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Microalgae as Potential Feedstock for Biodiesel Production-A Review

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Abstract: **This paper provides a background on the usage of microalgae which are increasingly recognized as promising for biofuel production. Compared to terrestrial crops, microalgae are very biodiverse and offer considerable versatility for a range of biotechnological applications including; the production of animal feeds, fuels, high value products and waste-water treatment. Microalgae are used as nutraceuticals and pharmaceuticals, as well as other industrial applications. In terms of environmental biotechnology, they are useful for bioremediation of agro-industrial wastewater, and as a biological tool for assessment and monitoring of environmental toxicants such as heavy metals, pesticides and pharmaceuticals. Microalgae are being considered as a viable feedstock for large-scale production of biodiesel. However, it may look simpler to obtain lipids from microalgae, the overall process of choosing an algal strain, cultivation, harvesting, dewatering, and extraction of oil is quite complicated and may not be economical at present.**

Keywords: **Biodiesel, Culture, Feedstock, Pharmaceuticals, Renewable energy, Microalgae.**

1. INTRODUCTION

Fossil fuel provides about 90% of the total world energy (Gutti et al. 2012). The continued use of fossil fuel is now widely recognized as unsustainable and detrimental to the environment. Energy demands due to the increase in population and industrialization have become a major concern to international communities (El-Moneim et al. 2010; Fulke et al. 2013). Shortfalls of the fossil fuels were reported (El-Shimi et al. 2013; Ahmad et al. 2013 and Galadima et al. 2011) as non-renewable and leads to global and international conflicts especially in the developing countries, galloping increase in cost, environmental threat majorly the emission of CO_2 leading to climate changes (Highina, 2010), emergence of drought, spread of diseases and variation in population sizes of both plant and animal species.

Guedes and Malcata (2012) and Jakob et al. (2013) stated that if we are to stay within the so called 'safelimit' (2°C) defined by the intergovernmental panel on climate change, then there is need to develop and implement renewable energy technologies such as solar, biomass, geothermal, wind, and hydropower. Biomass is a renewable energy source regarded as source with the greatest potential to satisfy all the global energy needs (Brian, 2012; Piasecka et al. 2014). Fatty acid alkyl (usually methyl) esters, known as biodiesel, have a great potential as the substitutes for conventional diesel fuel (Poljanšek and Likozar, 2011).

The objective of this paper is to examine the basics of microalgae-fuel production (biodiesel) with identification and applications of different microalgae species also, to compare the benefits and limitations with other feedstocks in biodiesel production.

2. FEEDSTOCK'S FOR BIODIESEL PRODUCTION

The pursuit of a stable, economically-sound and environmentally-friendly source of transportation fuel has led to the research and development (R&D) efforts focused on the conversion of various feedstocks into biodiesel. Currently, biodiesel is made from a variety of feedstocks, including pure vegetable oils (edible or/ and non-edible), waste cooking oils, animal fats, agricultural residue and natural vegetation bioenergy (Shelef et al 1984; Wen and Johnson, 2009). Animal's fats are derived from animals' fats and tallow, compared to the plants crops; these fats frequently offer an economic advantage because they are often priced favourably for conversion into biodiesel (Dhiraj and Mangesh, 2012). Residue and waste cooking oils, are sourced from municipal and industrial waste, food processing industries, recycled oil and grease from restaurants and food industries, it utilizes waste products that can otherwise be disposal problems. However, recycled oils have many impurities that require preprocessing which makes biodiesel production process more complicated and costly (Stebbins, 2009; Piasecka et al. 2014).

Pure vegetable oil are derived from plants such as soyabeans, rapeseed (canola), corn, cottonseed, flax, sunflower, peanut, palm and jatropha, it has the advantage of cutting down on preprocessing steps and makes consistent quality of biodiesel product, it's major shortfall is increase in worldwide food prices and shortage (Edirin and Ogie, 2012; Patel and Krishnamurthy, 2013). Agricultural residue and natural vegetation bioenergy, derived from agricultural fields or in forest and include branches and twigs from logging, cereals straw from harvesting and dung from livestock operations, residue from processing wood (sawdust/bark), and rice husk. It is a sustainable bioenergy and has the potential to improve performance of the agricultural sector and improving the livelihoods of poor farmers in developing countries, while preserving the environment (Shelef et al. 1984; Njoku, 2012).

2.1 Microalgae as Feedstock for Biofuel Production:

According to Chu, (2012), microalgae represent the largest, yet one of the most poorly understood groups of microorganisms on earth, they appear to be the only source of biodiesel that has great potential to replace fossil-based diesel. Microalgae are diverse group of prokaryotic and eukaryotic photosynthetic micro-organisms that can grow rapidly due to their simple structure. They are microscopic unicellular organisms capable of converting solar energy to chemical energy via photosynthesis (Mata et al. 2010; Priyadarshani and Rath, 2012b; Martin, 2013). Eukaryotic algae are grouped under the Kingdom Protista while the prokaryotic algae (cyanobacteria) or blue-green algae are classified as bacteria (Kingdom Monera) (Chu, 2012). Grouping of algal strains follows as;

Prokaryotic taxonomic group are (Kangwa, 2012):

- Blue green algae or cyanobacteria (cynophyceaes) and
- Golden algae (chrysophyceae)

Eukaryotic taxonomic group are (palmer, 2003; Hu et al. 2008):

- Yellow green algae (*xanthophyceae*)
- Red algae (*rhodophyceae*)
- Brown algae (*phaeophyceae*)
- Dinoflagellates (*dinophyceae*)
- Green algae (*chlorophyceae*) and
- Diatoms (*bacillariophyceae*)

Sharma (2011) reported that, microbes which accumulate more than 20% of their cellular dry weight in lipid-like oil (triacylglycerol) are called oleaginous organisms' i.e. algae, yeast, fungi.

2.1.1 The Oleaginous Algae:

The oil content in some microalgae is around 80% of their dry weight in perfect harvest conditions (Munir et al. 2013). Algae have the potential to produce more oil per acre than any other feedstock being used to make biodiesel (Ahmad et al. 2013). Oleaginous microalgae can be found among diverse taxonomic groups, and the total lipid content may vary noticeably among individual species or strains within and between taxonomic groups of the strains examined. Green microalgae represent the largest taxonomic group from which oleaginous candidates has been identified (Hu, 2008). It has been investigated and found that green microalgae is desirable for biodiesel production because of their huge lipid

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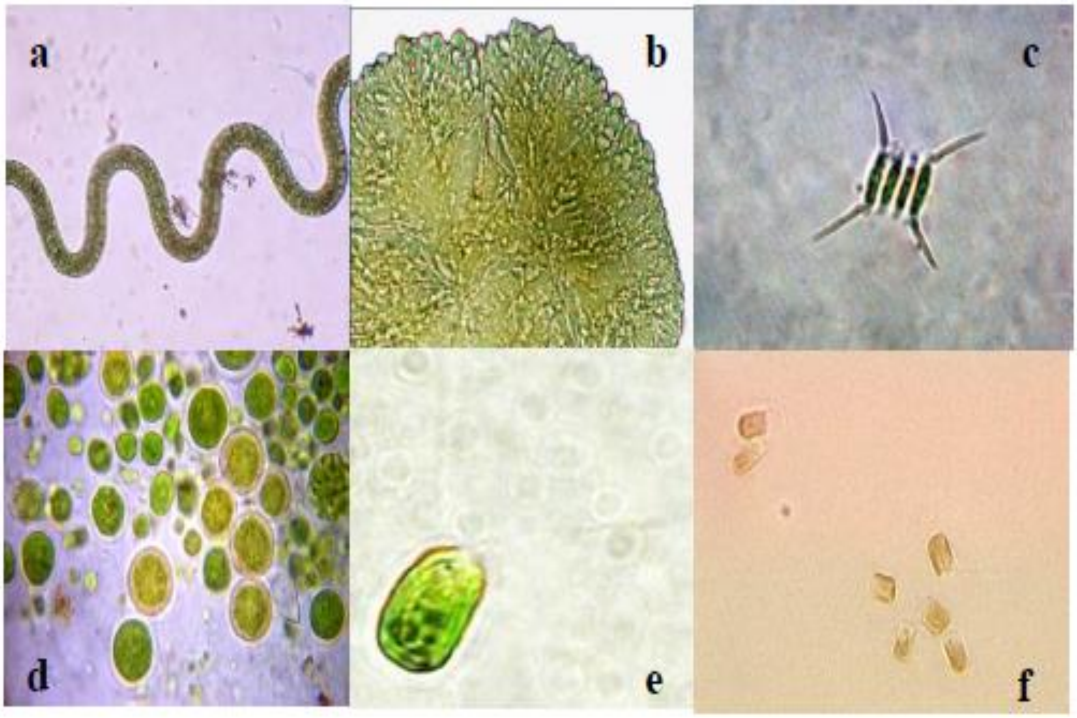
content. (Campbell, 2008; Sharma et al. 2011; Muthukumar et al. 2012; Thao et al. 2013). Microalgae demonstrate a great biodiversity (between 200,000 and several millions of species) but around 30,000 have been studied (Shalaby, 2011; Rajvanshi and Sharma, 2012).

Microalgae biomass contains three main components; carbohydrates and/or hydrocarbon, proteins, and lipids/natural oil, the bulk of natural oil made by microalgae is in the form of triacylglycerides (TAGs) which is the right kind of oil for producing biodiesel (Muthukumar et al. 2012; Thao et al. 2013). *Dunaliella* species, *Chlorella* species and *Spirulina* species are discovered by Priyadarshani and Rath, (2012a) to be the three major types of microalgae that have been used successfully to produce high concentrations of valuable compounds such as lipids, protein and pigments. Table 1 showed the oil contents of some microalgae strains and their uses. The lipids used for biofuels have important physiological roles in plants, including energy storage, structural support as membranes, and intercellular signaling. Storage lipids differ from both structural and signaling lipids in that they are mainly composed of glycerol esters of fatty acids (TAG). These lipids are generally stored in a compartment specialized for lipid storage, the lipid body. This compartment is found in most oleaginous plant cells, and is used to store a variety of TAG molecules depending on the species (Yu et al. 2011).



(Sources: Raja et al. 2014)

Fig. 1: Few commercially important microalgal strains. (a) *Arthrospira maxima* (b) *Botryococcus brauanii* (c) *Scenedesmus quadricauda* (d) *Chlorella vulgaris* (e) *Dunaliella salina* (f) *Chaetoceros muelleri.*

Triaglyceride is complex primary water soluble molecule that plants and animals use for storing food energy (fat) (Campbell, 2008). Fats and oil are hydrophobic substances that are made up of one molecule of glycerol and three molecules of fatty acids and are referred to as triaglycerides (Shah et al. 2013). Lipids from algae are categorized into three parts; Neutral lipids: comprised of triaglycerides, free fatty acids, hydrocarbons, sterols, wax and sterols esters and free alcohols. Total lipids: comprised of pigments, phospholipids, glycolipids and neutral lipids Crude lipids: includes neutral lipids and pigments (Sharma et al. 2011).

2.2 Other Application of Microalgae:

Priyadarshani and Rath (2012a) discovered that the potential of microalgal photosynthesis for the production of valuable compounds or for energetic use is widely recognized due to their more efficient utilization of sunlight energy as compared with higher plants. The microalgae biomass can be utilize for other purposes other than biofuel productions, these include the following;

TABLE 1: OIL CONTENTS OF SOME MICROALGAE STRAINS AND THEIR USES

Specie	Oil content (% dry weight)	Uses	Reference
Chlorella sp.	25-75	Aquaculture, Lipids – triglycerides and hydrocarbons	Brian, 2012; Chu, 2012; Yaakob et al. 2014
Dunaliella salina	28	produce carotenoids (β-carotene)	Verma et al. 2010; Chu, 2012
Phaeeodactylum tricornutum	20-30	Source of antioxidants	Rajvanshi and Sharma, 2012
Porphyridium cruentum		Pharmaceuticals, cosmetics, nutrition	Priyadarshani and Rath, 2012b
Arthrospira maxima		High protein content-nutritional supplement	Priyadarshani and Rath, 2012b; Raja et al.,2014
Brotryococcus brauni	25-45	Pharmaceuticals	Verma et al., 2010; Priyadarshani and Rath, 2012a; Guedes and Malcata, 2012

+They are potential source of high value product such as, natural colorants, biopolymers, and therapeutics and, aquaculture feed for shellfish and fish juveniles. Algae oil extracts can be used as livestock feed, additive of natural pigments containing carotenoids as astaxanthin produced from *haematococcu*s to the diet of farmed animals (Mirón et al. 2002; Yaakob et al. 2014).

+Depending on the microalgae species, other compounds may be extracted with valuable applications in different industrial sectors, including a large range of fine chemicals and bulk products such as natural dyes, sugars, pigments, antioxidants, antibacterial enzymes, anticancer agents, peptides, toxins and sterols, high value bioactive compounds, and other biomass. Furthermore, the production of long chain omega-3 polyunsaturated fatty acids important for human diet (DePauw et al. 1984; Thompson, 2005; Shalaby, 2011; Munir et al. 2013).

+Blue green algae were first used as a means of fixing nitrogen by allowing cyanobacteria to multiply in the soil. Certain species of algae can be land-applied for use as pesticides and organic fertilizer, either in its raw or semi-decomposed form (Veillette et al. 2012).

+In wastewater-treatment facilities, microalgae can be used to reduce the amount of toxic chemicals needed to clean and purify water (water pollution treatment) in addition; algae can also be used for reducing the emission of CO_2 from power plants (Wen and Johnson, 2009).

+In a process called biophotolysis, a number of microalgae and cyanobacteria are able to split water into hydrogen and oxygen using light as source of energy (Yu and Takahashi 2007; IEA, 2011).

+Extracted microalgae oil is esterified to produce biodiesel however, if left unrefined, the oil can act as straight vegetable oil (SVO); SVO has higher viscosity biodiesel (IEA, 2011).

+ Microalgae can produce several different types of biofuels including biomethane by anaerobic digestion, biohydrgen by photobiological process, bioethanol by fermentation, liquid oil by thermal liquefaction and production of bioplastic materials (Shelef et al. 1984; Yu and Takahashi, 2007; Christenson, 2011; Muthukumar et al. 2012; Veillette et al. 2012; Kumar and Sharma, 2013).

3. BIODIESEL COMPARED TO OTHER FEEDSTOCK (TERRESTRIAL) AND PETROLEUM DIESEL

3.1 Microalgae vs other Feedstock (Terrestrial):

- Microalgae grow rapidly and have higher solar conversion efficiency than most terrestrial plants (Liang et al. 2009; Fulke et al. 2013).
- Microalgae can be harvested batch wise or continuously almost all year round. They reproduce themselves every 2 or 3 weeks *(*Adesanya et al. 2012; El-Shimi et al. 2013).

- Yield oil exceeding 10x the yield of the best oilseed crops (Prommuak et al. 2010; Patil et al. 2012).
- Compared to plant-based oils, algae oil has relatively high carbon and hydrogen contents and low oxygen content these characteristics make microalgae an attractive biodiesel feedstock because they lead to a fuel with high energy content, low viscosity, and low density (Martins, 2013).
- Microalgae farming could be potentially more cost effective than conventional farming (Li et al. 2008).
- Not only the oil content in microalgae is slightly higher than that in other terrestrial plants, but also the biomass productivity is by far the highest (Thao et al. 2013).
- Algae production facilities can be allocated on otherwise non-productive, non-arable land, it does not conflict with the food crisis, since it is not the main food (Li et al. 2008; Verma et al. 2012; El-Shimi et al. 2013; Kumar and Sharma, 2013).
- Species of algae can be grown in polluted, saline, brackish, and freshwater (Hughes et al. 2011; Sharma et al. 2011; Raja et al. 2014).
- Microalgae can use waste water CO_2 sources thereby potentially mitigating the release of GHG into the atmosphere. $1m^3$ of waste water is required to produce 800g of dry algae. (Zheng et al. 2011; El-Shimi et al. 2013).
- The biomass feedstock (terrestrial crops) for making biodiesel is diverted from the important uses, typically food production (Mata et al. 2010).

3.2 Biodiesel Vs Petroleum Diesel:

- Microalgae oil extracts can be used as livestock feed (Shalaby, 2011).
- Substituting biodiesel for petroleum diesel results in substantial reductions of soot sulphur, unburned hydrocarbon, and polycyclic aromatic hydrocarbon emissions (Campbell, 2008; Kothari and Gujral, 2013).
- Biodiesel has twice the viscosity of petroleum diesel; its lubricants properties can improve engine life (Yaliwal et al. 2011; Muthukumar et al. 2012).
- No sulphur dioxide (SO_2) emissions compared to diesel fuel (Romano and Sorichetti, 2011).
- Waste water treatment by removing NH_4^+, NO^-_3, SO_4^{-3} using these water contaminants as nutrients (Shalaby, 2011; Martin, 2013).
- Checkmate the reduction in the use and competition of crude oil based fuel (Kothari and Gujral, 2013).
- Biodiesel can be used in existing diesel engines blended in (Sanchez et al. 2012).
- Biodiesel is considered renewable because no net emissions of GHG is expected to take place during its production and use, and therefore they are considered C-neutral or even C-capturing than releasing, it helps in carbon balance (Campbell, 2008; Sharma et al. 2011*;* Chanakya et al. 2012; Shah et al. 2012).
- It has higher cetane number (about 60-65 depending on the vegetable oil) than petroleum diesel (53) which reduces the ignition delay moreover, it has higher flash point (100 ^{O}C minimum) *(*Suwannakarn, 2008; Romano and Sorichetti, 2011; Veillette et al. 2012).
- Biodiesel produces increased NOx emissions, relative to petroleum diesel, owing to the higher compression ratios typically used in biodiesel engines (Johnston, 2006; Campbell, 2008).

4. CHALLENGES AND LIMITATION OF MICROALGAE IN BIODIESEL PRODUCTION

Biodiesel has great potential; however, the high cost and limited supply of organic oils prevent it from becoming a serious competitor for petroleum fuels. For biodiesel to become the alternative fuel of choice it requires an enormous quantity of cheap biomass using new and innovative techniques for cultivation, algae may allow biodiesel production to achieve the price and scale of production needed to compete with, or even replace, petroleum. Other challenges of biofuel are:

- The need of continued research and development (R&D) to reduce the cost in all segments of the production (Christenson and Sims, 2011; IEA, 2011 Mulumba and Farag, 2012).
- Identifying strains with high production rates and/or oil yield. However, the high price and unsustainable supply of feedstocks are the major bottlenecks for increasing biodiesel production (Dong et al. 2013).
- It is less stable than diesel fuel, and therefore, long time storage (more than six months) of biodiesel is not recommended (Romano and Sorichetti, 2011).
- It can be oxidized into fatty acids in the presence of air and causes corrosion of fuel tank, pipe and injector (Shah et al. 2013).
- Low biomass concentration in the microalgae culture in combination with the small size of algal cells makes the harvest of algal biomass relatively costly (Li et al. 2008).
- The price of biodiesel is typically higher than fossil-based diesel (Thanh et al. 2012).
- Biodiesel causes excessive carbon deposition and gum formation (polymerization) in engines and the oil gets contaminated and suffer from flow problems. It has relatively higher viscosity (11 to 18 times more than petroleum diesel) and lower volatility than diesel and thus needs higher injector pressure (Shah et al. 2013).
- Biodiesel has 12% power energy content than diesel, this leads to an increase in fuel consumption of about 2 to 10% also, it has higher cloud and pour points with lower volatilies that cause the formation of deposits in engines due to incomplete combustion characteristics (Shah et al. 2013).
- Using biodiesel reduces the power output of a diesel engine compared to petroleum diesel (<2% overall) (Campbell, 2008).

5. CONCLUSION

Microalgae are viable feedstock for biofuel production because it is a renewable, biodegradable, and carbon dioxide (CO_2)-neutral energy source. Microalgae biomass offers a number of advantages over conventional biomass such as higher productivities, use of non-productive land, reuse and recovery of waste nutrients, use of saline or brackish waters, and reuse of CO_2 from power-plant flue-gas. The production of microalgae biomass reduces Greenhouse Gases (GHG) and provides biofuel as a replacement for fossil fuels (biodiesel, biomethane, biohydrogen, bioethanol), moreover, it attains different objectives such as: production of hydrocarbons, proteins, various organic substances, wastewater treatment, solar conversion or combination of the above. Microalgae represent an important group of organisms for biotechnological exploitation, especially for valuable products, processes and services, with important impact in food and pharmaceutical industries as well as in public health. It is known that diverse range of metabolites with various bioactivities that are yet to be fully exploited from microalgae. However, it has its shortcomings in both pre and post-harvest processing i.e in strain selection and culturing method, oil-extraction and storage limitation. Hence, there is room for research and development efforts in developing a genetically and metabolically alter algal strain species for the purpose of increasing oil content, also, to improve and develop new technologies for culturing, oil-extraction, storage and ASTM quality alliance fuels

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