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Microalgae's potential of CO_2 sequestration and textile waste water treatment: a review

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ABSTRACT

Excessive use of fossil fuels for energy purposes leading towards climate change by emitting increased greenhouse gases level while changing climate has threatened water availability and food insecurity. On the other hand, available water resources are used unwisely. Textile industry is also contributing to loss of available fresh water resources. The textile sector consumes a large amount of water at different stages with the variety of chemicals and releases vast amount of wastewater. These effluents have serious harmful effects on ground and surface water resources and ultimately human health. Microalgae have potential to replace fossil fuel for energy purposes due to higher growth rate by sequestering atmospheric CO_2 in photosynthesis. Microalgal biofuel can play important role in replacing fossil fuel use by providing renewable energy. Some species of microalgae also have the ability to grow fast on polluted dye containing water and may lead towards pollution control by decreasing GHGs and wastewater treatment. Other potential uses of microalgae in food, pharmaceutical, and cosmetics industry is also discussed in this review paper.

Keywords: Climate change, wastewater, microalgae, greenhouse gases (GHGs)

1. INTRODUCTION

We have just passed by and forgotten that we have not left for our next generation many gifted natural resources like fresh air, water, and many others. At present, most of the world is facing negative effects of climate change. Foremost climatic indicators are glaciers, and their current retreating rate provides strong evidence of rapid variation in Earth's climatic system (Thompson, 2010). Climate change will have intensified effects on hydrological cycle of the world, affecting surface as well as ground water supply. These impacts will be more severe on developing nations due to their lacking potential and resources to adapt to the variability of climate. Impacts will be in the form of change in frequency, intensity, and amount of precipitation (Gosain et al., 2006). Other indicators include the rise in global GHGs concentration, average temperature, and disease outbreak. In Pakistan, people believe that their lives will be affected by the changing climate due to its' significant impacts on the energy sector and elevation of health risks as a result of an increase in vector-borne diseases (Zaheer and Colon, 2013). Floods are leading source of deaths worldwide with about 6.8 million lives in last century. Asia was at the top with 50% of total deaths. Flood of 2010 resulted in massive destruction in Pakistan and affected around 14 to 20 million people. Total deaths reported were 1700 with the destruction of 1.1 million homes and 436 health care facilities. Out of 135 districts, about 46 districts were affected, and the country faced the financial loss of $9.7 billion (Kirsch et al., 2012). Sindh province is facing the immense loss of peacock, poultry and other animal's due to change in climate. There will be a significant increase in intensity and frequency of extreme events, siltation of major dams due to frequent floods, reduced agricultural productivity due to water stress conditions, enhanced heat waves caused by rise in temperature, forced migration caused by rise in sea level and floods, and high temperature of sea surface resulting in enhanced cyclonic activity (NCP, 2012).

The whole world is facing the energy crisis and is ultimately leading to heightened prices for energy resources. Temperature, changing the concentration of GHGs, food availability, severe impacts of climate change on water resources and human health, and global warming has focused researchers to move towards renewable energy resources (Mobin and Alam, 2014; Sadiq et al. 2016a & 2016b; Pierantonio Belcaro et al. 2016). The world's greenhouse gas emissions are going to increase and he years ahead will lead to greater food insecurity due to climate change and other environmental disturbances, such as water resource availability, change in land cover (Augusta Ayotamuno and Akuro Ephraim Gobo, 2016), and Nitrogen availability (Rosegrant & Cline, 2003).Increasing demand of energy resources due to increasing population, predicts that global oil reserves will be completely depleted after 2050. With the development of new economies, the global requirement for energy will increase and result in more damage to the global environment (IEA, 2007).

Textile sector has a major share in country's economy, but water pollution from textile industry is a serious hazard for public health. Textile sector consumes a large amount of water at different stages with the variety of chemicals and releases vast amount of wastewater. These effluents have serious harmful effects on ground and surface water resources (Aslam et al., 2004; Shamshath Begum et al. 2015). Therefore, textile industry wastewater should be treated before being disposed of. Main parameters for textile industry that should be assessed are pH, electrical conductivity, total dissolved solids, chlorides, sulphates, biochemical oxygen demand and chemical oxygen demand. Various techniques could be used to remove pollutants from wastewater such as coagulation, anaerobic and aerobic microbial degradation, filtration, flotation and reverse osmosis (Sivakumar et al., 2013). Renewable energy is the only solution to finite fossil fuel resources and to control GHGs. For sustainable economy and environment, fuels production process should not only be renewable but they should also have the capability of capturing atmospheric CO2.

Algae have potential to fulfill the demand of energy because of being able to grow fast as compared to other plants even in wastewater and marginal lands by sequestering atmospheric CO_2. Microalgae are considered superior because of more oil contents as compared to terrestrial plants, more nutrient assimilation, and high photosynthetic efficiency. Microalgae are not only useful for biofuel production but also to control water pollution (Bhateria & Dhaka, 2014). Microalgae are photosynthetic unicellular microorganisms that have the ability to grow on marine, fresh and wastewater resources and can sequester atmospheric CO_2 to algal biomass. Biofuel is a renewable energy resource produced from biomass, which can be used as a substitute for petroleum fuels. The benefits of biofuels over traditional fuels include greater energy security and reduced environmental impact (Demirbas, 2010).

2. TEXTILE INDUSTRY. A CASE STUDY OF PAKISTAN

Pakistan is an agricultural country and itself provides raw material to its' different industrial sectors including textile sector. This background is an important reason for the flourishing textile sector since independence. The textile industry is the backbone of Pakistan's economy, with a share of about 8.5% of GDP, providing employment to about 15 million people and 51.8% share of the country's exports (Ahmad, 2010). In Pakistan, approximately 670 textile mills are working of which 370 are in Punjab while rests are in Karachi (Haydar & Bari, 2011). At present, this sector is facing a major decline due to the severe energy crisis, increase in labor cost and decrease in production of raw material thanks to climate change (Ahmad, 2010).

2.1. Water Consumption and Wastewater Produced

Textile sector is a major industrial component in Pakistan with many stages that use a large quantity of water like dyeing, printing, and bleaching, producing a large quantity of wastewater. A total of 3840m3/day of water is used in textile industries of Pakistan in different processes (Aleem et al., 2016). They bear a major share in environmental pollution due to over use of water in these processes and release about 35 billion tons of wastewater with high values of pH, EC, and TSS (Bibi et al., 2016).According to World Bank, dyeing and finishing of textile sector are responsible for 17-20% of total wastewater effluents. About 70 types of hazardous chemicals were found in these effluents and 30 types of chemicals were very difficult to remove (Kant, 2012). Wastewater production has increased due to over population and higher standards of living. A large amount of water used in industries and in agriculture generates wastewater with the end product (Ellis, 2011). Global water demand for industries in 2009 was 800 billion m3 and is expected to reach 1500 billion m3 by the year 2030 if economic growth rate does not cross average. Of total water requirements, 16% is used in the industrial sector which will be 22% by 2030 with more demand from China (Vajnhandl and Valh, 2014).

Table 1 Estimates of wastewater Generation Rate in different units of the textile industry

Sr. No	Industrial Sector	Production Capacity (million metric ton/year)	No of Industries	Wastewater Generated (m3/day)
1	Small	2510	507	146417
2	Medium	5145	676	428750
3	Large	1940	212	129333
4	Total	9595	1395	704500

Source: Govt. of Punjab 2008

A consumptive portion of the total water used in textile industry is very small while the major portion of the water used is released in form of effluents. About 120 m3/tone wastewater is generated for nylon and polyester, and 150m3/tone wastewater for rayon fabric (Sharma, 2015). This wastewater is disposed of in untreated form, resulting in poor quality of drinking water and health issues in big cities. Wastewater has high biological oxygen demand (BOD), chemical oxygen demand (COD) (Shaheen et al., 2010), organic mass such as proteins, lipids, volatile acids, and inorganic compounds i.e. sodium, calcium, potassium, magnesium, chlorine and heavy metals (Abdel et al., 2012).

Textile wastewater plays a major role in degrading the quality of water with release of effluents to water bodies and resulting in the death of organisms at an alarming rate. Therefore, textile wastewater has a damaging effect on the aquatic ecosystem (Kaur et al., 2010). Dyes containing wastewater cause decreased light penetration, leading to the decreased photosynthetic activity of flora and effect the source of food seriously. This also results in decreased level of dissolved oxygen, which ultimately affects aquatic life (Annuar et al., 2009). Toxicity of textile wastewater also causes disruption of ecological balance (Apostol et al., 2012; Modi et al., 2010). The adverse impact of releasing wastewater, having organic and inorganic complexes like P and N, to other water bodies is eutrophication (Pizaro et al., 2002). This issue can be handled by growing microalgae on wastewater that will eliminate nutrients from wastewater (Munoz & Guieysse, 2006). If used as irrigation source, textile wastewater diminishes seed germination of winter vegetables and also affects seedling growth (Rahman and Bhatti, 2009). In Pakistan, textile wastewater is a constant source of irrigation. Farmers voluntarily use these effluents due to the presence of some nutrients and ignore health consequences (Khan et al., 2011).

2.2. Dyes

The textile industry is one of the leading industries in Pakistan but it is very important to check environmental issues related to this industrial sector. This sector uses a huge amount of water and releases contaminated water in all of its processes including dying, washing, bleaching and washing of end products (Chisti, 2008; Shamshath Begum et al. 2015). Dyes are an important component of the textile sector that are used to produce different color combinations to meet the demands of fashion. Dyes can be direct, vat, disperse or reactive, while disperse and reactive dyes are most important in cotton textile industry because of their capability to produce brightness (Noreen et al., 2011). Most commonly used synthetic dyes are dispersed dyes that are used for dyeing polyester and nylon. In 2011, worldwide market of disperse dyes was about 570, 000 metric tons (UNSD, 2013).

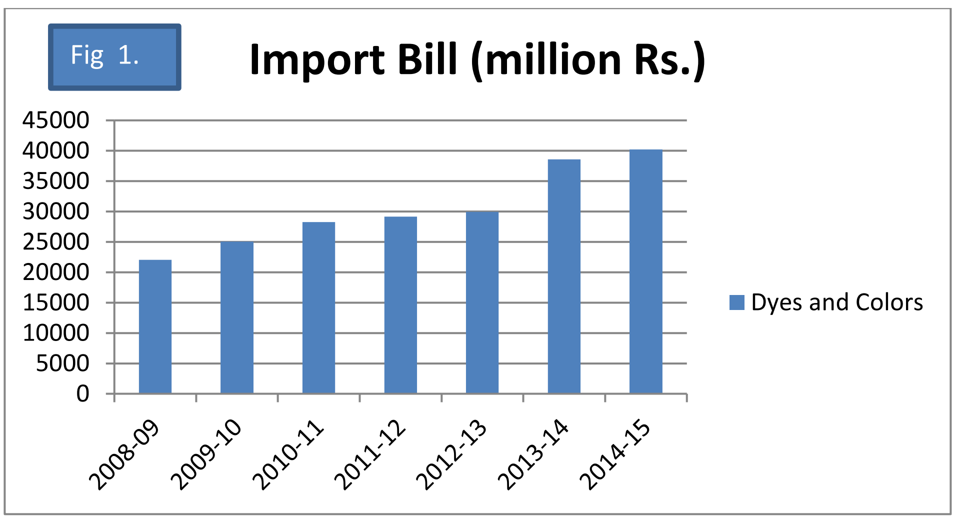


Figure 1 shows annual bill for import of dyes and colors. Graph shows continuous increase in import of dyes which reveal increased use of these dyes in country.

Source: Economic Survey of Pakistan 2015-16.

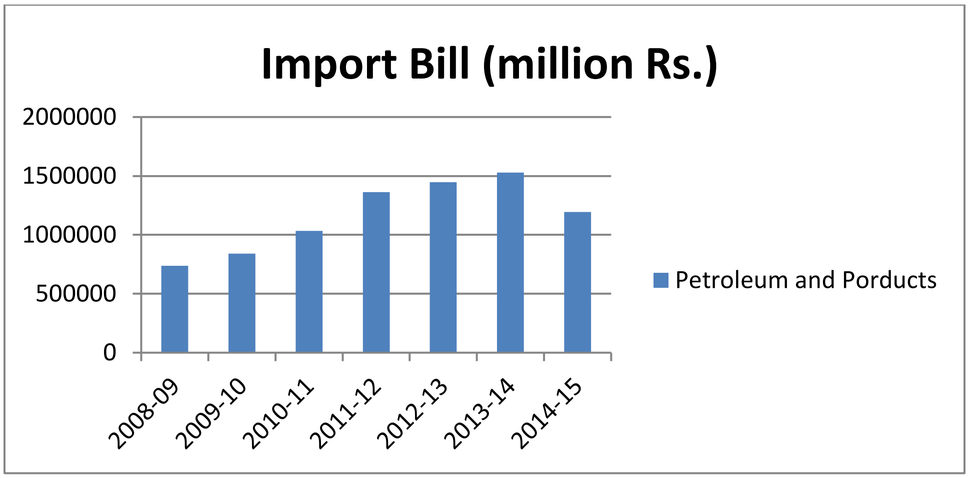
About 100,000 dyes are available commercially of which 50% are Azo dyes. Every year,the total amount of dyes produced is more than 1 million tons and two third of total production is used in textile industry (Singh & Arora, 2011). Azo dyes are the synthetic group of dyes having more than one chromophores, and thus are electron deficient and have sulphonic and azo electron withdrawing family, which creates the deficiency of electrons in molecules and make compounds more sensitive to oxidative degradation by microorganisms. These dyes have the tendency to persist for prolonged time in aerobic conditions (Riegar et al., 2002). Azo dyes have recalcitrant and toxic nature. That’s why, these are grouped as hazardous to the environment (Ulson et al., 2010) and metabolic intermediates of these synthetic dyes are carcinogenic and mutagenic in nature (Yang et al., 2013). Severe health consequences like nausea, skin ulceration and hemorrhagic fever could be the result of trace metals if present in drinking water (Ghaly et al., 2014). A large amount of dyes is lost in discharged wastewater because of having inefficient utilization process. Amount of dyes lost in wastewater depends upon class of dyes. Their amount in discharged effluents can be 2% in case of basic dyes, while 50% for reactive dyes (Wins and Murgan, 2010).

3. BIOFUEL PRODUCTION POTENTIAL OF MICROALGAE

3.1. Energy Fulfillments

Energy requirements can be fulfilled either by nonrenewable or renewable resources. But the issue with nonrenewable is that these are finite sources and have serious hits on the environment (Balat, 2010; Ulusarslan et al., 2009). The share of fossil fuel combustion in the total of carbon emissions is about 98% (Kirtay, 2009).

Pakistan has enormous reserves of renewable energy resources but country heavily relies on imported fossil fuels, which have 80% share in total energy supply. The one-sixth demand of energy is only fulfilled by the domestic dwelling of oil (GOP, 2006). In 2010-11, Pakistan's import of crude oil was 6.9milliontons, while of petroleum products was 12.4milliontons. Total cost for import of these two commodities was 10.46 billion dollars (GOP, 2011). If country cuts these huge energy sector expenditures by reducing dependency on imported energy sources, it can boost its economy by three folds. Indigenous sources of renewable energy will become cost effective and GHG emissions will be reduced as well (Anwar, 2016). Petro-diesel fuel can be replaced by a leading candidate biodiesel that is formed by mixing fatty acid alkyl esters and produced by the transesterification of oils with methanol or ethanol in the presence of the catalyst (Boro et al., 2011: Khan et al., 2015).



Source: Economic Survey of Pakistan 2015-16

Renewable energy could be the best alternative to finite oil resources. Renewable energy also has environment-friendly nature. Their share in total GHG emissions is very low if compared with fossil fuels (Dincer, 2008). Edible oils like sunflower, canola, Jatropha, palm, and soybean are mostly used for biofuel production (Singh & Singh, 2010) but microalgae can be the best replacement for fossil fuels because of its higher photosynthetic efficiency, exhausting non-renewable reserves, environment friendly nature, use of uncultivable lands, and its ability to grow on wastewater by using wide variety of nutrients (Sheehan et al., 1998). Microalgae's biofuel is third generation fuel that doesn't require the large area for cultivation and has an ability to entirely replace petroleum oil (Chisti, 2007). Microalgae are the best source of biomass for renewable oil production. There is a number of microalgae types that have a large amount of oil contents with cases exceeding 80% of the total dry mass of algae. Microalgae often termed as third generation biofuel have higher oil contents than first and second generation biofuels. It is most suitable in mitigation of climate change because it reduces the emission of fuel gas CO2 by using it for growth (Demirbas, 2010). Microalgae have fast growing capability due to the utilization of CO2 and having more oil content than any other source per acre. Peripheral lands can also be best sites for microalgal growth (Demirbas, 2009).

Microalgae have the ability to store lipids like higher plants and some species have the ability to store lipids greater than 60% of total dry mass (Sheehan et al., 1998). If higher oil containing species of microalgae are cultured under optimized conditions, their potential to yield oil per acre could be 19,000-57,000 liters that are about 200 times higher than any other source of biofuel (Chisti, 2007). About 47,000-3, 08,000 liters of oil could be produced per hectare from algal sources and per barrel cost would be 20 US $ (Demirbas, 2009). Cycle of algae takes 3 months to 3 years for completion and biomass starts production of oil after 3 to 5 days which can be collected on daily basis. Microalgae have ability to produce 50 times extra biomass than switch grass, which is rapidly growing earth plant (Li et al., 2011). To replace United States transportation fuel by 50%, estimates tell that 1540 M ha would be required for biofuel production in case of corn, 594 M ha for soybean and 43 M ha for microalgae biofuel (Wigmosta et al., 2011). Pakistan State Oil (PSO) Company is using gasoline with 10% mixing of bioethanol that is domestically produced from molasses, wood and paper waste. About 2 M tons of molasses is processed annually with production of about 40,000 tons (Fizza et al., 2011).

Microalgae mass cultivation, called "controlled eutrophication process", should be managed carely by providing adequate air supply and it's harvesting at regular intervals (Kamilli et al., 2013) but eutrophication can be a serious risk for biodiversity. Dead cells of algal biomass use dissolved oxygen causing asphyxiation of organisms that depend on dissolved oxygen. Eutrophication also results in turbidity and hypoxia, which leads to reduction of biodiversity (Handler et al., 2012).

3.2. Wastewater treatment potential

Worldwide, about 75% of total sewage generated is discharged into water bodies without any treatment which poses serious threats to health and environment (WWDR-4, 2012).Due to inefficient use of dyes in the textile industry, a major portion of dyes is discharged directly to the environment. Very small quantity of dyes, even for some dyes smaller than 1mg/l, if present in discharged wastewater can build color resulting in lower aesthetic quality and transparency (Kangwansupamonkon et al., 2010). Presence of synthetic dyes decreases penetration of light to water body resulting in the decreased photosynthetic activity of flora and thus affects food source of aquatic life. Dissolved oxygen value decreased with high BOD effects aquatic fauna (Annuar et al., 2009). In such cases, microalgae spread efficiently and accumulate metals and nutrients leading towards economical and suitable wastewater treatment (de-Bashan and Bashan, 2010).To grow algae on larger scale, domestic and industrial wastewater can be the best source because it provides water and essential nutrients at very low cost (Usher et al., 2014). There are several microalgae strains that have ability to grow in wastewater because they have the capability of efficiently using N, P and organic Carbon. Wastewater treatment by algal strains is encouraged. The capability of microalgae to grow effectively in high nutrient environment and its ability to accumulate metals and nutrients efficiently assists in cheaper and sustainable wastewater treatment (de-Bashan and Bashan, 2010).
Chlorella pyrenoidosa is most favorable in decolorizing of azo dyes water. In no-nitrogen nutrient conditions, efficiency to decolorize was higher than in no-carbon situation (Hong-wen et al., 1999). El-Sheekh et al. (2009) checked the decolorizing efficiency of Lyngbyalagerlerimi, chlorella vulgaris, Elkatothrixviridis, Nostoclincki and Volvoxaureus for Methyl red, G-Red and Orange II. Their efficiency to remove color varied greatly from 4-95% depending upon dye structure and growth state. Mohan et al. (2002) explained that Spirogyra sp. is a potent biomaterial for phyco-remediation of azo dye (Reactive Yellow 22). Scendesmus have the ability to accumulate about 97% of nickel from wastewater within only 5 minutes. If a water source has 30mg of nickel and 30 mg of zinc, algae can accumulate these metals in 5 minutes of treatment onset (Chong et al., 2000). Nutrient uptake by microalgae has reduced the cost of wastewater treatment. A study from Taiwanese researcher reveals that 33% of P removal while 100% removal of N can be achieved by *Chlamydomonas* sp. (Wu et al., 2012).*Chlorella* sp. has the ability to remove ammonia, N, total P and COD only in 14 days (Li et al., 2011).

A water footprint can be defined as the total requirement of water for the production of goods and services (Guieysse et al., 2013). Water footprint for biofuel production from microalgae in a closed photobioreactor is lower when compared with other biofuel sources like soya, palm or sugarcane. The reason is that microalgae show higher growth rates in wastewater and seawater. That's why biofuel production from microalgae, grown on wastewater, can lead towards greater sustainability because of economical and environmentally friendly production nature (Yang et al., 2011).

3.3. CO_2 Sequestration Potential

C- Emissions in last 50 years have risen dramatically and still continue at the rate of 3% annual increase (Pires *et al.*, 2012). CO_2 emissions by combusting fossil fuel will be lifted to 39% by 2030 (Mofijur et al., 2012).In 2014, total emissions were 6870 MMT (Million Metric Tons) of CO_2 eq. and their share in GHG emissions worldwide was 81% (Wilbanks and Fernandez, 2014). There will be an increase in the use of fossil fuels with an increase in population as well as the increase in per capita GDP. The results will be increased CO_2 concentration that leads to GHGs based climate change (Parry, 2007). Many countries of the world including neighboring countries of Pakistan are successfully involved in generating energy from biomass sources but our country is far behind in using its own biomass resources to get rid of energy crisis (Zuberi et al., 2015) as well as to decrease GHG emissions.

For capturing CO_2, several approaches have been developed. These approaches include physical techniques (Biochar), Chemical (mineral carbonization), and biological techniques like CO_2sequestration by microorganisms during photosynthesis (Grover et al., 2015; Leung et al., 2014, Udhaya Sankar, 2017). United Nations technical agencies have developed methods of calculating tons of CO2 sequestered. For example, 3.5 tons of CO_2 emissions decreased with the replacement of about 1 ton of diesel. 12 tons of CO_2 is sequestered per year in 1ha of eucalyptus (Soares et al., 2013). Algae can be the potential sink for removing atmospheric CO_2. Algae have the ability to sequester CO_2 very efficiently and are responsible for sequestering 40% of total C-Sequestration (Falkowski et al., 1998). Total algal mass comprised of only 2% of global C but have a role in sequestering 30–50 billion tons per year and generate organic matter (IEA, 2010). Algae have the capability of sequestering CO_2 one to two times higher than terrestrial species (Wang et al., 2008). Higher oxygen contents in bioethanol provide less emission of gases when combusted with gasoline, and thus leads to cleaner burning (Rodolfi et al., 2009). Some algal species have the ability to double biomass only in 6 hours, while some species lend two doublings in a day (Huesemann et al., 2009).

Microalgae could be the best approach for CO_2biosequestration because it uses CO_2 in photosynthesis (Cheah et al., 2015). They have microscopic nature and use atmospheric CO_2 for production of biomass (Zeng et al., 2012). Microalgae has an extensive share in organic matter production. They produce about 40% of total 2×10^{11} tons annum^{-1} with use of about 40% of total photosynthetically fixed CO_2 out of 8×10^{10} tons (Ravishankar & Sarada, 2007). One hectare of microalgae has annual ability to store 500 tons of CO2 to produce biomass that is excellent storage body (Bilanovic et al., 2016), while for 1-ton woody or nonwoody biomass, about 1.1 to 1.8-ton CO2 is used in photosynthesis. Once used in biomass production, it will not be able to acidify water like atmospheric CO_2 does (Vandenbroucke & Largeau, 2007). Microalgae are capable of sequestering industrial flue CO_2 and also have the potential of using CO2 from soluble $NaHCO_3$ and Na_2CO_3 (Wang *et al*., 2008).

GHG and total energy balances should be calculated from Wells to Wheels to check the efficiency of biofuels. If compared with gasoline, cars with E85 ratio fuel (ethanol 85%: Gasoline 15%) could save 68% fossil fuels with 60% decrease in GHGs and SO_2 reduced to 39-43% (Wu et al., 2006). Research reveals that the different algal species show different response to CO_2 concentration level. Chlorella sp. and T. suecica show different growth responses to the elevated level of CO_2, which depends upon tolerance and adaptability characteristics. T. suecica is able to grow in higher CO_2 levels and is the best source for CO_2 capture but both microalgae can be used for bio-fixation source of CO_2 for cleaner and sustainable approach (Kassim & Meng, 2017).

4. ADVANCES IN GENETIC ENGINEERING APPROACHES FOR ALGAL BIOFUEL

There are several challenges to replace fossil fuels with economical biofuels. These challenges include harvesting, biomass expansion and extraction of oils, and these can be ensured by genetic and molecular techniques to produce algae based fuels that will be economically favorable (Gimpel et al., 2013). Genetic engineering currently has gained intensive research efforts on the global level with aim of modification and enhancing storage of HCs, lipids and other compounds that can store energy in organisms with photosynthetic nature (Radakovits et al., 2010). Genetic engineering can be used for manipulation of enzymes that play role in oil production, hence increasing oil contents (Benson et al., 2008).

Some organisms may have one or few of desired traits. Engineering techniques can be used to manipulate a single strain that will be viable in terms of economics and production (Hennon et al., 2010). Suppose, a variety among present species has the ability to grow 0.3g/l in a day with oil contents of about 40%, then resulting cost will be $310/barrel. By using breeding techniques with molecular genetics to produce optimized strains, oil contents can be enhanced to an optimum level (Alabi et al., 2009).

Metabolic and Genetic engineering techniques can be used for enhancing microalgae productivity (Chistiy, 2008). These two techniques are best choices for better biofuel production due to low cost and these can be best sources of economic improvements in microalgae based biofuels (Dunahay et al., 1996). Genetic engineering may help in enhancing lipid contents by cutting synthesis of starch. This method is very important in increasing overall lipid level in algae (Spalding et al., 2010). Metabolic engineering can be a powerful tool for improving cellular phenotype capabilities (Stephanopoulos, 2007). Metabolic engineering helps in enhancing precursor availability by using upstream genes and produce over expression. Higher Precursor amount can also be achieved by cutting down competitive pathways. Higher concentration of precursor leads the reaction favorably and also produces required products in large quantity (Atsumi, 2008). Molecular engineering has potential to enhance biomass production by triggering photosynthetic activity, more oil content, decreased photo inhibition and reinforced tolerance of temperature (Nazari & Raheb, 2015).

To produce desired strains of algae, other algal genomes can be manipulated by using genetic tools (Cuff & Young, 1980). More than about 30 strains of microalgae have been modified by genetic engineering techniques (Eichler-Stahlberg et al., 2009). First time in 1994, manipulation of desired character gene in diatom algae *Cyclotellacryptica* was done with help of protoplast and results were productive (Gautam et al., 2015). Modifications in algal strains will result in more lipid content. Genetic engineering helped to enhance lipid secretion level to 133mg/l per day (Liu et al., 2009). Lipid biosynthesis could be manipulated in microalgae by using genetic engineering techniques (Nazari & Raheb, 2015). Enzymes could be used for creating over expression with aim of enhancing lipid content (Siloto et al., 2009). And lipid synthesis in the result of over expression will affect proliferation of microalgae (Quinn &Merchant, 1995). Complexities of regulation of lipids have been further discussed in detail and modifications in lipid metabolism have also been upgraded (Weselake et al., 2009). Gasoline fuel has higher energy and better storage property than ethanol fuel. Gasoline and longer chain alcohols both have higher energy densities. Now genetic engineering has helped scientists towards the development of C3-C8 alcohols that can be transported and stored easily (Hanai et al., 2007). Yeast cells have the capability to accumulate intracellular fatty acids to high concentration with manipulating fatty acid enhancers. Yeast then secretes free fatty acids. Reproducing microalgae also have the potential of these kinds of secretions and positive results have been achieved in Cyanobacteria by using synthetic genomes (Roessler et al., 2009; Gupta, 2016).

5. MICROALGAE PRODUCTS AND BY PRODUCTS

Microalgae are worthy photosynthetic creatures with many products, coproducts and applications. These provide a source of food to all trophic levels by fixing atmospheric carbon into organic substances and thus help in managing food web. The only biofuel from microalgae couldn't be economical due to high production cost. Recent advances in engineering techniques in the production of products and byproducts from residue are best approaches for improving the economics of microalgae biofuel.

One possible solution for economical biofuel from microalgae is to use all constituents. Microalgae comprise 70% of lipids and carbohydrates, with several uses like bio-hydrogen, bio-methane, plastics, nutrients and animal feed (Rizwan et al., 2015). Valuable substances can be collected from microalgae because of their biosynthesizing capacity (Christaki et al., 2011). These substances help in economical biofuel production and prove favorable to replace fossil fuel (Hannon et al., 2010).

5.1. Food Source

Microalgae products can be the source of food for humans and animals, with use in environmental protection, pharmaceutical and cosmetics (Christaki et al., 2011). Microalgal bioproducts are used as fish pigments, food supplements and in infants feed because of having more advantages and effectiveness of synthetic products (Spolaore et al., 2006). Nowadays, approximately 30% algal products worldwide are used as nutritional source for animals because of high-value proteins (Becker, 2007).

Blue green algae, photosynthetic prokaryotes, have shared in the food supply to humans because of having vitamins, proteins (Singh et al., 2005). Chlorella and Spirulina (Arthrospira) can be widely used as a food source due to their biological actions and constituents (Pulz & Gross, 2004).

Some microalgal species have more valuable proteins, better than vegetable proteins. Peptides, pigments, vitamins, and trace elements are also present in microalgae (Das et al., 2015). These protein contents have more quality value as compared to other protein sources like legumes, wheat, and rice but can't replace animal source protein like milk and meat (Teresa et al., 2010). Microalgal biomass can be added to pasta, candies, bread, yogurt, biscuits and soft drinks. Digestive tract functioning can be maintained by Spirulina if added in foods, which helps in stimulation of lactobacilli species. I. galbana is a source of fatty acids mainly EPA and DHA (Brennan & Owende, 2010).

Many products including nutrients and metabolites, which are good for both humans and animals, come from microalgae (Jin et al., 2003). Carotenoids, vitamin, pigments, antioxidants, and polyunsaturated fatty acids are important secondary bioproducts which form under stress conditions like high salinity and temperature in microalgal cells (Priyadarshani & Rath, 2012; Mata et al. 2010). Carotenoid, an orange pigment, is used widely as a food colorant and also a precursor for Vitamin A. (Ben-Amotz, 2004). B-carotene which is the main carotenoid of D. Salina microalgae can be used in cheese and butter (Spolaore et al. 2006).

5.2. Role in Health

Different types of sterols, such as clionasterol, are present in microalgae. It helps in the formation of plasminogen that plays role in activation of endothelial cells, leading to prevention of cardiovascular disease. Extracts from Chlorella species have many health benefits such as increasing hemoglobin level and lowering blood sugar. They also have a role in malnutrition and intoxication of ethionine by acting as hypocholesterolemic and hepatoprotective (Barrow & Shahidi, 2007). Spirulina is helpful against cancer and viral infections by triggering immune systems. Its use in human feed helps to maintain bacteria in GI (gastrointestinal) tract and results in hormonal balance (Barrow & Shahidi, 2008). Several compounds of microalgae help in protection from oxidative stress which can cause a broad range of diseases (Teresa et al., 2010).

Consumer demand for natural and sustainable products has increased due to over use of chemicals in cosmetics. To fulfill their demand, microalgal derived products can be better source because of their immune response and can be used as coloring pigment in cosmetics (Koller et al., 2014; Wang et al., 2015). These natural antioxidants have more bioavailability and provide safer effects than synthetic products (Gouveia et al. 2008).

Microalgal biomass is also widely used in pharmaceutical manufacturing (Spolaore et al., 2006). Microalgae have 0.5–1.5% dry matter of Chlorophyll and can be extensively used in pharmaceuticals due to wound healing and anti-inflammatory properties, besides controlling Ca oxalate (Ferruzi and Blakeslee 2007). Astaxanthin and b-carotenoids act as strong antioxidants and play role in protecting cells from free radicals, and have more powerful results than Vitamin E but less powerful than man-made antioxidants butylated-hydroxyanisole (Natrah et al. 2007). Blue green algae are the source of many chemicals and bioactive substances. These reasons have focused scientist towards cyanobacterial genetics. These creatures play role as antiviral, anti-HIV, anti-tumor while also provide useful food additives (Singh et al., 2005).

5.3. Co-Products

Net energy required(NER) in biomass production is 2 times more than the net energy required in process of biofuel production from biomass but residues can help in balancing energy in this whole process. Many co-products like expensive cosmetics and proteins help in cost-effectiveness. Microalgae residues can also be used for biogas and bioethanol production, with the major production of biodiesel. Glycerol chemical is expensive and has much commercial use as a by-product of microalgal biofuel (Burton et al., 2009). Crude glycerol is the main by-product during biodiesel production. About 1.05 pounds glycerol is produced from 1gallon biodiesel production. It means if a plant has an annual capacity of 30 million gallons, 11,500 tons glycerol will be produced as a by-product with 99.9% purity. Projected biodiesel production by 2016 was 37 billion gallons with the production of crude glycerol gallons to about 4 billion (Yang et al 2012).

Co-products can help in the production of economical bio-oils by saving energy in the overall process (Zhu, 2014). Microalgae, a green gold, help in the production of biopolymers (a valuable coproduct) (Waltz, 2009). Carotenoids such as lutein, zeaxanthin, lycopene, bixin, b-carotene and astaxanthin and long-chain polyunsaturated fatty acids are coproducts of microalgae (Jin et al., 2003).

6. MERITS AND DEMERITS OF MICROALGAE BASED BIOFUEL

6.1. Merits

1- Microalgae can be grown in a very short period with the high amount of oil.
2- Can be the best source of biogas and biodiesel.
3- Marshy areas and wastewater are best places for cultivation (Wang, 2013).
4- Algae based biofuels have no toxicity.
5- Bio-degradable
6- Able to capture CO_2 where grown (Green et al., 1996).
7- Algal crude has same chemical nature as fossil fuel and already installed refineries by petroleum companies can refine it to usable fuels (Maher & Bressler, 2007).
8- Some microalgae have the capability of growing under utmost conditions that do not suit too many contaminants. For example, *Dunaliellasalina* and *Arthrospira* possess the ability to defy 35% of salinity and pH of 10 (Matsudo et al., 2008).
9- Due to greater protein content and composition of amino acids, microalgae can be used to meet nutritional requirements of animals and humans. Cyanobacteria *Arthrospira constitutes 60-70%* of dry protein and is being used as supplements for food (Becker, 2004).

6.2. Demerits

1- The massive difference between production cost and biofuel value makes it unsuitable.
2- Market acceptance is unclear (Wang, 2013).
3- Biodiesel produced has unstable nature because of having many polyunsaturates.
4- Microalgae biodiesel performance is poor if compared with fossil fuel (Green et al., 1996).
5- Free concentration of CO_2 is low that is required for higher algal growth and algae grazers are ignored (Schenk et al., 2008).
6- For gasoline from algal oil, the improved catalyst is required (Maher & Bressler, 2007).
7- Contamination is an issue in microalgae cultivation and can potentially result in loss of products (Matsudo et al., 2008).
8- Lignocellulose generates inhibitors that restrain enzyme hydrolysis and fermentation process in biofuel production (Kim et al., 2011).

7. CONCLUSION

The world is facing serious challenges due to climate change the main reason of fossil fuel burning in transportation and energy production. Microalgae have potential to replace fossil fuel use in energy production and transportation and can play important role in climate change mitigation. Microalgae have high contents of oil than any other biofuel source and can be grown on uncultivable lands. It's cultivation on textile industry wastewater show fastest growth rates and can provide larger amounts of renewable fuels, products, and coproducts with the cheaper treatment of textile effluents.

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