangerous for the aquatic environment such as nutrients, heavy metals, pesticides, organic and inorganic toxins, pathogenic organisms, especially nitrogen and phosphorus in water and wastewater, by using or accumulating pollutants in their cells and cells (Şen et al., 2003).

1.3.6. Use of Algae in Bioplastic Production

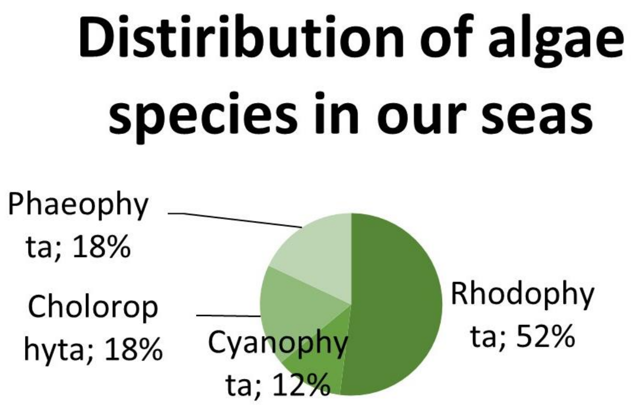
The main element used in the production of bioplastics is polysaccharides (Rajendran et al., 2012). Therefore, in production, polysaccharides must be determined and extracted. Polysaccharides are polymers of monosaccharides linked by glycosidic bonds with stabilizing, thickening (gelling), and emulsifying properties (Özdemir and Erkmen, 2013). Marine algae contain high amounts of structural polysaccharides (cellulose, hemicellulose, neutral polysaccharides) as well as mucopolysaccharides and storage polysaccharides (laminarin (β-1,3-glucan) (Rajendran,et al., 2012; Özdemir and Erkmen, 2013). Since the amount and types of polysaccharides are species-specific, different extraction methods have been developed (Özdemir and Erkmen, 2013).

1.4. Macroalgae Diversity in Turkey

It has been reported that 92 Cyanophyta, 413 Rhodophyta, 144 Phaeophyta, and 139 Chlorophyta species are distributed in the seas of our country (FAO, 2015). The taxa numbers of macrobenthic algae distributed in our Black Sea, Marmara, Mediterranean, and Aegean seas are given in Table 1.

Table 1. Algae distribution in our seas (Durucan and Turna, 2010)

Taxon	Marmara	Karadeniz	Ege	Akdeniz
Cyanophyta	43	12	71	45
Chlorophyta	90	55	92	82
Phaeophyta	103	53	99	85
Rhodophyta	264	139	253	228
Total	500	259	515	440



2. CONCLUSION

Algae, which have been used in many areas throughout human history, continue to be used in many countries today. According to 2014 FAO data, macroalgae constitute 28% of the total marine products obtained through aquaculture, and the economic size of production reaches 5 billion dollars (FAO, 2015).

Studies on algae have demonstrated the presence of antimicrobial, cytotoxic, antimitogenic, anticancer, and antitumoral activities. The presence of phenolic compounds such as phenol and flavonoid tannin in algae indicates antioxidant activity and free radical scavenging effect (Meenakshi, et al., 2012).

In studies on species that are distributed in our seas and have economic importance in terms of their composition; alginic acid, agar, carrageenan, vitamin B12, some organic acids, and cellulose were obtained from algae (Aktar and Cebe, 2010).

In today's world, where the nutritional problem is getting bigger, the efforts to benefit from algae are increasing, and besides benefiting from naturally reproducing algae, they are also benefiting from the cultures of these algae (Cirik and Cirik, 2011).

Author contributions

Büşra PEKSEZER: Conceptualization, Investigation, Writing- Original draft preparation, Writing Reviewing and Editing.
Mehmet Tahir ALP: Writing Reviewing and Editing.
Deniz Ayas: Investigation, Writing- Original draft preparation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence this paper.

Statement of Research and Publication Ethics

The authors declare that this study complies with Research and Publication Ethics.

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