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Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi 2023; 9(1): 42-53 Derleme Makale/Review Article

Use of Microalgae and its Importance in Türkiye and Worldwide

Canan BİRİNCİ-AĞLAMAZ [1], Eylem AYDEMİR-ÇİL[2]*

[1] Graduate Institute, Sinop University, Sinop/Türkiye
[2] Department of Environmental Engineering Faculty of Engineering and Architecture, Sinop University, Sinop/Türkiye

***E-mail:** eylemaydemir@sinop.edu.tr

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Abstract

The increasing global environmental pollution, rising energy consumption, and global warming, which are important problems worldwide, have led countries to seek different solutions in environmental issues. Türkiye and other countries are making efforts to continue living in a healthier environment economically and socially while meeting the increasing energy demand and rising environmental pollution. Renewable technologies are being developed and produced. Therefore, sustainable ecology and sustainable green economy have started to take the top spot on the global agenda. For this reason, the use of microalgae in environmental applications is increasing rapidly, and microalgae technology is being rapidly developed. Photobioreactors are currently at the forefront of microalgae production. Accordingly, microalgae are being used in many different areas of biotechnological and technical applications, such as health, food, cosmetics, pharmaceutical production, wastewater treatment, heavy metal removal from the environment, and animal feed. In addition, the production of biofuels based on microalgae is also attracting attention. Therefore, microalgae are creating potential alternatives to coal, petroleum, and natural gas. In this sense, it seems inevitable that microalgae will be one of the main energy sources in the future, and a green revolution will take place with the development of microalgae technology. This study aims to reflect the current situation of algae and microalgae used and that can be used in biotechnology, along with new applications and necessary considerations in Türkiye, as well as in the world.

Mikroalg kullanımı ve Türkiye ile Dünya'daki Önemi

Makale Bilgisi

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Öz

Küresel çevre kirliliğinin artması, enerji tüketiminin artışı ve küresel ısınma, dünya genelinde önemli sorunlar olup, ülkeler çevre sorunlarında farklı çözümler aramaktadır. Türkiye ve diğer ülkeler artan enerji talebini ve artan çevre kirliliğini karşılayarak daha sağlıklı bir çevrede ekonomik ve sosyal olarak yaşamaya devam etme çabası içindedir. Yenilenebilir teknolojiler geliştirilmekte ve üretilmektedir. Bu nedenle, sürdürülebilir ekoloji ve sürdürülebilir yeşil ekonomi küresel gündemin en önemli konularından biri haline gelmiştir. Bu nedenle, mikroalglerin çevresel uygulamalarda kullanımı hızla artmakta ve mikroalg teknolojisi hızla geliştirilmektedir. Fotobioreaktörler şu anda mikroalg üretiminde öncü konumdadır. Buna göre, mikroalgler sağlık, gıda, kozmetik, ilaç üretimi, atıksu arıtımı, çevreden ağır metal çıkarımı ve hayvan yemi gibi biyoteknolojik ve teknik uygulamaların birçok farklı alanında kullanılmaktadır. Ayrıca, mikroalg temelli biyoyakıt üretimi de dikkat çekmektedir. Bu nedenle, mikroalgler kömür, petrol ve doğal gaz gibi potansiyel alternatifler yaratmaktadır. Bu bağlamda, mikroalglerin gelecekte ana enerji kaynaklarından biri olacağı ve mikroalg teknolojisinin geliştirilmesiyle yeşil bir devrimin yaşanacağı kaçınılmaz görünmektedir. Bu çalışma, Türkiye'de ve dünyada biyoteknolojide kullanılan alg ve mikroalglerin mevcut durumunu, yeni uygulamaları ve gerekli düşünceleri yansıtmayı amaçlamaktadır.

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INTRODUCTION

There are two different methods used in microalgae production: open (external) systems and closed (internal) systems (Suali & Sarbatly 2012).

a) Open Systems (Open Ponds)

Open (external) system microalgae production is carried out in non-mixed and mixed type (channel) open ponds (Figure 1.; Figure 2.) (Suali & Sarbatly 2012). It is known that microalgae cultivation in open ponds started in the 1950s (Pawlowki et al., 2014; Kargın, 2020). Large-scale bioreactors and channel ponds are commonly used in these types of microalgae cultures (Christenson & Sims 2011; Rawat et al., 2013; Kargın, 2020). Since the channel (raceway) ponds are open, the ion concentration in the culture water increases due to evaporation. Therefore, microalgae production is negatively affected (Rawat et al., 2013). In addition, easily contaminable microorganisms can negatively affect production in open systems (Bahadar & Khan 2013). Factors such as temperature changes during the day and seasonal variations also affect production. As the density of microalgae increases, the amount of CO_2 in the culture medium decreases, which also negatively affects production (Kargın, 2020).

Figure 1. Outdoor Production Systems (Anonymous, 2022a).

Figure 2. Channel (Raceway) Type Pond Systems (Kumar & Mohan 2014)

b) Closed Systems (Photobioreactors)

In closed photobioreactors, there are tubular, flat, and spiral (Figure 3.) models with continuous circulation of the culture medium and stirring during the production process (Demirbas, 2010).

Figure 3. Large Bag Production Systems (Gezici, 2012)

Tubular photobioreactors are commonly designed as horizontal, vertical, and spiral (Figure 4.; Figure 5.) bioreactors in microalgae production (Khan et al., 2009). The production materials of tubular photobioreactors are made of glass and plastic tubes (Chisti, 2007). Tubes can be produced vertically, horizontally, spirally, and inclined (Chisti, 2007; Rawat et al., 2013).

Figure 4. Flat-panel photobioreactor production system (Kükdamar & Tokuç 2015).

Figure 5. Horizontal (flat) production system in photobioreactor (Gezici, 2012).

When comparing closed type photobioreactors with open ponds, advantages include the ability to control temperature, pH, and light, the ability to continuously and easily mix, minimal losses due to evaporation, higher microalgae production quantities, predictability of production, and high-quality production. However, the construction costs for closed systems are considerably higher than those for open ponds. Since microalgae can adhere to surfaces, culturing on large surface areas can make it difficult to control temperature and CO_2 levels. Stirrers are not necessary in flat-panel photobioreactors, as the gas distributor system located at the bottom of the reactor serves as the stirrer. Air-lift photobioreactors are preferred bioreactors for microalgae production due to their easy design and low cost. Flow columns are also present in photobioreactors made of glass and plastic to facilitate vertical flow.

Application areas of microalgae products

Metabolites (phototoxins) generally refer to small molecules and represent intermediate products of metabolism. Secondary metabolites are chemical compounds directly related to the normal growth, development, or reproduction of organisms. The importance of studying these organisms for pharmaceutical purposes has been demonstrated by the discovery of new agents through physical techniques and biomedical applications of chemical prototypes (Dos Santos et al., 2005).

Microalgae-derived metabolites are a promising group of bioactive molecules for biotechnological applications. Bioactive metabolites are an important source, especially for cytotoxic agents. These types of compounds are mainly produced by dinoflagellates and cyanobacteria, especially in marine or freshwater environments with harmful algal blooms. Excessive growth of dinoflagellates can cause red tides and color changes in the sea, while cyanobacteria can cause eutrophication in lakes, especially due to increased nitrogen and phosphorus (Lipton, 2003). Many microalgal metabolites have different biological activity and chemical structure. Research on the effects of algae on human health and other beneficial effects is increasing (Guedes et al., 2011).

Metabolites stored in algae cells are also used in various sectors such as food, health, animal feed, fertilizer, organic food coloring, and cosmetics. They are also used in wastewater treatment because of their ability to bind to metals (Gökpınar et al., 2013).

Since the necessary climate conditions and nutrient elements for the production of algae, which are considered to meet the raw material requirements of some energy sources, are available in Türkiye, it is seen that our country is suitable for economic algae production. When considering only thermal power plants that operate with natural gas, microalgae are an inexhaustible source due to CO_2 being their main nutrient (Ulukardeşler & Ulusoy 2012). Maximizing the utilization of existing resources and minimizing waste and losses is necessary, within a framework that includes not only water resources but also all economic and social resources to gain value (Mostafa et al., 2012).

a. Food

The use of microalgae by humans dates back to ancient times, and it is known that in China, they used *Nostoc* as a food source to survive during times of famine (Figure 6).

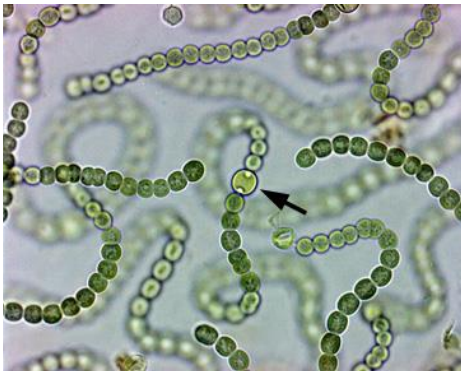

Figure 6. *Nostoc* genus (Anonymous, 2022b).

Hunger, which is becoming an increasingly problematic issue worldwide, affects 1 in 10 individuals, and this ratio is gradually increasing. Particularly, protein and energy deficiency are major reasons for health problems and premature death (FAO, 2017; Muslu & Gökçay 2020). The United Nations predicts that the global population could reach 9.7 billion in 2050. While many people still lack access to food, alternative sources of nutrition must be explored, and existing production must be increased to meet the needs of the growing population (UN DESA, 2019; Muslu & Gökçay 2020).

Commercial microalgae applications are primarily controlled by four strains: *Arthrospira*, *Chlorella*, *Dunaliella salina*, *Aphanizomenon* and *Arthrospira* species (Figure 7) are used in human nutrition due to their high protein content and nutritional value (Rangel-Yagui et al., 2004; Soletto et al., 2005).

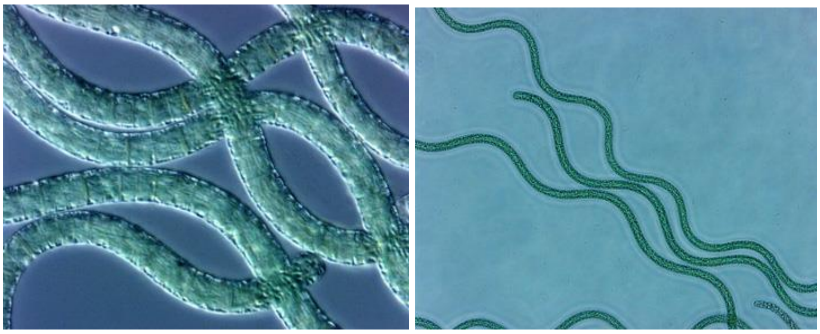

Figure 7. *Arthrospira* genus (Anonymous, 2022c).

Microalgae for human nutrition are currently marketed in various forms such as tablets, capsules, and liquids. They are also added to pasta, snack foods, candy bars, gum, and beverages (Table 1.) (Yamaguchi, 1997; Liang et al., 2004; Sasa et al., 2020).

Table 1. Some studies conducted with microalgae addition (Sasa et al., 2020).

Microalgae	**The food to which it is added**
Spirulina sp.	Yogurt Muffin Cookie Biscuit Bread Gluten-free bread Pasta
Chlorella sp.	Cheese Cookie Bread Oil/water emulsions
Dunaliella sp.	Bread Pasta

According to the data of the Food and Agriculture Organization of the United Nations in 2016, microalgae production reached 89,000 tons in 11 countries. However, China reported a production of 88,600 tons in the same year. Many microalgae species are used as dietary supplements, including *Spirulina* spp., *Chlorella* spp. and *Haematococcus pluvialis*, among others. It is believed that production may exceed what is reported in production reports (FAO, 2018; Muslu & Gökçay 2020). The U.S. Food and Drug Administration (FDA) refers to any organism, substance, or chemical that is safe for human consumption as "Generally Recognized as Safe (GRAS)" for all individuals. Algae such as *Dunaliella bardawil, Chlamydomonas reinhardtii, Auxenochlorella protothecoides, Chlorella vulgaris, Arthrospira platensis*, and *Euglena gracilis* and their derivatives are considered GRAS (Muslu & Gökçay 2020). The amino acid contents of the algae considered GRAS are given in Table 2 (Muslu & Gökçay 2020; Torres-Tiji et al., 2020).

Table 2. Amino Acid Content of GRAS Algae (Muslu & Gökçay 2020; Torres-Tiji et al., 2020).

Amino Acid	Species of Algae					
	A. platensis	*C. reinhardtii*	*A. protothecoids*	*C. vulgaris*	*D. bardawil*	*E. gracilis*
Alanine	9,5	8,8	6,2	7,9	7,3	15,8
Arginine	7,3	7,2	13,4	6,4	7,3	3,4
Aspartic Acid	11,8	9,7	7,1	9	10,4	7,1
Cysteine	0,9	-	1,6	1,4	1,2	0,2
Glutamic acid	10,3	11,3	10,3	11,6	12,7	9,5
Glycine	5,7	5,7	5,5	5,8	5,5	7
Histidine	2,2	2,3	3	2	1,8	2,2
Isoleucine	6,7	4,4	3,7	3,8	4,2	0,2
Leucine	9,8	9,8	5,6	8,8	11	3,7
Lysine	4,8	6,6	4,9	8,4	7	4,9
Methionine	2,5	2,7	2,1	2,2	2,3	0
Phenylalanine	5,3	5,6	5,5	5	5,8	0,9
Proline	4,2	5,6	5,6	4,8	3,3	0
Serine	5,1	4,3	5,1	4,1	5,4	10,6
Threonine	6,2	5,1	4,9	4,8	5,4	4,5
Tryptophan	0,3	2,8	0,5	2,1	0,7	1,7
Tyrosine	5,3	4,3	4,7	3,4	3,7	0,7
Valin	7,1	6,5	5,2	5,5	5,8	8

Microalgae are widely used in a variety of applications, ranging from aquaculture to pet and livestock feed. Around 30% of global algae production is used for animal feed, with more than 50% of current Arthrospira production used as a dietary supplement (Becker, 2004).

b. Agriculture

The world's energy demand is increasing parallel to the growing population. Various solutions are being researched and new regulations are being developed in Türkiye and other countries to meet this demand. Regulations highlight the importance of environmentally friendly, sustainable, and renewable energy sources (Karakaş et al., 2014).

In recent years, the advantages and disadvantages of bioenergy sources have been discussed in terms of their effectiveness in sustainability. The use of oilseed plants (OSP) in biofuel production has been emphasized in this context. The interest in these plants has been increased by their widespread use in various sectors.

In Türkiye, sunflower is the top oilseed crop produced in 2019 with approximately 1.9 million tons, followed by cottonseed with 1.32 million tons, rapeseed with 180 thousand tons, soybean with 150 thousand tons, sesame with 16.9 thousand tons, and flaxseed with 21.9 thousand tons. Sunflower has the largest cultivation area with 675.9 thousand hectares, followed by cotton with 477.9 thousand hectares, rapeseed with 52.5 thousand hectares, soybean with 35.3 thousand hectares, sesame with 24.9 thousand hectares, and flaxseed with 15.9 thousand hectares. Accordingly, in 2019, approximately 3.6 million tons of oilseeds were produced on an area of about 1.28 million hectares in Türkiye. The total domestic usage value of sunflower is 4.7

million tons, and 2.8 million tons are met by imports. The domestic consumption value of soybean is 2.6 million tons, and a large portion of 2.4 million tons is provided by imports (TÜİK, 2020).

Despite its potential for YTB production, Türkiye's YTB production is insufficient. As a result, it becomes difficult for the biodiesel sector to access YTB as a valuable raw material, and the increase in raw material prices under market conditions negatively affects the sector's competitiveness (Hatunoğlu, 2010). Due to the difficulties in obtaining biofuels from agricultural products, alternative sources are being preferred. Algae are considered the most efficient product in terms of oil content compared to other oilseeds and are the fastest-growing source of biofuels worldwide (Demirbaş & Demirbaş 2011).

Environmental factors such as air and water pollution, soil depletion, and declining biodiversity contribute to degradation. Synthetic chemicals, agricultural pesticides, and fertilizers pollute soil, water, and air, harming both the environment and human health (Horrigan et al., 2002).

Heterocystic cyanobacteria are known for their ability to fix atmospheric nitrogen. The productivity of most tropical rice fields is attributed to the nitrogen-fixing activities of cyanobacteria. In order to increase soil fertility, the inoculation of cyanobacteria has been successfully achieved. Recently, it has been reported that cyanobacteria with nitrogen fixation ability dominate desert soils. It is believed that this significantly contributes to the fertility of desert soils and eventually facilitates the vegetation of deserts (Mahdi et al., 2010).

Reducing CO_2 in the atmosphere can be addressed with the transition to more widespread use of biofuels, nuclear, and renewable energy sources through CO_2 reduction. Microalgae are important for CO_2 fixation and biofuels because they can convert CO_2 (and additional nutrients) to biomass through photosynthesis at much higher rates than traditional biofuel products. This biomass can then be converted to methane or hydrogen through processes facilitated by anaerobic bacteria (Haiduc et al., 2009).

c. Wastewater Treatment

According to UNESCO (2003) data, water usage distribution is 22% in industry, 8% in domestic use, and 70% in agriculture. A significant portion of this water is discharged into the environment as wastewater. Therefore, a modern approach is needed for the treatment of industrial waste. Industrial wastewater mostly contains heavy metals, organic toxins, and surfactants. Waste from the textile, electroplating, and other metal processing industries contain significant amounts of toxic metal ions (Ahluwalia & Goyal 2007). Microalgae can use low-quality water sources such as agricultural runoff or municipal, industrial, or agricultural wastewater as growth media and can be used for the recovery of wastewater (Valverde et al., 2016). The biological uptake of heavy metal ions through various mechanisms such as ion exchange, complex formation, and electrostatic interactions occurs at the micro-scale. The residual nutrients and heavy metal ions in domestic, agricultural, and industrial wastewater are responsible for the pollution of rivers, lakes, and oceans (Michalak & Chojnacka 2002). The fundamental advantage and potential of using algal biomass for the biological removal of heavy metal ions are the sustainability of the process and, therefore, the cost-effectiveness of the method at an industrial scale (O'Connell et al., 2008).

d. Biofuels

In recent years, algal biomass (living and non-living) has been used for the biological removal of heavy metals. Laboratory studies have shown that algal biomass (dead or alive) actively absorbs various heavy metals (Volesky, 2007).

Microalgae, single-cell photosynthetic organisms, have many advantages over other biofuels in terms of higher area efficiency, the ability to use non-arable waters for growth, and the conversion of carbon dioxide and other industrial wastes into useful products (Lohrey & Kochergin 2012). For these reasons, using microalgae for biodiesel production is more attractive both environmentally and economically (Demir, 2015).

Microalgal fuels are not yet commercialized (Chisti et al., 2011). The high production cost is the primary obstacle to the commercialization of microalgal biofuel production (Bahadar & Khan 2013). In the future, microalgal-based biofuel production will become more important in light of the ecological impacts if petroleum reserves become depleted or scarce (Chisti et al., 2011).

e. Alg Flora of Türkiye

The lakes in Türkiye exhibit different structures, formations, and hydrological properties, which also support algal biodiversity in these conditions (Demir et al., 2021). Studies on freshwater algae have been conducted in 275 lakes in Türkiye, and 1363 phytoplankton taxa have been identified. As a new record, 30 *Ochrophyta* taxa were identified. This study also identified 10 genera (*Bitrichia, Chromulina, Ochromonas, Chrysococcus, Kephyrion, Kephyriopsis, Chrysosphaerella, Phacomonas, Pseudotetraëdron, Ducellieria*) as new records for the algae flora of Türkiye (Demir et al., 2021).

Production Status of Microalgae in the World

The oldest known application of microalgae is their use as fertilizers in the Far East. Similar applications were made in some European countries with extensive coastlines in the 12th century. In the 17th century, France and later England began to use microalgae, and by the end of the 18th century, Scotland started using microalgae, with an annual microalgae production of 20,000 tons of dry algae reported. This amount is equivalent to approximately 400,000 tons of fresh algae (Kargın, 2020).

Since the mid-2010s, the importance of microalgae has increased, and the US Department of Energy has pledged $24 million in financial support to three research companies to commercialize algal biofuels (Kargın, 2020). From the 1970s to the mid-1990s, the US National Renewable Energy Laboratory conducted studies on improving the use of microalgae for biodiesel production, and Cyanotech began using *Haematococcus pluvialis* as a source of carotenoids at the end of the 1990s (Deng et al., 2009; Mata et al., 2010). The US Department of Energy discontinued the studies in the mid-1990s due to the decrease in fossil fuel prices.

In 2008, ABDEB started reinvesting in research on biofuels (Deng et al., 2009). Nowadays, various companies are conducting research to commercialize algae-based fuels. For instance, Exxon Mobil has allocated a budget of 600 million dollars for algae fuel production (Chisti et al., 2011). Origin Oil has conducted studies that have reduced production costs to as low as 0.60$/L (Gendy & El-Temtamy 2013). According to a report by Singh & Gu (2010), 78% of companies producing algae fuel are located in the United States, 13% in Europe, and 9% in other regions. In 2009, the United States led the microalgae production sector with a 47% share. Most of the microalgae produced in the United States are used in the pharmaceutical and cosmetic industries, with a smaller portion used for algae-based fuel production. China is in second place in algae production with a 21% share, using all of its production in the food sector. Australia and New Zealand follow with a 14% share, with New Zealand being the most effective in using microalgae for biofuel production. The European Union countries, Argentina, and Brazil follow in the rankings (Figure 8).

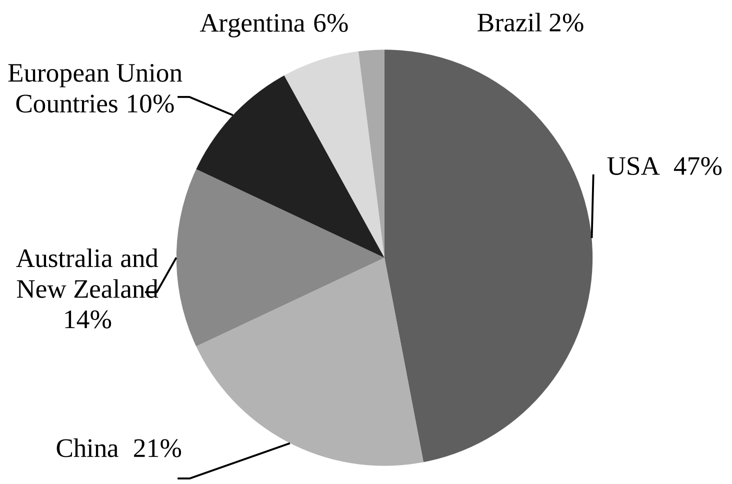

Figure 8. Microalgae production quantities of countries (%) (FAO, 2009).

While microalgae cultivation falls under the definition of aquaculture, serious investments should also be made in other sectors (Energy, Cosmetics, etc.) for microalgae cultivation. The cultivation of microalgae species such as *Spirulina* spp., *Chlorella* spp., *Haematococcus pluvialis*, and *Nannochloropsis* spp. has turned into large-scale commercial production and is produced especially for use as nutritional supplements for humans and other purposes. According to FAO data, countries with large-scale microalgae farms include Australia, the Czech Republic, France, Iceland, India, Israel, Italy, Japan, Malaysia, Myanmar, and the United States (Figure 9, Figure 10, Figure 11, Figure 12, Figure 13).

Figure 9. Green Fuel Tech Aurora Biofuels Gmbh, Arizona, Algae Production Facility (Gezici, 2012).

Figure 10. Algepower Gmbh Algae Production Facility in Manhattan, USA (Gezici, 2012).

Figure 11. Otto Pulz Microalgae Production Facility in Germany (Gezici, 2012).

In recent years, algae production facilities have been developed on a larger scale using open and closed photobioreactors (Figure 2) compared to previous years.

Production Status of Microalgae in Türkiye

Scientific studies related to microalgae in Türkiye are mainly focused on larval feed production and monitoring eutrophication in marine surface waters. Additionally, there are ongoing photobioreactor design studies for food and active substance production at the Department of Biomedical Engineering at Ege University. Microalgal biomass production has begun in Türkiye, particularly at Ege University (Figure 12); however, there is a lack of research on energy production using microalgae.

Figure 12. Ege University Microalgae Production Greenhouse (Gezici, 2012).

In Türkiye, scientific studies on microalgae are mostly carried out for larval feed production and monitoring eutrophication in surface waters. In addition, the Department of Biomedical Engineering at Ege University conducts photobioreactor design studies for food and bioactive substance production. Microalgal biomass production has also started in Türkiye, particularly at Ege University (Figure 12); however, there is not enough research on energy production.

One of the few studies in this field is the TUBITAK-funded "Innovative Approaches to Microalgal Biomass Production" project, which started in April 2010 under the Gebze Institute of Technology. In addition, experiments are carried out to investigate biomass and oil production along with nutrient consumption rates and CO_2 absorption rates by propagating algae samples collected from different natural environments and from the waste water of the Ömerli Municipal Wastewater Treatment Plant at specific intervals. Harvesting, or the successful and cost-effective separation of algae from water, is crucial for the success of this process. None of the commonly used industrial approaches have been economical or suitable for large-scale microalgal production (Asla et al., 2016).

Many private companies in Türkiye are conducting research on microalgae individually or in partnership with the government. One such company is Ege Biotechnology Inc., which produces high yielding microalgal species in its laboratories and has a collection of approximately 30 microalgal species. Algal fuel is produced at the Production Facilities (Figure 13) owned by Ege Biotechnology Inc. in Bergama. Laboratory units were established at the Production Facilities in Bergama of Ege Biotechnology Inc. with support from KOSGEB to determine the conformity of the obtained algal fuel with standards. Another organization supporting this project, the Environmental Research and Application Center (ÇEVMER) at Dokuz Eylül University, will provide contaminated water to be used in microalgae production and will determine the chemical and physical properties of this water and the water after microalgae culture. In addition, it will contribute to oil extraction and the processes involved in algal fuel production (Gezici, 2012).

Figure 13. Ege Biotechnology Inc. Microalgae Production Facility (Gezici, 2012)

DISCUSSION

Finding renewable energy sources is one of the main research topics for scientists. Currently used energy sources are decreasing and the concern about not being able to meet the demand in the coming years is increasing. Therefore, it has become inevitable to find and develop new energy sources, and algae have become the focus of attention. Industrial and domestic waste pollute water and wastewater treatment is becoming increasingly important. In order to find solutions to heavy metal pollution caused by pollution in wastewater, the use of algae is evaluated and their use is becoming more widespread. Additionally, the use of microalgae for energy production reduces wastewater costs, so the use of microalgae in wastewater treatment has also become important.

When the polluting effect of human activity on the environment and the factor of global warming come together, our biodiversity is subject to destruction. Therefore, the current algae culture established to preserve the existing biodiversity is inadequate. In Türkiye, the existence of the Istanbul Microalgae Biotechnology R&D Unit (IMBIYOTAB) at Bogazici University and the algae culture collections belonging to Ege University are not considered sufficient compared to other countries. Although Türkiye's rich algae diversity has been observed in studies on the country's algae flora, the algae culture collection is inadequate. When looking at the studies conducted in our country, most of them consist of laboratory-scale or different modeling of strains studied abroad. This situation does not allow for the observation of positive and negative results that may arise in different strains. In addition, studies conducted under laboratory conditions can only be recorded as scientific studies, as they cannot be commercialized due to problems with finding resources, costs, and insufficient support from public institutions. When looking at the studies conducted in our country over the past quarter-century, there are many valuable academic studies and scientists researching freshwater and saltwater sources, and algae flora. However, when looking at the world, it is seen that we are far behind in terms of time and more studies and support are needed. In this context, a strategy that encourages breakthroughs in energy and other areas that can be realized with R&D and innovative approaches should be implemented to go beyond these goals in Türkiye. When looking at our country's energy policies, increasing economic, environmentally friendly, and renewable energy sources is the most important goal. In this direction, the use of national and environmentally friendly energy sources and the use of algae in fields such as agriculture, industry, cosmetics, and animal feed are of great importance.

CONCLUSION AND RECOMMENDATIONS

The development and widespread use of microalgae for energy production is likely to be an alternative to fossil fuels in the future. Microalgae production for commercial purposes is limited in Türkiye, with most of the research being conducted in laboratory-scale scientific studies. Although many wastewater treatment studies are being carried out with microalgae in the field of environmental engineering, some universities are also working on biofuel production. The benefits of using microalgae for sustainable environment and renewable energy are clear, and microalgae will be a priority microorganism in many areas (environment, energy, and economy) in the future. Therefore, funding should be allocated for algae biotechnology studies in Türkiye, and large-scale algae ponds should be established with the support of public institutions and enterprises under the leadership of trained scientists in suitable areas. Efforts should be made to develop suitable areas and systems to increase production.

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