مجلة العلوم الشاملة
المجلد (10) العدد (40)، مايو 2026
ردمد: 3014-6266

عدد خاص بالمؤتمر العلمي الدولي الأول لأبحاث
التنمية المستدامة عن بعد 12-14 مايو 2026

Extracting Biofuel from Local Algae Species

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Received: 2-3-2026; Revised: 6-3-2026; Accepted: 10-3-2026; Published: 12-5-2026

الملخص العربي

تهدف هذه الدراسة إلى استكشاف الموارد المحلية بوصفها نقطة انطلاق نحو التحول إلى استخدام الطاقة البديلة، وذلك من خلال إنتاج الوقود الحيوي (الديزل الحيوي) باستخدام تقنيات معالجة بسيطة ومنخفضة التكلفة. أُجريت التجربة على ثلاثة أنواع مختلفة من الطحالب: Ulva وCystoseira وJania المجمّعة من ساحل خليج سرت،.

ركّزت الدراسة على تقييم تأثير تقنيات التجفيف المختلفة على كفاءة استخلاص المواد الخام والزيوت من الطحالب، وذلك باستخدام ثلاث طرق: التجفيف بمجفف كهربائي، والتجفيف الشمسي، والتجفيف بالفرن. وأظهرت النتائج التجريبية أن أعلى Jania التجفيف بمجفف كهربائي أعطى أعلى معدلات استخلاص للزيت للأنواع الثلاثة، إذ سجّلت الطحلب الأحمر كمية من الزيت المستخلص بلغت 53.0 مل لكل 10 غ من الطحالب المجففة بهذه الطريقة.

أشارت التحليلات إلى أن العينات المجففة بمجفف كهربائي حققت أفضل كفاءة في استخلاص الزيت، تلتها طريقة التجفيف بالفرن. في المقابل، جاء التجفيف الشمسي الأقل كفاءةً، مع وجود تباين واضح في كميات الزيوت والمواد الخام المستخلصة خلال المعالجة. تُثبت هذه النتائج التأثير المباشر لطريقة التجفيف على كفاءة استخلاص الزيوت العضوية من الأنواع المختلفة من الطحالب. وتؤكد التحليلات الإحصائية صحة هذه الفوارق، مما يُبرز أهمية اختيار الطريقة المناسبة في المعالجة الحيوية للحصول على أفضل مردود من الزيوت الحيوية.

تتسق هذه النتائج مع عدد من الدراسات السابقة، وهي ذات أهمية بالغة في معالجة التحديات المتعلقة بكفاءة إنتاج الديزل الحيوي. كما تُسهم في تعزيز القدرة على تقييم الموارد الطاقية المحلية ودعم مسيرة تحسين تقنيات المعالجة الحيوية. ويُشكّل هذا المشروع أساساً علمياً راسخاً لتطوير منتجات الديزل الحيوي المستقبلية المستندة إلى الموارد الطبيعية المتاحة محلياً

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Abstract

This study aims to explore local resources as an entry point for the shift toward alternative energy use, by producing biofuel (biodiesel) using simple and low-cost processing techniques. The experiment was conducted on three different species of algae: Ulva, Cystoseira, and Jania, collected from the coast of the Gulf of Sirte.

The study focused on evaluating the effect of different drying techniques on the efficiency of extracting raw materials and oils from the algae, using three methods: electrical dryer drying, sun drying, and oven drying. Experimental results showed that electrical dryer drying yielded the highest oil extraction rates for the three species, with the red alga Jania recording the highest amount of oil extracted, at 53.0 ml per 10 g of algae dried using this method.

The analyses indicated that samples dried using a electrical dryer achieved the best oil extraction efficiency, followed by oven drying. Sun drying, however, was the least efficient, with a clear variation observed in the quantities of oils and raw materials extracted during processing. These results demonstrate the direct impact of the drying method on the efficiency of extracting organic oils from different algae species. Statistical analyses confirm the validity of these differences, underscoring the importance of choosing the appropriate method in bioprocessing to obtain the best yield from bio-oils.

These results are consistent with several previous studies, which are important for addressing challenges related to biodiesel production efficiency. They also contribute to enhancing the ability to assess local energy resources and support the drive to improve bioprocessing technologies. This project serves as a solid scientific foundation for developing future biodiesel products based on locally available natural resources.

Keywords: Algae; Biofuel; Biodiesel; Drying methods; Oil extraction; Transesterification; Gulf of Sirte.

1. Introduction

With growing environmental concerns related to climate change, the depletion of fossil fuel resources, and increasing pressure on agricultural land and water, the shift toward renewable energy sources has become a strategic and inevitable choice for ensuring energy sustainability [1]. Renewable energies include solar, wind, hydropower, and biomass (Figure 1); however, each has its own set of challenges. In this context, microalgae have emerged as a promising source for biofuel production due to their high efficiency in absorbing carbon dioxide and converting it into energy [2].

Figure 1: Renewable energy sources including solar panels and wind turbines in a natural landscape.

Macroalgae are large photosynthetic organisms that grow in aquatic environments such as oceans, rivers, and lakes (Figure 2). Like other photosynthetic organisms, they convert sunlight, water, and carbon dioxide into energy-rich compounds, including lipids, carbohydrates, and proteins [3]. Compared to conventional terrestrial crops, macroalgae offer significantly higher productivity. For instance, cultivating macroalgae on 10,000 square meters of non-arable land can yield up to 100 times more oil than traditional oilseed crops such as soybean or rapeseed [4].

Figure 2: Macroalgae growing in a natural aquatic environment, illustrating their structure and high biomass potential.

Algae also boast rapid growth rates, with some species completing a production cycle every 3–5 days. Moreover, they can be cultivated in wastewater or saline environments, making them an ideal candidate for utilizing non-arable and marginal resources [5]. Thus, biofuel production from algae does not conflict with food production, unlike first-generation biofuels that rely on food crops like corn or wheat [3].

Several technologies are available to convert algal biomass into biofuel, including pyrolysis, anaerobic fermentation, and the chemical process of esterification or transesterification [8], as illustrated in Figure 3. For instance, thermal pyrolysis of wet algae biomass can produce bio-oil without the need for costly drying steps, with oil yields exceeding 50% of dry weight in species such as Chlorella protothecoides [9].

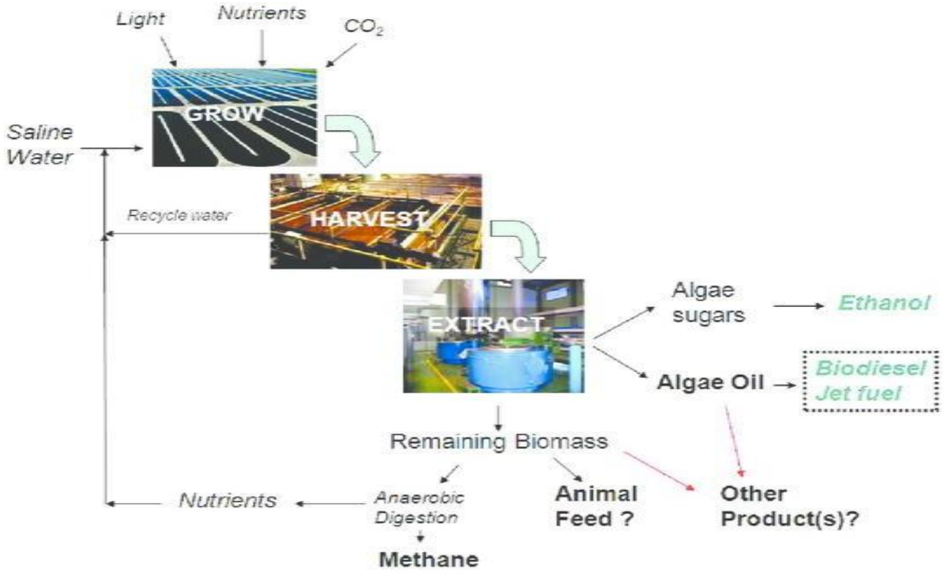

Figure 3: Conversion Pathways of Algal Biomass into Biofuel via Pyrolysis and Transesterification.

The lipids extracted from fat-rich algae can also be transformed into high-quality biodiesel through a chemical reaction involving alcohol (such as methanol) and a base catalyst like NaOH, as shown in Figure 4. This process yields biodiesel and glycerin as a by-product [10]. Such technology is already in use at an industrial scale in some countries.

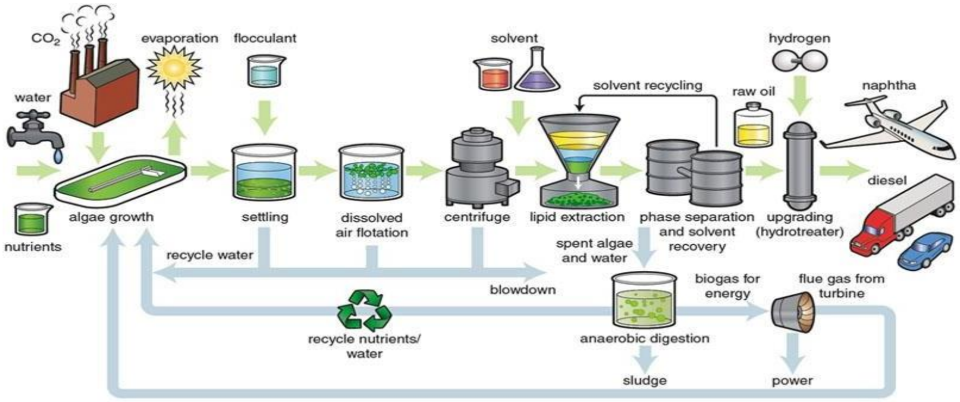

Figure 4: Biodiesel Production from Algal Lipids via Transesterification.

In addition, the sugars present in algal cells—such as glucose and mannose—can be used to produce bioethanol via enzymatic hydrolysis and fermentation using Saccharomyces cerevisiae [11], as depicted in Figure 5. This allows for full utilization of the biomass, whether it is rich in lipids or carbohydrates.

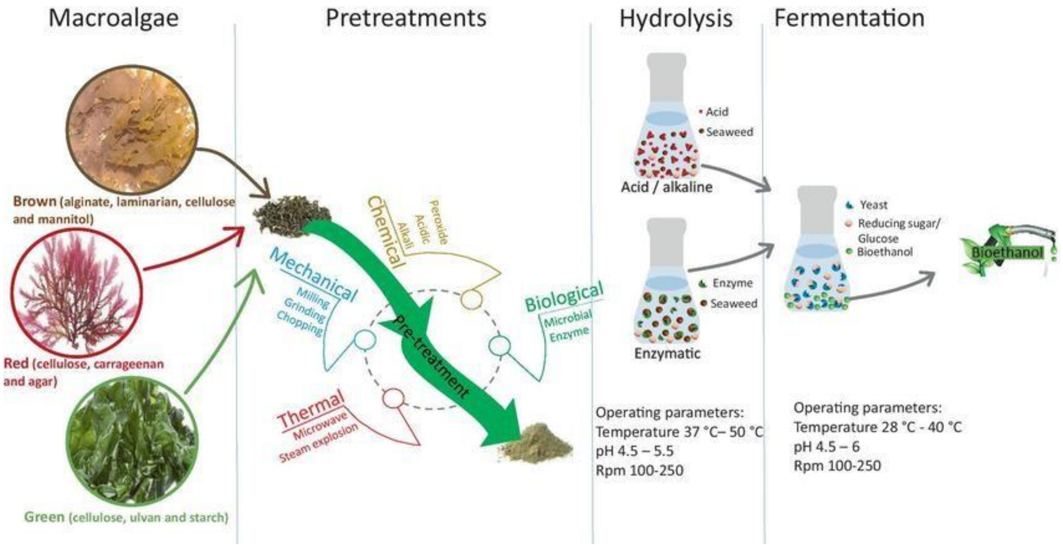

Figure 5: Bioethanol Production from Algal Biomass via Enzymatic Hydrolysis and Fermentation.

Despite these significant potentials, several obstacles still hinder large-scale adoption, such as the high costs of cultivation systems (e.g., closed photobioreactors or open ponds), and the challenge of harvesting biomass due to its low density and the microscopic size of algal cells [4]. Moreover, conversion processes require precise control of temperature and pressure, leading to higher energy consumption and operational costs [12].

This research falls within ongoing efforts to promote the use of local algal species for sustainable biofuel production. A simple and cost-effective production method has been selected, based on the use of readily available resources such as saline or wastewater. By integrating the findings of previous studies, this work aims to develop a small-scale, replicable model for biofuel production from algae, tailored to local environmental conditions [13].

2. Research Context and Problem Statement

2.1 Research Context

Faced with the global energy crisis and the gradual depletion of fossil fuels, research is increasingly focused on sustainable alternative sources. Algae, particularly local macroalgae, offer significant potential for biofuel production thanks to their high lipid content, rapid growth, and ability to thrive in non-agricultural environments. Unlike food crops, they do not directly compete with human food, making them particularly attractive in the context of the "food versus energy" debate. Furthermore, their ability to capture CO_2 makes them an environmentally friendly tool in the fight against global warming. This project therefore aims to exploit local algae species to produce biofuel using simple, inexpensive processes adapted to local resources.

2.2 Research Problem

In light of increasing fossil fuel depletion and rising greenhouse gas emissions, the development of renewable energy sources has become a global priority. While current biofuel technologies often depend on food-based crops, this creates competition with food supply and raises sustainability concerns. Algae—especially local species—represent a promising yet underutilized alternative due to their high productivity, ability to grow in non-arable conditions, and potential for CO_2 capture.

This research addresses a key challenge: how to evaluate and optimize the use of local algal species for the sustainable production of biofuels. Specifically, it aims to identify:

- The most suitable macroalgae species in terms of lipid or carbohydrate yield.
- The most efficient and economical production method for converting this biomass into usable biofuel.

2.3 Research Objectives

The main objective of this research is to exploit local resources, particularly native algae species, as raw materials for the production of sustainable biofuels. This study aims to develop a simple, economical, and environmentally friendly production process to contribute to the energy transition and reduce dependence on fossil fuels.

2.4 Research Significance

The significance of this research lies in its contribution to the development of local biological resources, particularly algae, for the production of sustainable biofuels. In a global context marked by the depletion of fossil fuels, climate change, and the search for clean energy alternatives, the use of algae as a renewable source represents a promising solution. This study not only offers an opportunity to reduce greenhouse gas emissions but also to promote local, economical, and environmentally friendly energy production. It can also encourage rural development and technological innovation in developing countries.

3. Literature Review

3.1 Biofuels

The increasing global demand for energy, coupled with the environmental consequences of fossil fuels, has led to an intensified search for alternative, renewable energy sources. Among these, biofuels have emerged as a promising solution due to their potential for carbon neutrality and their adaptability across various sectors. Biofuels refer to fuels derived from biological sources such as plants, algae, or organic waste [2]. They can be produced in solid, liquid, or gaseous forms and are often classified into different generations based on their source and production technology.

First-generation biofuels are derived from food crops such as corn, sugarcane, and soybeans. While these have been widely implemented, concerns have been raised over their impact on food prices and land use [14]. In contrast, second-generation biofuels utilize non-food biomass such as agricultural residues and forestry waste, thereby reducing pressure on food resources and minimizing competition for arable land [15].

In recent years, the focus has shifted toward third-generation biofuels, primarily produced from microalgae. Microalgae offer several advantages over terrestrial crops, including higher biomass productivity, the ability to grow in non-arable land, and the capacity to utilize saline or wastewater [16]. Additionally, microalgae consume significant amounts of CO_2 during photosynthesis, making them valuable in climate change mitigation strategies [17]. Studies show that algae can produce 10–100 times more oil per hectare than traditional oil crops [4].

Several production methods have been explored for converting algal biomass into biofuels. Transesterification remains the most commonly used method for producing biodiesel, involving the reaction of algal oil with alcohols such as methanol or ethanol, in the presence of a catalyst

[10]. Other promising conversion methods include thermochemical processes such as pyrolysis, liquefaction, and gasification [9].

3.2 Algae Species Used for Biofuel Production

Microalgae have gained significant attention in recent years as a sustainable and high-yielding feedstock for biofuel production. Among the most commonly studied species, Chlorella protothecoides demonstrates high lipid accumulation under heterotrophic conditions, with lipid content exceeding 55% of dry weight [13]. Botryococcus braunii is known for producing long-chain hydrocarbons (25–75% of dry weight) that closely resemble crude petroleum [3]. Spirulina platensis, a cyanobacterium, is a potential candidate for biogas and biohydrogen production via anaerobic digestion [19].

Other frequently studied species include Scenedesmus sp., Nannochloropsis sp., and Dunaliella tertiolecta. The selection of algal species for biofuel production is typically based on the desired end-product and the adaptability of the strain to local environmental conditions [5].

3.3 Types of Algal Biofuels

Algal biofuels have emerged as a promising alternative to conventional fossil fuels due to their high productivity and potential for carbon dioxide mitigation. Key types include:

- Biodiesel: Produced from the lipid content of microalgae through transesterification, where triglycerides react with alcohols to produce fatty acid methyl esters (FAMEs) and glycerol [10].
- Bioethanol: Derived from the carbohydrate content of algal biomass through hydrolysis and fermentation using yeast such as Saccharomyces cerevisiae [11].
- Biogas: Composed primarily of methane, produced from algal biomass through anaerobic digestion [13].
- Biohydrogen: Generated under photobiological conditions in the absence of sulfur and oxygen [19].
- Bio-oil/Syngas: Produced via thermochemical conversion technologies like pyrolysis and gasification [9].

3.4 Algae Cultivation Technology

Algae thrive in diverse environments, including freshwater, brackish water, and marine waters. There are two main approaches to algae cultivation: open ponds and closed photobioreactors.

Open ponds, although simple and economical, have limitations in terms of environmental control, contamination, and yield [16]. Closed photobioreactors offer a more controlled environment, increased light efficiency, and greater productivity, capable of producing up to 57,000 liters of oil per hectare per year [9].

Microalgae can be cultivated using wastewater or saline water, reducing pressure on freshwater resources [3]. Hybrid systems combining open ponds and photobioreactors are being developed to maximize efficiency while minimizing costs [20].

3.5 Oil Extraction Techniques

Oil extraction from algal biomass is a crucial step in biofuel production. Conventional extraction processes generally use organic solvents, such as hexane or dichloromethane, to isolate lipids from algal cells. Hydrothermal liquefaction has also been explored as a promising alternative, allowing direct conversion of wet biomass into bio-oil under high pressure and temperature [11]. Ultrasound-assisted extraction facilitates cell wall disruption and improves lipid recovery [43]. Fast pyrolysis can achieve oil yields of 48.2–55.3% of dry weight at 625 K [8].

3.6 Environmental and Economic Considerations

Algae cultivation for biofuel production offers numerous environmental benefits, primarily in terms of reduced CO_2 emissions and non-competition with agricultural land. However, a comprehensive life cycle assessment (LCA) is essential to accurately assess environmental impacts across all process stages [21]. Economically, microalgae can produce 19,000 to 57,000 liters of oil per hectare per year [5], but harvesting and oil extraction costs remain high [19]. Technological advances and integration with wastewater treatment may lower production costs and improve sustainability [20]. Recent reviews further confirm that optimizing lipid content and biomass productivity remains central to achieving commercial viability [22, 23].

4. Materials and Methods

This part of the research aims to produce crude biodiesel from local algae in a laboratory setting using simple and low-cost technologies. This involves extracting oil from dried algae biomass and then converting it into biodiesel via the esterification process.

4.1 Biological Materials

Three types of local marine algae were used, namely (Figures 6 and 7):

- Ulva Algae (Green Algae)
- Cystoseira Algae (Brown Algae)

- Jania Algae (Red Algae)

Figure 6: Ulva Algae (Green Algae) used in the study.

Figure 7: Cystoseira Algae (Brown Algae) used in the study.

The samples were collected from the coast of the Gulf of Sirte.

4.2 Chemicals

1. n-Hexane: An organic solvent for extracting oil from algae.
2. Methanol (CH_3OH): Used in the esterification process.
3. Sodium Hydroxide (NaOH): As the primary catalyst for the chemical conversion process.
4. Distilled Water: For cleaning and dilution.

4.3 Laboratory Equipment

5. Beakers, test tubes, and sterile glassware
6. Hot water bath or magnetic heating device
7. Separating funnel for separating layers
8. Filter paper for sample preparation
9. Sensitive balance for mass measurement
10. Personal safety equipment (gloves, goggles, lab coats)
11. Graduated pipette, thermometer, and glassware

4.4 Drying Methods

The three algae species were subjected to various drying methods to assess the effect of the drying technique on the quantity of oil extracted (Figure 8). The methods used were:

- Drying with an electric electrical dryer (medium temperature for 30 minutes).
- Drying with direct sunlight (1 day in sunny conditions; up to 2 days in moderate conditions).
- Drying in a thermal oven (at 80°C for one hour, then leaving the sample in the switched-off oven for one hour).

Figure 8: Drying process in a laboratory oven.

4.5 Sample Distribution and Weights

Samples were taken at a fixed weight after drying:

- Ulva Algae: 2.6 g (dryer, sun, and oven drying)
- Cystoseira Algae: 3.2 g (dryer, sun, and oven drying)
- Jania Algae: 8.2 g (oven drying only)

4.6 Hexane Quantities Used

Hexane (n-hexane) was added to the dried samples to extract oils as follows (Figure 9):

- Ulva Algae: 25 mL of hexane added to each of the three drying samples.
- Cystoseira Algae: 32 mL of hexane used for all samples.
- Jania Algae: 82 mL of hexane used for the oven-dried sample.

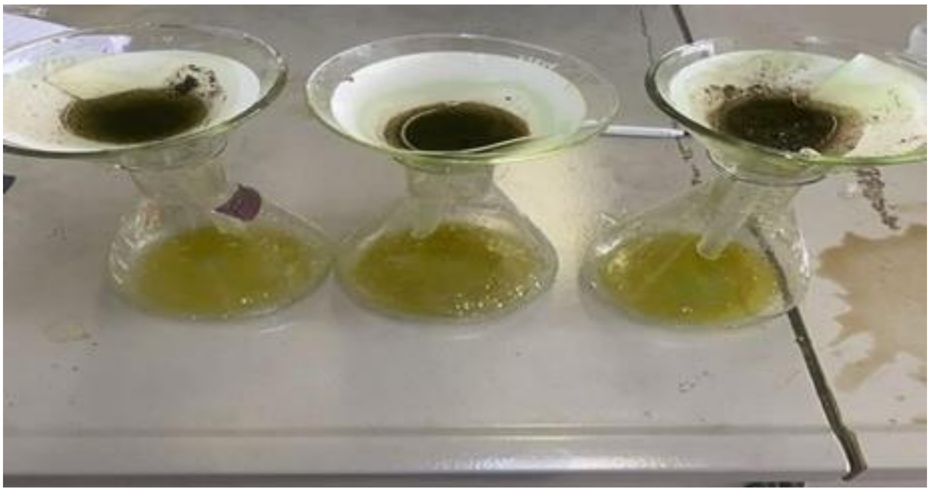

Figure 9: Oil extraction process using hexane with algae samples in glass flasks.

4.7 Experimental Procedure

The overall biodiesel production process followed three sequential stages, as outlined in the flowchart below:

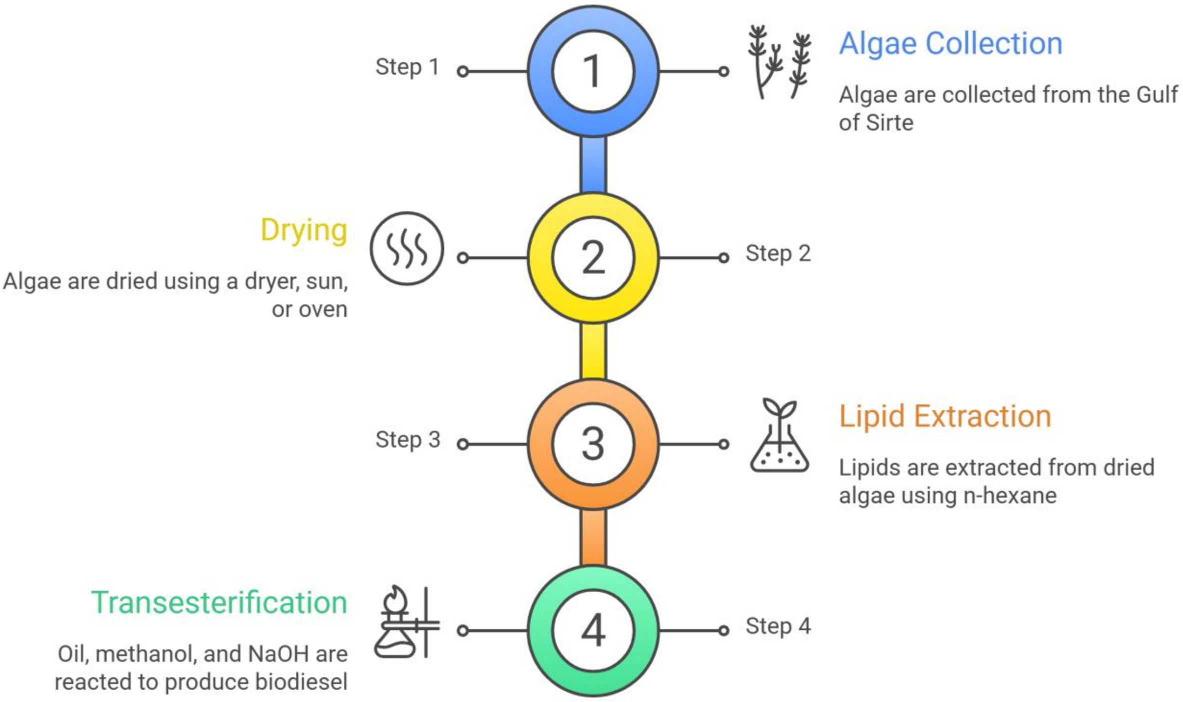

Figure 10: Flowchart of the biodiesel production procedure from algal biomass.

Step 1: Algae Collection

Ulva, Cystoseira, and Jania specimens were collected from the Gulf of Sirte along the central–northern coast of Libya.

Step 2: Drying

All water was removed from the algae before extraction. Biomass was dried using one of the previously mentioned drying methods to ensure complete moisture removal prior to oil extraction.

Step 3: Lipid Extraction

Ten grams (10 g) of dried algae biomass were mixed with 100 mL of hexane and stirred for 1–2 hours at room temperature using a magnetic stirrer. The mixture was then filtered to separate the solvent (containing lipids) from the solid biomass. The solvent was subsequently evaporated to recover the crude algal oil.

Step 4: Biodiesel Conversion (Transesterification)

The crude algal oil was mixed with a methanol solution (methanol–to–oil ratio of 6:1) with the addition of 0.3–0.5 g of NaOH catalyst. The mixture was heated to near boiling and then transferred to a mixing device for stirring for one hour to complete the transesterification reaction, yielding biodiesel and glycerol as a by–product.

4.8 Reagent Proportions

Table 1 summarizes the volumes of extracted oil, methanol, and NaOH used for each algae species under each drying method.

Table 1: Biofuel Extraction Conditions from Different Algae Species Under Various Drying Methods

Algae Species	Drying Method	Extracted Oil Volume (mL)	Methanol Volume (mL)	NaOH Volume (mL)
Ulva	Dryer	0.8	0.13	0.3–0.5
	Sun	0.3	0.05	0.3–0.5
	Oven	0.6	0.1	0.3–0.5
Cystoseira	Dryer	0.7	0.1	0.3–0.5
	Sun	0.1	0.01	0.3–0.5

Algae Species	Drying Method	Extracted Oil Volume (mL)	Methanol Volume (mL)	NaOH Volume (mL)
Jania	Oven	0.8	0.13	0.3–0.5
	Dryer	44	7.3	0.5
	Sun	—	—	—
	Oven	—	—	—

4.9 Biodiesel Production Calculations

Various ratios of methanol and sodium hydroxide (NaOH) were used after oil separation to perform the conversion reaction to biodiesel. To normalize results to a standard 10 g algae weight, the following equation was applied:

$$\text{Volume of extracted oil (mL)} = (10 \times \text{Volume of oil (mL)}) / \text{Weight of algae (g)}$$

5. Results and Discussion

This section presents and discusses the experimental results obtained from oil extraction tests conducted on three algae species (Ulva, Cystoseira, and Jania) using three different drying methods: oven drying, sun drying, and dryer drying. The analysis focuses on oil yield volume, extraction efficiency, and statistical comparisons between species and drying techniques.

5.1 Oil Yield from Algae Under Different Drying Methods

Table 2 illustrates the oil yields extracted from 10 g of each algae species after applying the three drying methods. The results clearly demonstrate that the drying method significantly influences the volume of oil recovered.

For Jania algae, the yield is particularly remarkable, with an oil volume of 53.6 mL after dryer drying, which far exceeds all other observed results. This aligns with the findings of Demirbas and Demirbas [4], who emphasized that oil yield can be significantly enhanced through optimized processing conditions, especially when dealing with lipid-rich algal species.

Ulva algae shows a maximum yield with the dryer (3.07 mL), higher than those obtained with oven drying (2.3 mL) and sun drying (1.1 mL). These differences may be attributed to the preservation of lipids sensitive to thermal or photochemical degradation, which is better controlled during mechanical drying [3, 5].

Cystoseira algae follows the same trend, although with smaller volumes (2.5 mL in the oven, 2.2 mL in the dryer, 0.3 mL in the sun), possibly due to lower lipid content or tougher cell walls that hinder oil release [13]. Overall, the results confirm that dryer drying is the most effective method for maximizing oil extraction from algae.

Table 2: Volume of Extracted Oil (mL) from 10 g of Algae Using Various Drying Methods

Algae Species	Weight (g)	Oil Volume from Oven (mL)	Oil Volume from Sun (mL)	Oil Volume from Dryer (mL)
Ulva	10	2.3	1.1	3.07
Cystoseira	10	2.5	0.3	2.2
Jania	10	—	—	53.6

5.2 Oil Extraction Efficiency

Table 3 presents the extraction efficiency (%) from 10 g of each algal species using three different drying methods. Oil extraction efficiency ranges from 9.9% with sun drying, to 20.7% with oven drying, and peaks at 27.63% with dryer drying for Ulva algae. This trend supports prior findings by Demirbas and Demirbas [4], who emphasized the role of controlled drying environments in preserving lipid integrity and improving oil recovery.

Cystoseira showed the highest efficiency under oven drying (22.5%), followed by dryer drying (19.8%), and the lowest with sun drying (2.7%). The dramatic decline in efficiency with sun exposure reflects the vulnerability of Cystoseira lipids to light-induced degradation [3].

Remarkably, Jania algae achieved an exceptional oil extraction efficiency of 482.4% under dryer drying—a value that may reflect extraordinarily high lipid density in this species under optimized drying conditions, or may indicate a methodological discrepancy that warrants further investigation [4].

Table 3: Oil Extraction Efficiency (%) from 10 g of Algae Using Different Drying Methods

Algae Species	Efficiency – Oven (%)	Efficiency – Sun (%)	Efficiency – Dryer (%)
Ulva	20.7	9.9	27.63
Cystoseira	22.5	2.7	19.8
Jania	—	—	482.4

5.3 Comparison Between Species: Oven Drying

Table 4 compares oil yields from Ulva and Cystoseira algae after oven drying. Cystoseira produced a slightly higher volume (2.5 mL) than Ulva (2.3 mL). The t-value (-3.22) and p-value (0.032) indicate a statistically significant difference between the two species, suggesting that even small variations in oil volume can reflect real biological differences under controlled experimental conditions [3, 9].

Table 4: Comparison of Oil Volume Extracted by Oven-Drying (t-test)

Algae Species	Oil Volume from Oven (mL)	T-value	P-value
Ulva	2.3	-3.22	0.032
Cystoseira	2.5		

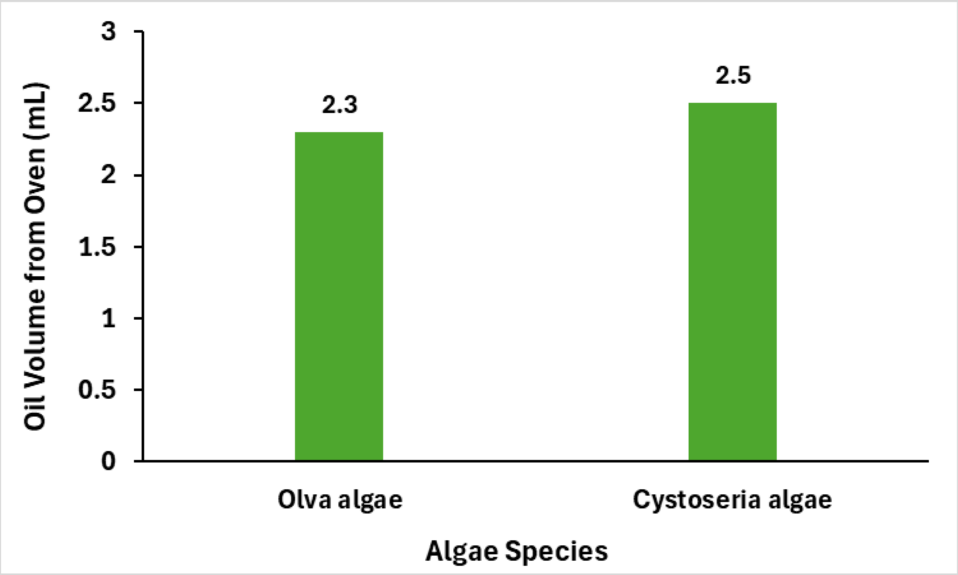

Figure 11: Volume of Oil Extracted (mL) by Oven-Drying for Ulva and Cystoseira algae.

5.4 Comparison Between Species: Sun Drying

Table 5 presents oil extraction results from sun-dried algae. Ulva algae yielded 1.1 mL per 10 g of biomass, compared to only 0.3 mL for Cystoseira. The statistical analysis (t-value = 16.8; p-value = 0.0005) confirms a highly significant difference. Ulva appears to maintain greater lipid integrity under sun-drying conditions, suggesting a more stable cellular matrix or antioxidant profile that protects its lipids from photo-oxidative degradation [5, 15].

Table 5: Volume of Oil Extracted by Sun-Drying (t-test)

Algae Species	Oil Volume from Sun (mL)	T-value	P-value
Ulva	1.1	16.8	0.0005
Cystoseira	0.3		

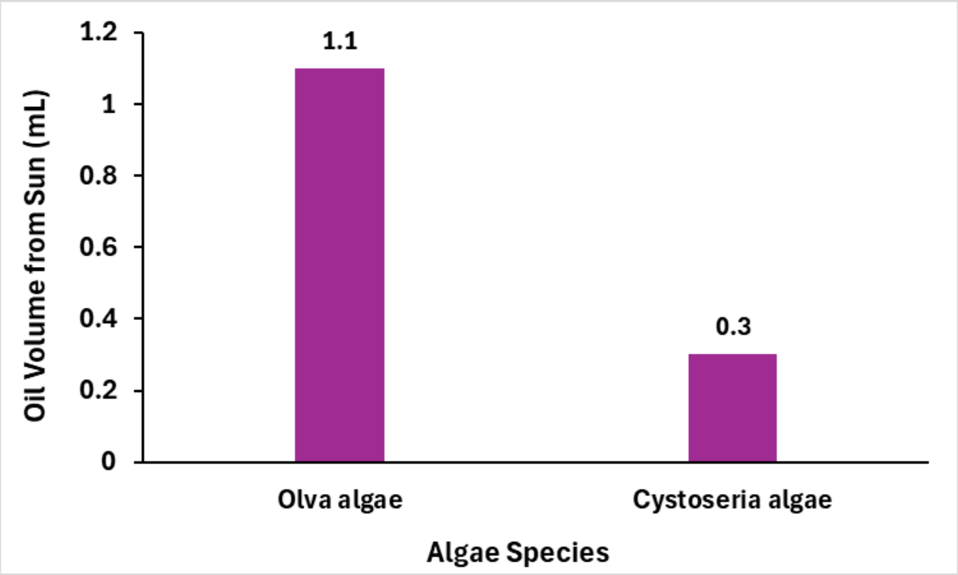

Figure 12: Visual Comparison of Oil Yield (mL) under Sun Drying between Ulva and Cystoseira algae.

5.5 Comparison Between Species: Dryer Drying

Table 6 reveals significant variation in oil yield between all three algal species dried using a dehydrator. Jania algae demonstrates an exceptional yield of 53.6 mL per 10 g of biomass, compared to only 3.07 mL for Ulva and 2.2 mL for Cystoseira. The very high F-value (27385.8) and highly significant p-value (1.31×10^{-12}) confirm that the differences between species are statistically robust [3, 4].

Table 6: Volume of Oil Extracted Using a Dehydrator (ANOVA)

Algae Species	Oil Volume from Dryer (mL)	F-value	P-value
Ulva	3.07	27385.8	1.31×10^{-12}
Cystoseira	2.2		
Jania	53.6		

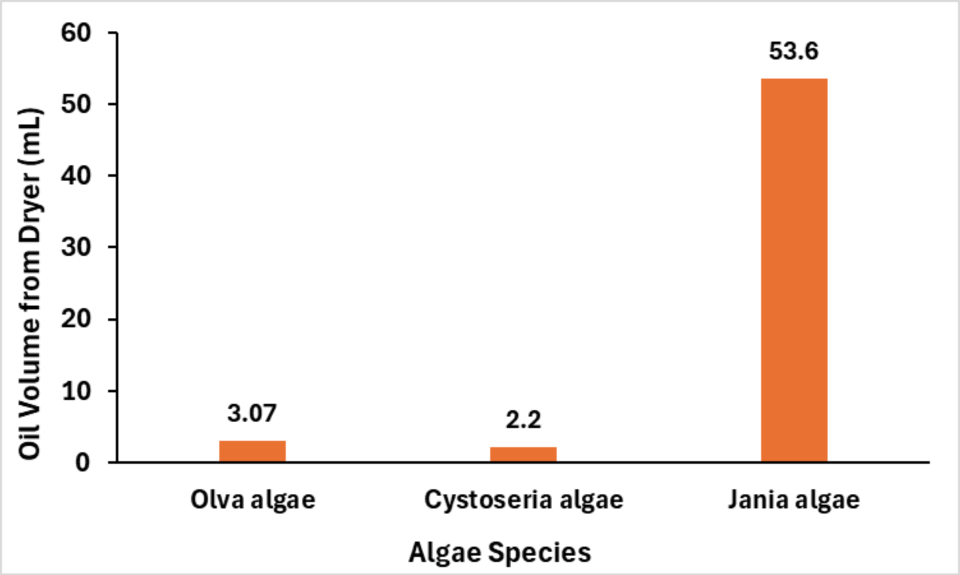

Figure 13: Oil Yield of Different Algal Species after Drying in a Dehydrator.

5.6 Effect of Drying Method on Ulva Algae Oil Yield

Table 7 highlights the significant impact of drying method on the oil yield of Ulva seaweed. ANOVA analysis showed a high F-value (785.012) and a highly significant p-value (5.52×10^{-8}), confirming that these differences are statistically significant. The dehydrator was the most effective method (3.07 mL), followed by oven drying (2.3 mL), with sun drying being the least efficient (1.1 mL) [3, 4].

Table 7: Oil Volume (mL) Extracted from Ulva Seaweed Using Different Drying Methods (ANOVA)

Drying Method	Ulva Oil Volume (mL)	F-value	P-value
Oven	2.3	785.012	5.52×10^{-8}
Sun	1.1		
Dryer	3.07		

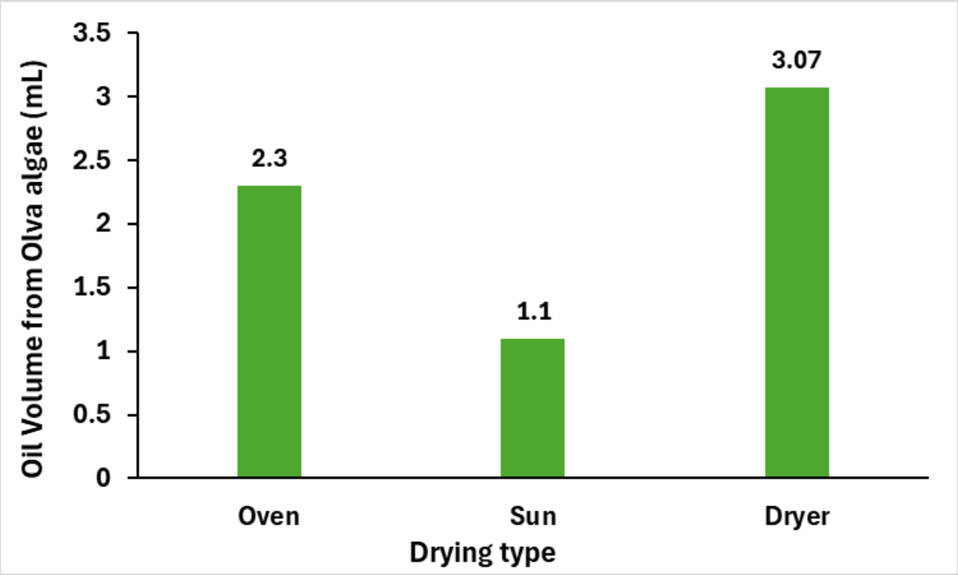

Figure 14: Comparison of Oil Volume Extracted from Ulva Seaweed by Drying Method.

5.7 Effect of Drying Method on Cystoseira Algae Oil Yield

Table 8 illustrates the significant impact of drying method on lipid extraction efficiency of Cystoseira algae. The highest oil yield was obtained by oven drying (2.5 mL), followed closely by dehydrator drying (2.2 mL), while sun drying resulted in a markedly lower yield (0.3 mL). ANOVA revealed a very high F-value (1094.9) and a highly significant p-value (2.04×10^{-8}). The similar performance between oven and dehydrator suggests both are effective drying methods for this species [3, 15].

Table 8: Oil Volume (mL) Extracted from Cystoseira Algae by Drying Method (ANOVA)

Drying Method	Cystoseira Oil Volume (mL)	F-value	P-value
Oven	2.5	1094.9	2.04×10^{-8}
Sun	0.3		
Dryer	2.2		

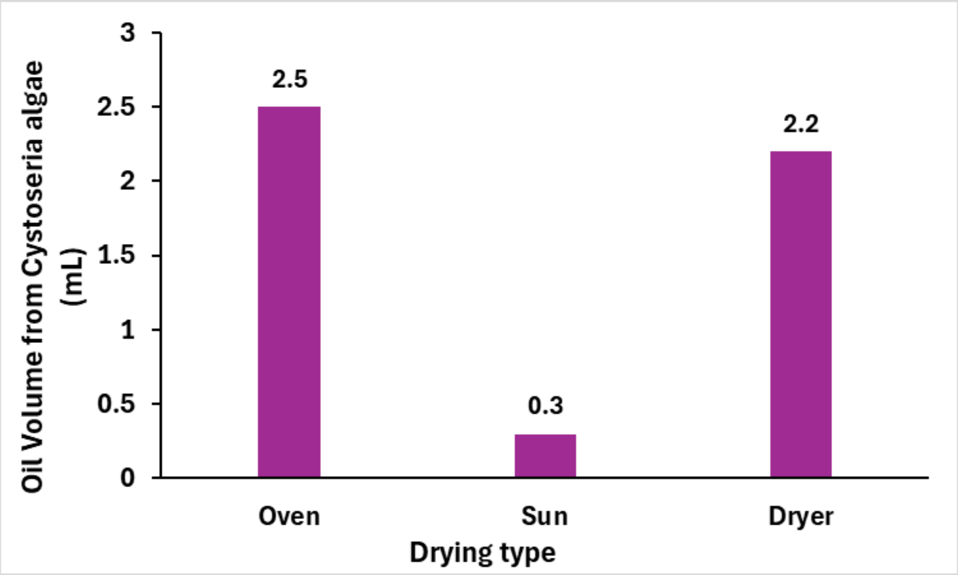

Figure 15: Cystoseira Algae Oil Yield According to Drying Method (Oven, Sun, Dehydrator).

6. Conclusion

This study demonstrated the potential of local algae as a sustainable source for biofuel production, particularly biodiesel. Three algae species (Ulva, Cystoseira, and Jania) were analyzed using three different drying methods: oven drying, sun drying, and dehydrator drying. The results revealed that the drying method significantly influences the amount of oil extracted.

Dehydrator drying proved to be the most effective overall, particularly for Jania algae, which produced an exceptionally high oil yield (53.6 mL per 10 g). Conversely, sun drying showed poor performance across all species, likely due to uncontrolled exposure to heat and light, which promotes lipid oxidation and photodegradation.

These observations confirm the critical importance of post-harvest preparation processes in optimizing biofuel production from algae. The use of local resources and simple but controlled techniques offers a promising avenue for sustainable energy development. Future research should focus on:

- Scaling up the extraction and transesterification processes for pilot-plant applications.
- Characterizing the biodiesel produced in terms of FAME composition, viscosity, and cetane number.
- Investigating additional local algae species with potentially higher lipid contents.
- Conducting a full life cycle assessment (LCA) to evaluate the environmental sustainability of the proposed production pathway.

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