https://doi.org/ 10.48047/AFJBS.6.7.2024.1746-1784

AFJBS African Journal of Biological Sciences
Journal homepage: http://www.afjbs.com
Research Paper Open Access

Green Technology Strategy for Bioremediation of Dairy Effluent for Production of Lipid Byproducts

Nisha Dhillon, Vivek Kumar, Geeta Bhandari & Sanjay Gupta*

Himalayan School of Biosciences, Swami Rama Himalayan University, Jolly Grant, Dehradun, Uttarakhand, 248140, India

Article History

Volume 6,Issue 7, 2024

Received: 29 Mar 2024

Accepted : 22 May 2024

doi: 10.48047/AF5BS.6.7. 2024. 1746-1784

Abstract

Considerable research endavors are currently in progress exploring Using different types of microalgae for purifying dairy wastewate, aiming to contribute to the waste-to-bioproducts economy. Numerous studies have primarily concentrated on removing essential nutrients such as phosphorus and nitrogen from dairy wastewater through microalgae-based treatment methods. Microalgae exhibit a dual functionality, serving both as effective bioremediation and prolific producers of valuable components including lipids, proteins, pigments, antioxidants, and vitamins. Among these compounds, microalgal lipids are versatile in applications across human health, nutraceuticals, cosmetics, pharmaceuticals, and biofuels. This current review hunts into the pivotal role of microalgae in offering a promising solution for dairy effluent treatment, while also serving as a nutrient reservoir for production of biomass and the accumulation of lipids, such as polyunsaturated fatty acids (PUFAs), carotenoids (pigments), and oxylipins (oxygenated PUFAs). These accumulated compounds hold substantial potential for the production of biodiesel and other commercially viable products. The advancement of technologies related to biohydrogen production, systems biology, and algal trans genomics is advocated for a comprehensive approach towards sustainable development in this domain.

Keywords: Dairy effluent; lipid by-products, microalgae, Phytoremediation

INTRODUCTION

Water stands as the paramount natural resource crucial for the ongoing survival of every species. Water that is clean and free of toxins is essential for a prosperous life. Our dairy industry's growth contributes significantly to water contamination and adversely impacts water bodies by releasing significant amounts of pollutants into the water. (Kolev salalov 2017; Qadir et al.2020; Gramegna et al. 2020; Ummalyma et al. 2021). By introducing toxins into the food chain, untreated wastewater further damages the ecology and has a detrimental effect on the survival of living things. Consequently, for a sustainable environment, wastewater management and treatment are essential. One of the major contributors of wastewater is the industry of dairy products. Milk is regarded as the most significant source of nutrients needed by the body and one of the main food elements in the world. Water is the primary ingredient utilised in the dairy industry to produce milk products, which generates large volumes of wastewater, making disposal a difficulty that cannot be disregarded (Swain et al., 2020). According to reports, the dairy sector produces 2 to 10 L of waste water for every litre of milk processed (Ummalyma and Sukumaran, 2014; Ragunath et al.2016; Daneshvar et al. 2019; Pang et al. 2020; Gramegna et al. 2020; Kusmayadi et al., 2022).

The loss of dissolved oxygen is one of the major issues brought on by raw dairy wastewater discharged directly into the environment. Because dairy effluents are high in oil and fat molecules, they form a thin layer on the water's surface that prevents oxygen from getting to the water's surface, making it difficult for the local flora and wildlife to survive. (Karadag et al. 2015; Choi 2016; Sharma et al. 2022).

Additionally, the majority of the whey production is discarded without being properly treated, in many cases due to an increasing cost for its treatment and disposal operations which leads to an excessive financial burden (Choi 2016; Gramegna et al.2020).

A stream with significant qualitative and quantitative fluctuations results (Porwal et al. 2015; Choi 2016; Panday, Srivastava & Kumar. 2019; Ummalyma et al.2022). Despite the compositional variations, dairy effluents are characterised by a significantly higher temperature. Dairy wastewaters are treated using mechanical, physicochemical, and biological techniques. To balance variations in both volumetric and mass flow, mechanical treatment is required. Additionally, some of the suspended particles are reduced. While emulsified compound removal can be accomplished with physicochemical procedures

(Kothari et al. 2011; Kolev Slavov, 2017; Swain et al. 2020). The highly biodegradable pollutants make biological wastewater treatment systems the preferred method. Employment of microalgae for remediating the dairy waste water results in decontamination of dairy effluent along with mass cultivation of microalgae (Gani et al. 2016; Choi, Jang & Kan. 2018; Kawamura et al. 2018; Sirohi et al. 2021a, 2021b; Joun et al. 2021; Ummalyma 2021; Ummalyma et al. 2022). Mass cultivated microalgae are harvested for lipids produced which are utilized in diverse industrial applications (Nguyan et al. 2022). This review focuses on various environmentally-friendly green technologies to recover lipids from microalgae using dairy wastewater as growth medium.

DAIRY INDUSTRY

The dairy sector holds significant importance in the Indian economy, offering substantial employment opportunities, and continues to expand steadily. Despite being a major source of wastewater, dairy industries contribute positively to the economic growth of the nation. India, as per FAO (2020), holds the title of the world's leading milk producer, contributing 22% to global milk production, followed by the USA and Pakistan. However, dairy operations globally leave a considerable environmental footprint, consuming substantial amounts of water, estimated at approximately three liters per liter of milk produced (Porwal et al., 2016). The production and consumption of dairy products, particularly milk, have been steadily increasing, with a projected global consumption rise of 13.7% by 2023 (Choi 2016).

Types of waste generated during the processing of dairy products

The wastewater discharged from dairy operations poses a substantial environmental hazard. These effluents typically contain suspended solids and organic matter, along with heightened levels of nitrogen and phosphorus. Additionally, they often contain oil, fat, and grease compounds. Furthermore, residues from the cleaning products utilized in utensil and equipment washing can also be present, (Kushwaha, Srivastava & Mall. 2011; Ahmad. 2014; Kolev Slavov. 2017; Chandra et al. 2021). According to their origin and composition, dairy effluents can be categorized into the following three types; a) processing water, b) cleaning wastewater and c) sanitary wastewater.

Processing water: Condensates resulting from milk or whey evaporation, along with the cooling process in specialized coolers and condensers, yield processing water. While evaporators may introduce milk or whey droplets, the vapor produced during milk and whey drying, upon condensation, generates the purest effluent. Generally, processing waters exhibit minimal contaminants and can be recycled or discharged alongside stormwater following basic pre-treatment measures. (Kolev Slavov. 2017).

Cleaning wastewater*:* This effluent typically originates from washing machinery that comes into touch with milk or other dairy products, such as tanker washing, refrigeration points, floor washing, boiler houses, etc. spills of milk and whey, mistakes in operation, and broken equipment are all included. More than 90% of the organic solids found in effluents consist of cheese particles, whey, cream, separated water, starter cultures, yogurt, fruit concentrates, and stabilizers. These effluents must undergo additional treatment because they are produced in large amounts and are highly contaminated (Carvalho, Prazeres & Rivas. 2013; Karadag et al. 2015).

Sanitary wastewater*:* The sanitary wastewater is produced in restrooms, showers, etc. And is typically piped directly to sewage works and shares a similar composition to municipal wastewater. Prior to further aerobic treatment and can be employed as a source of nitrogen for imbalanced effluents of dairy. Dairy product processing results in a huge amount of chemically modified liquid waste which needs proper treatment before discharge (Slavov 2017; These waste materials can be efficiently repurposed as raw materials for manufacturing other industrial goods or for generating energy. (Tan et al. 2018; Chandra et al., 2021).

Components of dairy effluent

The dairy industry primarily produces liquid effluent during the processing of different useful products from whole milk like buttermilk, condensed cream, sweet whey, curd, cheese, butter, ice cream, etc. The distinguishing features of dairy wastewater might be varying according to the formation of final products. Generally, dairy effluents contain high concentrations of lipids such as triacylglycerides, phospholipids, saturated and unsaturated fatty acids, carbohydrates such as; lactose, glucose, galactose, etc. The dairy waste water also contains two major soluble proteins casein and whey protein etc., resulting in high BOD (biological oxygen demand) and COD (chemical oxygen demand) levels (Mehrotra et al., 2016; Patel et al., 2020). Its high BOD depletes the dissolved oxygen content and creates anaerobic conditions in the aquatic system. Moreover, dairy effluent contains various inorganic and organic compounds of nitrogen and phosphorus, present in higher concentration and responsible for the alkalinity of the dairy waste other than it also contain a trace amount of some mono-valent and bi-valent cations like Na, Mg, Ca, Fe, K, Ni, Mn, etc. Use of detergents and chlorine in the dairy industry further deteriorates the quality of effluent (Kushwaha, Srivastava & Mall. 2011; Ahmed 2014; Patel et al., 2020; Gramegna et al. 2020; Vidya et al.2021).

Dairy effluents are biologically active because of the presence of a high organic and inorganic load and when it is discharged into water streams either untreated or semi-treated leads to water pollution. Hence, the proper treatment before the disposal of dairy waste effluent has become a major problem for the vitality of the dairy industry and the environment. Various attempts have been already made to solve this problem by reusing the nutrients rich dairy waste with diverse microorganisms to metabolize organic matter.

Dairy effluents treatment approaches

Various technologies can be used for the processing of dairy waste prior to release into the natural habitat or surroundings. Dairy waste treatment is done in two ways:

Physico-chemical treatment: Several Physico-chemical methods are used for the treatment of dairy wastewater, such as chemical precipitation, coagulation, coagulation/flocculation, adsorption, electrocoagulation, electroflocculation, membrane bioreactor, combined electrode system, etc. There are various demerits regarding the use of physicochemical treatments such as its higher cost, and generating secondary pollutants, because chemical reagents were used and they only perform partial treatment (Kushwaha, Srivastava & Mall. 2011; Shete and Shinkar 2013; Slavov 2017; Patel et al., 2020; Gramegna et al. 2020; Vidya et al. 2021).

Biological treatment: In order to compensate for the negative aspects of physico-chemical approach, biological methods are a suitable alternative for the treatment of dairy wastes. These are eco-friendly, cost-effective, and highly efficient to remove the contaminants from dairy effluents (Kolev Slavov 2017; Gramegna et al. 2020). Microorganisms have been employed in biological treatment methods. Among these, the microalgae are well-known bioremediator because of their ability to grow photoautotropically and mixotrophically (Choi,2016; Chokshi et al. 2016; Guldhe et al. 2017; Ahmad et al. 2019; Gramegna et al. 2020; Goswami, Agrawal & Verma 2022; Encarnacao et al. 2022; Xing et al. 2022). Dairy wastewater contains high contents of phosphorus, nitrogen, and organic matter thus, the nutrient-rich dairy waste effluent proved to be a suitable medium for the growth of microalgae (Gonçalves et al. 2017; Gramegna et al. 2020; Vidya et al. 2021).

MICROALGAE

Microalgae are unicellular, eukaryotic microorganisms which include algae, dinoflagellates, diatoms, etc. They can exist independently as a single colony or in a consortium as a group. Microalgae are a broad group of aquatic organisms that have the efficiency and ability to remove pollutants and produce lipids with high biomass production (Kalra, Gaur & Goel, 2021; Calijuri et al. 2022; Bhatt et al. 2022; Devi et al. 2022 Jiang et al 2022). Table 1 shows the different microalgae, their photosynthetic pigments, and reserve food material with examples (Heimann and Huerlimann, 2015; Enamala et al., 2018; Kalra, Gaur & Goel, 2021; Calijuri et al. 2022; Bhatt et al. 2022; Devi et al. 2022 Jiang et al 2022).

Table: 1. Types of microalgae based on their pigment and reserve food

Class	**Photosynthetic pigments**	**Reserve food material**	**Representative Genera**
Chlorophyceae (Green algae)	Chlorophyll a, b, Carotene	Starch	*Chlorella sp., Heamatococcuspluvialis, Dunalialla salina*

Xanthophyceae (Heterokont or Yellow green algae)	Chlorophyll a, c, b-Carotene, Xanthophylls	Fats, leucosin	*Chlorochromonas, Chlorosuccus, Vaucheria, Tribonema, Botrydinum*
Chrysophyceae (Yellow-brown algae)	Chlorophyll a, b, Carotenoids	Oils and leucosin	*Ochromonas, Dinobryon,Mallormonas, Synura, Rhizochrysis*
Bacillariophyceae (Diatoms)	Cholorophyll a, c, Carotenes	Leucosin and Fats	*Cyclotella, Rutelaria, Corethron, Navicula,Bacillaria*
Cryptophyceae	Chlorophyll a, b-Carotenes, Xanthophylls	Starch	*Falcomonas,Rhinomonas,Plagioselis,Chilomonas,Cryptomonas*
Dinophyceae (Dinoflagellates)	Chlorophyll a, c Carotenoids, Xanthophylls	Starch and oil	*Dinophysis, Polykrikos, Gonyaulax, Gymnodinium*
Chloromonodiae (Raphidophytes)	Chlorophyll a, b Carotenes, Xanthophylls	Oils	*Vacuolaria*
Euglenophyceae (Phototrophic-euglenids)	Chlorophyll a, b	Fats and paramylon	*Euglena*
Phaeophyceae (Brown algae)	Chlorophyll a, Xanthophylls	Laminarin, mannitol and fats	*Pelagophycus, Laminaria, Pelvetia, Sargassum*
Rhodophyceae (Red algae)	Chlorophyll a, phycocyanin, phycoerythrin	Floridian starch	*Vacuolaria, Gomyostomum, Chattonella, Psammamonas*
Myxophyceae (Blue-green algae)	Chlorophyll a, b-carotene, c-Phycocyanin and phycoerythrin	Glycoproteins, droplets of oil	*Chloroccus, Darmocarpa, Pleurocaspa, Oscillatoria, Stigonema*

Dual role of microalgae

Microalgae present a hopeful biological solution for dairy wastewater treatment owing to their adaptable metabolism, capable of engaging in photoautotrophic, mixotrophic, or heterotrophic activities. Their capacity to utilize inorganic nitrogen and phosphorus renders microalgae an efficient option for tertiary and quaternary treatments of dairy waste. (Choi et al., 2018). This type of bioremediation/ phycoremediation coupled with the production of potentially valuable biomass, which can be used for several purposes. Earlier researches suggested that cultivation of microalgae for the production of lipid components from dairy waste, had provide better results than any other wastewater used as microalgae cultivation medium (Chandrabose et al., 2013; Hu et al., 2018; Panday, Srivastava & Kumar. 2019; Swain et al. 2020; Pang et al. 2020; Gramegna et al. 2020; Biswas et al. 2021).

Many microalgae cultures displayed high growth on the diluted effluents from dairy. Moreover, the microalgae have the ability to use solar energy for its photosynthetic activity and combine water with carbon dioxide in order to make their food autotrophically, further; it converts the environmental carbon di oxide to oxygen. Due to this ability of microalgae, they have been used to remediate the dairy waste as the nutrient sources for their growth, and to reduce the concentrations of nitrogen, phosphorus and other inorganic substances. It has been reported that the microalgae are the better source for manufacturing of bio-fuel due to its elevated photorespiration activity, and rapidly growing biomass activity Panday, Srivastava & Kumar. 2019; Gramegna et al. 2020).

The microalgae strain which contains large number of fatty acids, like polar and non-polar or neutral lipids, and also flourishing in the native domain of dairy waste effluent have yet to be used for bio-fuel production. Micro algal feedstock is one of the best medium for bio-fuel production and as a replacement source of fossil fuel and also proved beneficial to eradicate greenhouse gas emissions (Mwangi et al. 2015; Khan et al. 2018; Shokravi et al. 2019; Debowski et al. 2021).

Lipid producing microalgal strains: Numerous species of microalgae have been scrutinized for their fatty acid compositions, with approximately 20-50% of dry biomass comprising lipid constituents. Such as species of *Nannochloropsis*, *Neochloris*, *Chlorella*, *Dunaliella*, *Crypthecodinium*, *Chlamydomonas, Cylindrotheca*, *Isochrysis*, *Nannochloris, Nitzschia*, *Schizochytrium*, *Phaeodactylum*, *Porphyridium*, and *Tetraselmis*have been recognized for containing certain classes of polar and non-polar lipids. Nonpolar or neutral lipids like sterols, free fatty acids acylglycerols, etc. and polar lipids like glycoacylglycerides, phosphoglycerides, and sphingolipids have been reported in microalgae (Mata et al. 2010; Ghosh, Roy & Das. 2017; Chen et al.2018; Panday, Srivastava & Kumar. 2019; Swain et al. 2020).

Table 2: Some lipid containing micro-algal species

Sr. No	**Microalgae species**	**Lipid Content (% Dry Weight)**	**Reference**
1.	*Botryococcus braunii*	25–45%	Lee et al., 2015; Ferreira et al. 2019
2.	*Schizochytrium sp.*	30–60%	Sajjadi et al. 2018; Menegazzo & Fonseca. 2019
3.	*Neochloris oleoabundans*	25–44%	Breurer et al., 2012
4.	*Nannochloropsis sp.*	31–68%	Ma XN et al., 2016; Shokravi et al. 2020
5.	*Nitzschia sp.*	45–47%	Jiang et al., 2015
6.	*Chlorella sp.*	35-58%	Ghosh, Roy & Das. 2017; Mirizadeh et al. 2020
7.	*Scenedesmus sp.*	40-68%	Kumar et al., 2021
8.	*Chlococcum sp.*	40–67%	Mahapatra and Ramachandra., 2013
9.	*Cylindrotheca sp.*	20 -35%	Demirel et al., 2015
10.	*Dunaliella sp.*	36-47%	Gharajeh et al.,2020
11.	*Chlamydomonas reinharditi*	55- 65%	Xu et al., 2018; Yang et al, 2018; Hang et al. 2020,

12.	*Phaeodactylum triconutum*	18- 57%	Yang et al. 2017; Desmukh et al. 2019
13.	*Chlamydomonas sp.*	21-27%	Desmukh et al. 2019
14.	*Pavlova salina*	12-30%	Desmukh et al. 2019
15.	*Phorphyridium*	9-14%	Desmukh et al. 2019

Biosynthesis of lipid in microalgae

The green microalgae generally synthesis two categories of lipids as free fatty acids or neutral fatty acids and triacylglycerols. Neutral fatty acids are synthesized in chloroplast while triacylgylcerols are, in smooth endoplasmic reticulum.14–20 carbon chains fatty acids are utilized in the preparation of biofuel and long carbon chains of 20 or more carbons which employed in food industry (Jacob-Lopes et al. 2015; Ratomski & Hawrot- Paw 2021). Microalgae produce and store large amounts of lipids in the form of triacylglycerides as oil droplets in the various cell organelles. The conversion and accumulation of lipid content, varies according to cultural conditions and microalgal strains (Bellou et al. 2014; Yang et al, 2017; Konget et al. 2019; Nayak et al. 2019; Grijalva et al 2020; Abomohra et al 2020; Udayan et al. 2022; Rawat et al. 2022). Biosynthesis of lipid in microalgae depends upon the production of carbon compounds by the process of photosynthesis. It includes light dependent reactions and light independent reactions also. In light dependent reactions oxygen, ATP and NAD(P)H are produced while in light independent reactions (Calvin cycle), a three-carbon compound (glyceraldehyde-3-phosphate) is produced, which is converted into acetyl CoA via glycolysis. This acetyl CoA is a major substrate for biosynthesis of lipid and precursors for proteins, nucleic acids, carotenoid and carbohydrates etc. The transformation of acetyl CoA to malonyl CoA is the first confide path in biosynthesis of lipids (Lv et al., 2010; Griffiths, Dicks and Richardson. 2011; Goldberg, 2016; Mimouni et al. 2018; Dolganyuk et al. 2020; Chen & Wang 2021). Many factors which are responsible for the accumulation of lipids inside the cells, such as availability of nutrients (mainly nitrogen, phosphorus and silica), temperature, salinity, pH, light, humidity and enzymes are mainly responsible for metabolic reactions (Han et al. 2012; Bartley et al. 2013; Lin & Wu, 2015; Sun et al. 2017; Chen et al. 2017; Chen & Jiang. 2017; Gao et al. 2021).

There are various strains of microalgae (*Chlamydomonas, Chlorella* sp. etc.) which have been employed as an experimental design to examine its anabolic and catabolic activities and functions (Scaife et al 2015). Genomes of *Chlamydomonas reinhardtii* have been sequenced and its molecular and genomic tools is also available. It can also accumulate considerable amount of triacylglycerols under salt stress or nitrogen deprived conditions (Li et al., 2010; Dean et al., 2010; Siaut et al., 2011; James et al., 2011; Fan et al., 2012; Msanne et al., 2012; Lei et al. 2012; Bartley et al. 2013; Liang et al. 2013; Li et al. 2014; Viegas et al. 2015; Sibi et al.2016; Juppner et al. 2017; Lei et al. 2018; Gifuni et al. 2019; Sulochana & Arumugam 2020; Hang et al 2020; Shokravi et al. 2020). Micro algal species collected from the dairy waste indicated great prospective for low-cost cultivation and producing lipid utilizing dairy waste, without modifying the procedure. It was reported that the *Chlorella* sp. isolated from the dairy waste water showed good biomass production when grown on dairy effluent, reduced its COD, and nutrients (Wang et al. 2010; Choi et al., 2018). This microalga was identified by using 18S rDNA sequencing, and the DNA sequences were analyzed via BLAST representing the high homology with *Chlorella* sp. ArMoo29B (98% homology).
Microalgae *Chlorella protothecoides* displayed good growth in a pre-treated whey solution. Since the use of microalgae approach alone was not sufficient for satisfactory removal of pollutants, therefore using hydrolysis and flocculation-struvite methods, the treated whey with 25:75 dilutions exhibited sufficient pollutants removal by designing biochemical approach. Using this approach, approximately up to 99% or 91–100% lessening of inorganic and organic contaminants was attained after nine days of cultivation of microalgae (Patel et al. 2020). In the similar study, reported that freshwater green microalgae *Chlorella* sp., UMACC344 was able to produce higher lipid amount in dairy waste, which could be utilized as potential biofuel.

In another study, *Chlorella* sp. isolated and cultivated in dairy wastewater, resulted in higher algal biomass production along with good amount of lipid production, the microalgae reduced BOD and COD, trace elements and other nutrients, thereby remediated dairy waste water (Choi et al., 2018; Hu et al. 2019). In another study, the dairy effluent supported the growth of *Chlorella vulgaris* and *Anabaena ambigua*, with significant lipid, carbohydrates, protein productivity. The lipid and carbohydrate content were higher in *Chlorella vulgaris* compared to *Anabaena ambigua*, which exhibited high protein content. A significant decrease in both COD and BOD along with other nutrients was also observed (Ahmad, 2014; Rani et al. 2015; Kolev Slavov, 2017; Ummalyma et al 2022)

Chlorococcum sp. RAP13 grown in dairy effluent produced great amount of biological mass and lipids, particularly under heterotrophic growth conditions. Lipid production and biomass increased expressively under heterotrophic cultural conditions. Higher amount of lipid production by these micro algae makes it a suitable candidate for biodiesel production. Moreover, use of dairy effluent as a source of energy and carbon by micro algae remediated the effluent in terms of BOD and COD (Ummalyma & Sukumaran, 2014).

Kothari et al. (2013) cultivated *Chlamydomonas polypyrenoideum* on dairy wastewater, which resulted in considerable lessening of nitrogen (90%) and phosphate (96%) on 10^{th} and 15^{th} day respectively. Biomass of microalgae after 10^{th} day treatment exhibited 42% (w/w) lipid contents, which was analogous to the bio-oil extracted from other natural resources as per FTIR results analysis. These outcomes proposed the possible usage of microalgae for biodiesel production as well as phyco-remediation of the dairy wastewater (Sharma et al 2022).

The following section discusses the role of micro-algae in diverse fields, where lipids produced by microalgae employed in commercial products.

Applications of microalgal lipids

Microalgae are rich in lipids, high density lipoproteins, oxylipins, carotenoids, proteins and carbohydrates etc. (Pohl & Kock. 2014; Santosh, Dhandapani, & Hemalatha. 2016; Bošnjaković and Sinaga 2020; Randhir et al. 2020). Many micro algal strains are able to synthesize the long chain fatty acids, with yields between 25 to 75% of their total lipids. Many fresh water microalgae such as *Chlorella* sp., and *Scenedesmus* sp. etc. and seawater microalgae *Thraustochytriacea* sp. and *Crythecodiniacea* sp. are currently used for the production of PUFAs (Udayan et al. 2021).

Microalgae strains have incredible adaptability to survive in extreme environmental conditions, and also have the huge potential for producing several advantageous by-products. Nowadays, the micro algal species are considered as lipid biofactories because of producing various kinds of lipids with remarkable applications in various fields such as in food and feed manufacturing industries, biofuel production, cosmetics, and pharmaceuticals etc. (Nascimento et al. 2013; Matos et al. 2017; Hess et al. 2018; Bhalamurugan et al. 2018; Maltsev & Maltseva 2021; Devadasu & Subramanyam 2021; Liu et al. 2022; Kuravi et al. 2022).

Food and nutrition field: Polyunsaturated fatty acids (PUFAs) have been known for its contribution in the field of human health benefits. Earlier, the major sources of polyunsaturated fatty acids were fish oil. But in the current scenario, the commercial production of PUFA from fish sources, are declined due to some limitations (fish population and diversity threatening and environmental hazards). Recently microalgae investigated for the production of oils or fatty acids which contain high amount of polyunsaturated fatty acids (EPA and DHA) (Winwood. 2013). Now days these are employed in the food industry, on a large scale. Various strains of microalgae are able to amalgamate various series of the PUFAs like1-6 series, which contains linoleic acid (LA), and arachidonic acid (ARA), and as well as of the PUFAs 1-3 series, containg linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) (Minhas et al., 2016; García, Vicente and Galan 2017; Camacho, Macedo & Malcata 2019; Koyande et al. 2019; Vieira et al. 2020). These fatty acids are having one or more double bond in their carbon skeleton. They have important ingredients for food and feed supplements, with many healthful benefits. The most common species of microalgae which are exploited in lipids production are *Schizochytrium sp., Scenedesmus sp., Arthrospira platensis, Ulkenia, Haematococcus pluvialis, Isochrysis galbana, Chlorella vulgaris, Chlorella pyrenoidosa, Chlorella ellipsoidea, Tetraselmis sp Dunaliella salina and Crypthecodinium.* (Xia et al. 2013; Park et al. 2018; Enamala et al. 2018; Costa et al. 2019; Gramegna et al. 2020; Mirizadeh et al. 2021.

In cosmetic industry: Microalgal PUFAs have been considered very useful and safe in the formulation of various cosmetic products due to having antioxidant and anti-inflammatory properties. Fatty acyls including fatty acids, fatty alcohols, esters, carotenoids, and eicosanoids etc. are the needed oily raw materials used as emulsifiers in cosmetics. In the cosmetic field, the fatty acyls used as the major bio-based oil surfactants (Xu & Qian 2014; Khan, Shin & Kim. 2018; Jeyakodi, Krishnakumar, & Chellappan. 2018; Ambati et al. 2019; Luca et al. 2021).

The microalgal lipids which are used as biosurfactants possess amphiphilic nature due to the presence of both hydrophilic and hydrophobic components within the chain. The main function of these biosurfactants, are reducing the interfacial tension which make easier solubilization of hydrophobic molecules in water and its lower micelle concentrations, allowing it to work at a very small concentration when compared with any synthetically prepared surfactant (Guillerme, Couteau & Coiffard, 2017; Cezare- Gomes et al. 2019; Couteau & Coiffard 2020; Shi et al. 2020; Puchkova et al. 2020; Cikos et al. 2022). They are also having antibacterial, antifungal, anti-tumor bioactivities and very less eco-toxicity. (Mondal et al. 2017; Ahmad & Ahsan. 2020;). Many fatty acids such as palmitic acid, stearic acid, lauric acid, and myristic acid, are playing an important role in the maintenance of normal skin barrier functions and making the skin smooth, soft and brighter (Mukherjee et al. 2011; Bishop, 2012; Thomas, and Kim, 2013; Christaki et al. 2013; Wang et al. 2015; Ariede et al., 2017; Yang, Zhou, & Song, 2020; Kuravi et al. 2022).

Pharmaceuticals: Many micro algal species produce high-value lipids which are utilized for pharmaceutical purposes. Production of these high value lipids or fats compounds (bioactive compounds) from microalgae has been considered as an emerging area. (Levine & Fleurence. 2018; Basheer et al 2020). The microalgae strains exploited in production of lipid bioactive compounds (carotenoids), include *Chlamydomonas* sp., *Spirulina* sp., *Chlorella* sp., *Dunaliella*, *Nannochloropsis*, *Nostoc*, *Crypthecodinium* and *Haematococcus etc*. Microalgal produced various kind of carotenoids such as astazanthin, lutein, zeaxanthin, etc. the green microalgae commonly contain beta carotene which can derived other forms of it by the action of various enzymes like hydroxylase and ketolase. (Novoveska et al., 2019).

Microalgae represent a good source of natural carotenoids. These are also called isoprenoids or terpenoids organic compounds, which containing 5 carbon atoms units (2 or more). Because of having anti cancerous, antioxidental properties, these are highly used in food, cosmetics, nutraceuticals and also in pharmaceutical industries (Zaid, Hammad & Sharaf. 2015; Lauritano et al. 2016; Yan et al. 2016; Huang et al. 2017; Deniz, Vaquero & Imamoglu. 2017; Hussain & Abdullah. 2020; Vieira et al. 2020; Rahman et al. 2020; Khavari et al. 2021; Togarcheti & Padamati 2021). *Nostoc sp.* has the capability to produce polyunsaturated fatty acids and essential fatty acids (omega 3 and 6 fatty acids) and

Chlamydomonas reinhardtii is able to produce glycerol, when grown in sulphur deprived medium, which is widely utilized in pharmaceutical industries (Singh et al. 2014; Yang et al. 2015; Scranton et al. 2015). *Chlorella* species containing high amount of α-tocopherol (vitamin E) and this can help in preventing macular degeneration and the occurrence of certain cancers (Noguchi, Maruyama & Yamada. 2014; Jayshree, Jayshree & Thangaraju. 2016; Bitto et al. 2020; Ferdous & Yosof. 2021). *Nannochloropsis gaditana* known to produce good amount of eicosapentaneoic acid (EPA) and *Crypthecodinium cohnii* for producing docosahexaenoic acid (DHA) (Adarme-Vega et al. 2012; Oliver et al. 2022). Long chain fatty acids EPA and DHA are the most valuable ones as having positive effects in the treatment and prevention of various diseases like; inflammation, hypertension, atherosclerosis, thrombosis, arthritis, and risk of chronic disease (Aderme–Vega et al. 2012; Toumi et al. 2022). DHA promotes eye health by enhancing the performance of retina and it also contribute in the brain functioning (Zang et al. 2020). EPA is showing the significant hypolipidemic activity. Hence it is very useful in preventing cardiovascular disease, and reducing the symptoms of depression (Mozaffarian & Wu. 2011; Kashiwagi &Huang. 2012). It also helps in the maintenance of normal growth and development of bone and hair, relaxation and contraction of muscles (Herrero et al.,2013; Yan et al.,2016; Blasio & Balzano 2021).

PUFAs also serve as precursors of eicosanoids and docosanoids which regulate gene expressions and biosynthesis of steroidal hormones that can maintain the good health of reproductive system. These are utilized in promoting the vasoconstrictive and aggregative activity of platelets in the process of coagulation. PUFAs are able to make some changes in their composition in the plasma membrane so that they can affect the fluidity and signaling process of the cell membrane. Omega-3 fatty acids have inhibitory effects on antibody production, lymphocyte proliferation and it also suppress to the activation of programmed cell death. Due to having above mentioned characteristic features, all these lipids are very important for pharmaceutical formulation (Ekka et al 2022).

Biofuel: The microalgal biomass has the ability to produce various kind of biofuel such as biodiesel by transesterification of the fatty acids, biogas by gasification or anaerobic digestion, bioethanol by direct fermentation of carbohydrate fraction of microalgae, methane gas by anaerobic fermentation of microalgal biomass. Microalgal lipids are the alternate resources which can be used to decrease the consumption of fossil fuels (Laurens. 2017). Microalgae cultivation gives much higher yields than any other conventional bioenergy crops. Some microalgal species eg. *Scenedesmus sp.*, *Schizochytrium* sp., *Nitzschia* sp., and *Botyococcus braunii* which contain higher amount of lipid approximately 40 to 60 %, therefore, are an excellent source of biofuel (Mata, Martins, & Caetano. 2010; Chinnasamy et al. 2010; Gong et al., 2011; Gouveia. 2011; Shah, Yadav, & Tiwari. 2011; Shenbaga – Devi et al. 2012; Mata et al. 2013; Sreekumar et al. 2016; Patel, Patel, & Krishnamurthy. 2016; Chye et al. 2018; Sharma et al. 2018; Hossain, Mahlia & Saidur. 2019; Culaba et al. 2020; Patnayak & Mallick. 2021; Moshood, Nawanir, & Mahmud. 2021; Mathushika & Gomes. 2021; Ebhodaghe, Imanah, & Ndibe. 2022; Mofijur et al. 2022).

Biodiesel: Nowadays, microalgae are being used as a potential source for production of biodiesel to overcome the ever exhausting and often increasing price of fossil fuels. They can produce high oil content (approx 50 to 80% of their dry weight) than any other traditional crops (Schlagermann et al. 2012; Eman & DM. 2013; Shin et al. 2015; Valdez-Ojeda et al. 2015; Sun et al. 2018; Aratboni et al. 2019; Hawrot- Paw 2021; Udayan et al. 2022).

Microalgal biomass contain good amount of triglycerols which is the main constituent of the biodiesel (Kim et al. 2014; Raheem et al. 2015; Hossain .2019; Lee. 2019; Kumar et al. 2017; Osman. 2021; Ebhodaghe, Imanah, & Ndibe. 2022; Kandasamy et al. 2022). Among them, transesterification is widely used process for the conversion of microalgal lipids into biodiesel. The microalgae biodiesel contains high caloric value and lower density and viscosity compared to the biodiesel obtained from other feedstock sources (Unpapran, Tipnee, & Ramaraj 2015). Microalgae biodiesel also help to reduce the level of carbon monoxide and other pollutants suspension in the atmosphere, as it does not contain aromatics hydrocarbons and sulfates. (Mondal et al. 2017; Bhalamurugan et al. 2018). Moreover, exploitation of microalgae for biodiesel is better option compared to usage of traditional food cops (oleaginous crops) and animal fats for the production of biofuel, since food supply could be affected severely.

Therefore, microalgae are proposed to be a better choice for producing biodiesel in a sustainable way because they possess capacity to grow on diverse industrial waste effluent and they can adapt themselves according to adverse environmental conditions. Many studies have been carried out by using *Chlorella sorokiniana and Scenedesmus* sp., for increasing the target number of fatty acids under a variety of culture conditions that could be used as a feedstock for producing good quality of biodiesel, under a variety of stress conditions (Jena et al. 2012; Ekka et al 2022; Khan et al. 2022).

Biohydrogen: The first green microalgae, *Scenedesmus obliquus* which was noted to produce hydrogen. After that, many microalgal strains such as *Chlorella sorokiniana*, *Chlamydomonas reinhardtii*, *Chlorococcum littorale*, *Platymonas subcordiformis* and *Chlorella fusca* etc. were used to produce hydrogen. Microalgae produce biohydrogen by employing various processes like photosynthesis, direct and indirect biophotolysis and fermentation (Kothari et al. 2015; Singh & Das. 2018; Hossain & Mahila. 2019; Limongi et al. 2021; Ordonez et al. 2021; Mondal & Khan. 2021). It was reported that microalgae produce low amount of hydrogen in dark but high amount of hydrogen produced in presence of sunlight. The hydrogen production in microalgae depend on the expression of hydrogenase enzyme and as well as the availability of sulphur containing components in the growing media (Amaro et al.,2013; Hariskos and Posten 2014; Eilenberg et al 2016;). It was reported that *Chlamydomonas reinhardtii* has high amount of hydrogenase enzyme around 10 to 100-fold, compared to other microalgal strains (Torzillo et al. 2016) But the commercial production of biohydrogen from this strain could not outstretch due to some technical issues (Batyrova & Hallenbeck. 2017). The studies on marine alga, *Platymonas subcordiformis* and on the fresh water green microalga *Chlorella sorokiniana* & *Chlamydomonas reinhardtii* demonstrated that they produced a high amount of biohydrogen when cultivated in sulphur deprived medium (Skjanes, Rebours, & Lindblad. 2013; Nomanbhav, Purvunathan & Yin. 2017; Vargas, Zaiat & Calijuri. 2021).

Chlorella vulgaris TISTR 8680 did not produce hydrogen (Ali, Rakshit & Kanhayuwa 2011; Kumari, Nasrand & Kumar. 2017). To attain profitable achievement in this field, genetically modified strains should be used which can be survive under adverse environmental conditions like sulfur- improvised state (Chader, et al., 2011; Shaishav, Singh, & Satyendra. 2013; Saifuddin, & Priatharsini. 2016; Feng et al. 2022; Ali et al. (2011)

CHALLENGES IN THE FIELD OF MICROALGAL BIOMASS PRODUCTIVITY

Current research on microalgal biomass productivity has been facing many challenges. Some of these are mentioned here as follows:

- To overcome maximum organic and inorganic load from effluent and recycling of dairy waste-water
- To enhance the outdoor microalgae productivity
- To develop efficient photo reactor for enhancing the microalgal growth
- Prevention of contamination from microalgal culture
- To improve the supply of light and CO_2 into dense cultures
- To develop low-cost methods for harvesting process and energy efficient strategies for extraction of lipids and other additional co-products
- To develop economic method for production of hydrogen
- To develop algal transgenomics technology

Converting solar energy into lipid and other organic molecules is the main objective of microalgal culture. The selection of well-characterized strains through genetic engineering and screening for new species are two strategies to overcome these obstacles and achieve optimal lipid productivity in microalgal cells. A variety of methods are employed to increase the amount of light available, such as adjusting the reactor's architecture, utilizing optics to direct light towards the reactor's center, creating flashes, and employing mixed species to use a range of light wavelengths that increase photosynthetic efficiency by trapping carbon. (Schneidermann et al., 2012; Scott and others, 2010). To increase the rate of productivity, the genes and key enzymes that control the metabolic pathways leading to lipid synthesis are presently being studied and altered. On the other hand, altering the nutrition supply can enhance the content of lipid cells (Bhowmick, Koduru & Sen. 2015; Sun et al. 2019; Shahid et al. (2020); Banerjee et al. (2020).

CONCLUSION

Microalgal cultivation holds significant potential for environmental bioremediation and the production of valuable by-products such as polyunsaturated fatty acids, omega-3 fatty acids, and B-carotenoids. Moreover, microalgae can be genetically engineered to produce alternative fuels like biohydrogen, bioethanol, and biobutanol. These bio-products find extensive applications in various industries including biofuel production, pharmaceuticals, nutraceuticals, food and nutrition, cosmetics, as well as aqua and animal feed. Microalgae biomass could be modified energy containing fuels through thermal processes. In future with continued progress being made in the field of systems biology metabolomics will play an important role as a holistic approach in generation of bio-fuels which produce lower emissions, for green energy production and thereby maintaining environmental sustainability.

RFERENCES

1. Ahmad T, Aadil RM, Ahmed H, ur Rahman U, Soares BC, Souza SL, Pimentel TC, Scudino H, Guimarães JT, Esmerino EA, Freitas MQ. Treatment and utilization of dairy industrial waste: A review. Trends in Food Science and Technology. 2019 Jun 1;88:361-72.

2. Al Ahamed SG. Dairy wastewater treatment using microalgae in Karbala city–Iraq. IJEEFUS 4 (2014); 13. 2014;22.

3. Ali I, Rakshit SK, Kanhayuwa L. Biohydrogen production from microalgae of *Chlorella* sp. In: The International Conference on Sustainable Community Development;27-29 January 2011; p.74-77.

4. Alishah Aratboni, H., Rafiei, N., Garcia-Granados, R., Alemzadeh, A., & Morones-Ramírez, J. R. (2019). Biomass and lipid induction strategies in microalgae for biofuel production and other applications. *Microbial Cell Factories*, *18*(1), 1-17.

5. Amaro HM, Esquível MG, Pinto TS, Malcata FX. Hydrogen production by microalgae. In: Reza Razeghifard, ed. Natural and artificial photosynthesis: Solar power as an energy source. 1st ed. John Wiley and Sons, Inc.; 2013. p. 231-241.

6. Ambati, R.R.; Gogisetty, D.; Aswathanarayana, R.G.; Ravi, S.; Bikkina, P.N.; Bo, L.; Yuepeng, S. Industrial potential of carotenoid pigments from microalgae: Current trends and future prospects. Crit. Rev. Food Sci. Nutr. 2019, 59, 1880–1902. [CrossRef]

7. Andersen RA, editor. Algal culturing techniques. Elsevier; 2005 Mar 4.

8. Ariede MB, Candido TM, Jacome ALM, Velasco MVR, de Carvalho JCM, Baby AR. Cosmetic attributes of algae – A review. *Algal Res.* 2017;25:483-487.

9. Banerjee, S., Banerjee, S., Ghosh, A. K., & Das, D. (2020). Maneuvering the genetic and metabolic pathway for improving biofuel production in algae: Present status and future prospective. *Renewable and Sustainable Energy Reviews*, *133*, 110155.

10. Bartley, M. L., Boeing, W. J., Dungan, B. N., Holguin, F. O., & Schaub, T. (2014). pH effects on growth and lipid accumulation of the biofuel microalgae Nannochloropsis salina and invading organisms. *Journal of applied phycology*, *26*(3), 1431-1437.

11. Basheer, S., Huo, S., Zhu, F., Qian, J., Xu, L., Cui, F., & Zou, B. (2020). Microalgae in human health and medicine. In *Microalgae biotechnology for food, health and high value products* (pp. 149-174). Springer, Singapore.

12. Batyrova, K., & Hallenbeck, P. C. (2017). Hydrogen production by a Chlamydomonas reinhardtii strain with inducible expression of photosystem II. *International Journal of Molecular Sciences*, *18*(3), 647.

13. Bellou, S., Baeshen, M. N., Elazzazy, A. M., Aggeli, D., Sayegh, F., & Aggelis, G. (2014). Microalgal lipids biochemistry and biotechnological perspectives. *Biotechnology advances*, *32*(8), 1476-1493.

14. Bhalamurugan GL, Valerie O, Mark L. Valuable bioproducts obtained from microalgal biomass and their commercial applications: A review. Environmental Engineering Research. 2018;23(3):229-41.

15. Bhatt, P., Bhandari, G., Bhatt, K., & Simsek, H. (2022). Microalgae-based removal of pollutants from wastewaters: Occurrence, toxicity and circular economy. *Chemosphere*, *306*, 135576.

16. Bhattacharjee M. Pharmaceutically valuable bioactive compounds of algae. *Asian J. Pharm. Clin. Res.* 2016;9:43-47.

17. Bilbao, P. S., Salvador, G. A., & Leonardi, P. I. (2017). Fatty acids from microalgae: targeting the accumulation of triacylglycerides. In *Fatty acids* (pp. 120-141). IntechOpen.

18. Bishop MA, West, Zubeck M. Evaluation of microalgae for use as nutraceuticals and nutritional supplements. *Nutr. Food Sci.* 2012;2:1-6.

19. Biswas, T., Bhushan, S., Prajapati, S. K., & Chaudhuri, S. R. (2021). An eco-friendly strategy for dairy wastewater remediation with high lipid microalgae-bacterial biomass production. *Journal of Environmental Management*, *286*, 112196.

20. Bošnjaković M, Sinaga N. The perspective of large-scale production of algae biodiesel. Applied Sciences. 2020 Jan;10(22):8181.

21. Branco-Vieira, M., Mata, T. M., Martins, A. A., Freitas, M. A. V., & Caetano, N. S. (2020). Economic analysis of microalgae biodiesel production in a small-scale facility. *Energy Reports*, *6*, 325-332.

22. Breuer G, Lamers PP, Martens DE, Draaisma RB, Wijffels RH. The impact of nitrogen starvation on the dynamics of triacylglycerol accumulation in nine microalgae strains. Bioresource Technology. 2012 Nov 1;124:217-26.)

23. Calijuri, M. L., Silva, T. A., Magalhães, I. B., de Paula Pereira, A. S. A., Marangon, B. B., de Assis, L. R., & Lorentz, J. F. (2022). Bioproducts from microalgae biomass: Technology, sustainability, challenges and opportunities. *Chemosphere*, 135508.

24. Camacho, F.; Macedo, A.; Malcata, F. Potential industrial applications and commercialization of microalgae in the functional food and feed industries: A short review. Mar. Drugs 2019, 17, 312. [CrossRef] [PubMed]

25. Carvalho F, Prazeres AR, Rivas J. Cheese whey wastewater: characterization and treatment. Sci Tot Env. 2013;445-446: 385–96. htt p://dx.doi.org/10.1016/j.scitotenv.2012.12.038

26. Cezare-Gomes, E.A.; del Carmen Mejia-da-Silva, L.; Pérez-Mora, L.S.; Matsudo, M.C.; Ferreira-Camargo, L.S.; Singh, A.K.; de Carvalho, J.C.M. Potential of Microalgae Carotenoids for Industrial Application. Appl. Biochem. Biotechnol. 2019, 188, 602–634. [CrossRef]

27. Chader S, Mahmah B, Chetehouna K, Amrouche F, Abdeladim K. Biohydrogen production using green microalgae as an approach to operate a small proton exchange membrane fuel cell. *Int. J. Hydrogen Energ.* 2011;36:4089-4093.

28. Chader S, Mahmah B, Chetehouna K, Mignolet E. Biodiesel production using *Chlorella sorokiniana* green microalga. *Revue Energ. Renouv.* 2011;14:21-26.

29. Chandra, R., Pradhan, S., Patel, A., & Ghosh, U. K. (2021). An approach for dairy wastewater remediation using mixture of microalgae and biodiesel production for sustainable transportation. *Journal of Environmental Management*, *297*, 113210.

30. Chen Z, Wang L, Qiu S, Ge S. Determination of microalgal lipid content and fatty acid for biofuel production. BioMed research international. 2018;2018.

31. Chen, B. Y., Chen, C. Y., Guo, W. Q., Chang, H. W., Chen, W. M., Lee, D. J., ... & Chang, J. S. (2014). Fixed-bed biosorption of cadmium using immobilized Scenedesmus obliquus CNW-N cells on loofa (Luffa cylindrica) sponge. *Bioresource technology*, *160*, 175-181.

32. Chen, H. H., & Jiang, J. G. (2017). Lipid accumulation mechanisms in auto-and heterotrophic microalgae. *Journal of agricultural and food chemistry*, *65*(37), 8099-8110.

33. Chen, H., & Wang, Q. (2021). Regulatory mechanisms of lipid biosynthesis in microalgae. *Biological Reviews*, *96*(5), 2373-2391.

34. Chen, W. H., Lin, B. J., Huang, M. Y., & Chang, J. S. (2015). Thermochemical conversion of microalgal biomass into biofuels: a review. *Bioresource technology*, *184*, 314-327.

35. Chinnasamy S, Bhatnagar A, Hunt RW, Das KC. Microalgae cultivation in a wastewater dominated by carpet mill effluents for biofuel applications. Bioresource technology. 2010 May 1;101(9):3097-105.

36. Choi HJ. Dairy wastewater treatment using microalgae for potential biodiesel application. Environmental engineering research. 2016;21(4):393-400.

37. Choi YK, Jang HM, Kan E. Microalgal biomass and lipid production on dairy effluent using a novel microalga, Chlorella sp. isolated from dairy wastewater. Biotechnology and Bioprocess Engineering. 2018 Jun;23(3):333-40.

38. Chokshi, K., Pancha, I., Ghosh, A., & Mishra, S. (2016). Microalgal biomass generation by phycoremediation of dairy industry wastewater: an integrated approach towards sustainable biofuel production. *Bioresource technology*, *221*, 455-460.

39. Chye, J. T. T., Jun, L. Y., Yon, L. S., Pan, S., & Danquah, M. K. (2018). Biofuel production from algal biomass. In *Bioenergy and biofuels* (pp. 87-118). CRC Press.

40. Costa, J. A. V., Cruz, C. G., & da Rosa, A. P. C. (2021). Insights into the technology utilized to cultivate microalgae in dairy effluents. *Biocatalysis and Agricultural Biotechnology*, *35*, 102106.

41. Couteau, C.; Coiffard, L. Phycocosmetics and Other Marine Cosmetics, Specific Cosmetics Formulated Using Marine Resources. Mar. Drugs 2020, 18, 322. [CrossRef] [PubMed]

42. Culaba, A. B., Ubando, A. T., Ching, P. M. L., Chen, W. H., & Chang, J. S. (2020). Biofuel from microalgae: Sustainable pathways. *Sustainability*, *12*(19), 8009.

43. Daneshvar, E., Zarrinmehr, M. J., Koutra, E., Kornaros, M., Farhadian, O., & Bhatnagar, A. (2019). Sequential cultivation of microalgae in raw and recycled dairy wastewater: microalgal growth, wastewater treatment and biochemical composition. *Bioresource technology*, *273*, 556-564.

44. De Bhowmick, G., Koduru, L., & Sen, R. (2015). Metabolic pathway engineering towards enhancing microalgal lipid biosynthesis for biofuel application—a review. *Renewable and Sustainable Energy Reviews*, *50*, 1239-1253.

45. De Luca, M., Pappalardo, I., Limongi, A. R., Viviano, E., Radice, R. P., Todisco, S., ... & Vassallo, A. (2021). Lipids from microalgae for cosmetic applications. *Cosmetics*, *8*(2), 52.

46. Dean AP, Sigee DC, Estrada B, Pittman JK. Using FTIR spectroscopy for rapid determination of lipid accumulation in response to nitrogen limitation in freshwater microalgae. Bioresource technology. 2010 Jun 1;101(12):4499-507.

47. Debowski, M.; Szwaja, S.; Zielin ̧ski, M.; Kisielewska, M.;́ Stanczyk-Mazanek, E. The influence of anaerobic digestion effluentś (ADEs) used as the nutrient sources for Chlorella sp. cultivation on fermentative biogas production. Waste Biomass Valorization 2017, 8 (4), 1153−1161)

48. Demirel Z, Imamoglu E, Conk Dalay M. Fatty acid profile and lipid content of Cylindrothecaclosterium cultivated in air-lift photobioreactor. Journal of Chemical Technology and Biotechnology. 2015 Dec;90(12):2290-6.

49. Deshmukh, S., Bala, K., & Kumar, R. (2019). Selection of microalgae species based on their lipid content, fatty acid profile and apparent fuel properties for biodiesel production. *Environmental Science and Pollution Research*, *26*(24), 24462-24473.

50. Devadasu, E., & Subramanyam, R. (2021). Enhanced lipid production in Chlamydomonas reinhardtii caused by severe Iron Deficiency. *Frontiers in plant science*, *12*, 615577.

51. Devi, A., Patil, K., Kumar, A., Gupta, N., Malik, A., & Pabbi, S. (2022). Production of valuable platform chemicals through microalgal routes utilizing waste streams. *Bioresource Technology Reports*, 101071.

52. Dolganyuk, V.; Andreeva, A.; Budenkova, E.; Sukhikh, S.; Babich, O.; Ivanova, S.; Prosekov, A.; Ulrikh, E. Study of morphological features and determination of the fatty acid composition of the microalgae lipid complex. Biomolecules 2020, 10, 1571. [CrossRef]

53. Ebhodaghe, S. O., Imanah, O. E., & Ndibe, H. (2022). Biofuels from microalgae biomass: A review of conversion processes and procedures. *Arabian Journal of Chemistry*, *15*(2), 103591.

54. Eilenberg, H., Weiner, I., Ben-Zvi, O., Pundak, C., Marmari, A., Liran, O., ... & Yacoby, I. (2016). The dual effect of a ferredoxin-hydrogenase fusion protein in vivo: successful divergence of the photosynthetic electron flux towards hydrogen production and elevated oxygen tolerance. *Biotechnology for biofuels*, *9*(1), 1-10.

55. Ekka B, Mieriņa I, Juhna T, Turks M, Kokina K. Quantification of different fatty acids in raw dairy wastewater. Cleaner Engineering and Technology. 2022 April 7:100430

56. Eman MF, El DM. Fatty acids composition and biodiesel characterization of *Dunaliella salina*. *J. Water Resour. Prot.* 2013;5:894-899.

57. Enamala MK, Enamala S, Chavali M, Donepudi J, Yadavalli R, Kolapalli B, Aradhyula TV, Velpuri J, Kuppam C. Production of biofuels from microalgae-A review on cultivation, harvesting, lipid extraction, and numerous applications of microalgae. Renewable and Sustainable Energy Reviews. 2018 Oct 1;94:49-68.

58. Encarnação, T., Mateus, A., Gaspar, F., Massano, A., Biscaia, S., Guincho, P. B., ... & Sobral, A. J. (2022). Bioremediation Using Microalgae and Circular Economy Approach: A Case Study. *Materials Proceedings*, *8*(1), 108.

59. Fan J, Andre C, Xu C. A chloroplast pathway for the de novo biosynthesis of triacylglycerol in Chlamydomonas reinhardtii. FEBS letters. 2011 Jun 23;585(12):1985-91.

60. Federation WE, APH Association. Standard methods for the examination of water and wastewater. American Public Health Association (APHA): Washington, DC, USA. 2005.

61. Feng H, Sun C, Zhang C, Chang H, Zhong N, Wu W, Wu H, Tan X, Zhang M, Ho SH. Bioconversion of mature landfill leachate into biohydrogen and volatile fatty acids via microalgal photosynthesis together with dark fermentation. Energy Conversion and Management. 2022 January 252:115035

62. Ferreira, G. F., Rios Pinto, L. F., Carvalho, P. O., Coelho, M. B., Eberlin, M. N., Maciel Filho, R., & Fregolente, L. V. (2021). Biomass and lipid characterization of microalgae genera Botryococcus, Chlorella, and Desmodesmus aiming high-value fatty acid production. *Biomass Conversion and Biorefinery*, *11*(5), 1675-1689.

63. Gani, P., Mohamed, N., Matias-Peralta, H., & Latiff, A. A. A. (2016). Application of phycoremediation technology in the treatment of food processing wastewater by freshwater microalgae Botryococcus sp. *J. Eng. Appl. Sci*, *11*(11), 7288-7292.

64. Gao, B., Wang, F., Huang, L., Liu, H., Zhong, Y., & Zhang, C. (2021). Biomass, lipid accumulation kinetics, and the transcriptome of heterotrophic oleaginous microalga Tetradesmus bernardii under different carbon and nitrogen sources. *Biotechnology for biofuels*, *14*(1), 1-16.

65. García JL, Vicente M, Galan B. Microalgae, old sustainable food and fashion nutraceuticals. *Microb. Biotechnol*2017;10:1017-1024.

66. Gharajeh NH, Valizadeh M, Dorani E, Hejazi MA. Biochemical profiling of three indigenous Dunaliella isolates with main focus on fatty acid composition towards potential biotechnological application. Biotechnology Reports. 2020 Jun 1;26:e00479.

67. Ghosh S, Roy S, Das D. Enhancement in lipid content of Chlorella sp. MJ 11/11 from the spent medium of thermophilic biohydrogen production process. Bioresource technology. 2017 Jan 1;223:219-26.

68. Gifuni, I., Pollio, A., Safi, C., Marzocchella, A., & Olivieri, G. (2019). Current bottlenecks and challenges of the microalgal biorefinery. *Trends in biotechnology*, *37*(3), 242-252.

69. Gonçalves AL, Pires JC, Simões M. A review on the use of microalgal consortia for wastewater treatment. Algal Research. 2017 Jun 1;24:403-15.

70. Goswami, R. K., Agrawal, K., & Verma, P. (2022). Microalgal-based remediation of wastewater: A step towards environment protection and management. *Environmental Quality Management*.

71. Gouveia L. Microalgae as a Feedstock for Biofuels 2011 (pp. 1-69). Springer, Berlin, Heidelberg.

72. Gramegna, G., Scortica, A., Scafati, V., Ferella, F., Gurrieri, L., Giovannoni, M., ... & Benedetti, M. (2020). Exploring the potential of microalgae in the recycling of dairy wastes. *Bioresource Technology Reports*, *12*, 100604.

73. Griffiths MJ, Dicks RG, Richardson C, Harrison ST. Advantages and challenges of microalgae as a source of oil for biodiesel. Biodiesel-feedstocks and processing technologies. 2011 Nov 9:177-200.

74. Guillerme, J.B.; Couteau, C.; Coiffard, L. Applications for marine resources in cosmetics. Cosmetics 2017, 4, 35. [CrossRef

75. Guldhe, A.; Kumari, S.; Ramanna, L.; Ramsundar, P.; Singh, P.; Rawat, I.; Bux, F. Prospects, recent advancements and challenges of different wastewater streams for microalgal cultivation. J. Environ. Manage. 2017, 203, 299−315

76. Han, F., Huang, J., Li, Y., Wang, W., Wang, J., Fan, J., & Shen, G. (2012). Enhancement of microalgal biomass and lipid productivities by a model of photoautotrophic culture with heterotrophic cells as seed. *Bioresource technology*, *118*, 431-437.

77. Hang, L. T., Mori, K., Tanaka, Y., Morikawa, M., & Toyama, T. (2020). Enhanced lipid productivity of Chlamydomonas reinhardtii with combination of NaCl and CaCl2 stresses. *Bioprocess and biosystems engineering*, *43*(6), 971-980.

78. Hariskos I, Posten C. Biorefinery of microalgae Opportunities and constraints for different production scenarios. *Biotechnol. J.* 2014;9:739-752.

79. Hawrot-Paw, M., Ratomski, P., Koniuszy, A., Golimowski, W., Teleszko, M., & Grygier, A. (2021). Fatty acid profile of microalgal oils as a criterion for selection of the best feedstock for biodiesel production. *Energies*, *14*(21), 7334.

80. Heimann K, Huerlimann R. Microalgal Classification: Major Classe sand Genera of Commercial Microalgal Species. Handbook of Marine Microalgae: Biotechnology Advances.,2015

81. Hena S, Fatimah S, Tabassum S. Cultivation of algae consortium in a dairy farm wastewater for biodiesel production. Water Resources and Industry. 2015 Jun 1;10:1-4.

82. Herrero M, Castro-Puyana M, Mendiola JA, Ibañez E. Compressed fluids for the extraction of bioactive compounds. *Trends Anal. Chem.* 2013;43:67-83.

83. Hess, S. K., Lepetit, B., Kroth, P. G., & Mecking, S. (2018). Production of chemicals from microalgae lipids–status and perspectives. *European Journal of Lipid Science and Technology*, *120*(1), 1700152.

84. Hossain, N., & Mahlia, T. M. I. (2019). Progress in physicochemical parameters of microalgae cultivation for biofuel production. *Critical reviews in biotechnology*, *39*(6), 835-859.

85. Hossain, N., Mahlia, T. M. I., & Saidur, R. (2019). Latest development in microalgae-biofuel production with nano-additives. *Biotechnology for biofuels*, *12*(1), 1-16.

86. Hossain, S. Z. (2019). Biochemical conversion of microalgae biomass into biofuel. *Chemical Engineering & Technology*, *42*(12), 2594-2607.

87. Hu J, Nagarajan D, Zhang Q, Chang JS, Lee DJ. Heterotrophic cultivation of microalgae for pigment production: A review. Biotechnology advances. 2018 Jan 1;36(1):54-67.

88. Hu X, Liu B, Deng Y, Bao X, Yang A, Zhou J. A novel two-stage culture strategy used to cultivate Chlorella vulgaris for increasing the lipid productivity. Separation and Purification Technology. 2019 Mar 18;211:816-22.

89. James SC, Boriah V. Modeling algae growth in an open-channel raceway. Journal of Computational Biology. 2010 Jul 1;17(7):895-906.

90. Jena J, Nayak M, Panda HS, et al. Microalgae of Odisha coast as a potential source for biodiesel production. *World Environ*. 2012;2:11-16.

91. Jeyakodi S, Krishnakumar A, Chellappan DK. Beta Carotene-Therapeutic Potential and Strategies to Enhance Its Bioavailability. Nutri Food Sci Int J Review Article. 2018;7(4).

92. Jiang, L., Pei, H., Hu, W., Han, F., Zhang, L., & Hou, Q. (2015). Effect of diethyl aminoethyl hexanoate on the accumulation of high-value biocompounds produced by two novel isolated microalgae. *Bioresource Technology*, *197*, 178-184.

93. Jiang, L., Zhou, Z., Xiang, H., Yang, Y., Tian, H., & Wang, J. (2022). Characteristics and synergistic effects of co-pyrolysis of microalgae with polypropylene. *Fuel*, *314*, 122765.

94. Joun J, Hong ME, Sirohi R, Sim SJ (2021) Enhanced biomass production through a repeated sequential auto-and heterotrophic culture mode in Chlorella protothecoides. 123 Phytochem Rev Bioresour Technol 338:125532. https://doi.org/10.1016/j.biortech.2021.125532)

95. Jüppner, J., Mubeen, U., Leisse, A., Caldana, C., Brust, H., Steup, M., ... & Giavalisco, P. (2017). Dynamics of lipids and metabolites during the cell cycle of Chlamydomonas reinhardtii. *The Plant Journal*, *92*(2), 331-343.

96. Kalra, R., Gaur, S., & Goel, M. (2021). Microalgae bioremediation: A perspective towards wastewater treatment along with industrial carotenoids production. *Journal of Water Process Engineering*, *40*, 101794.

97. Kandasamy, S., Bhuvanendran, N., Narayanan, M., & He, Z. (2022). Thermochemical conversion of algal biomass. In *Handbook of Algal Biofuels* (pp. 281-302). Elsevier.

98. Karadag, D., Köroğlu, O. E., Ozkaya, B., & Cakmakci, M. (2015). A review on anaerobic biofilm reactors for the treatment of dairy industry wastewater. *Process biochemistry*, *50*(2), 262-271.

99. Kashiwagi S, Huang PL. Dietary Supplements and Cardiovascular Disease: What is the Evidence and What Should We Recommend?. ISBN; 2012 Mar 14.

100. Kawamura, K., Sumii, K., Matsumoto, M., Nakase, D., Kosaki, Y., & Ishikawa, M. (2018). Determining the optimal cultivation strategy for microalgae for biodiesel production using flow cytometric monitoring and mathematical modeling. *Biomass and Bioenergy*, *117*, 24-31.

101. Khan S, Naushad M, Iqbal J, Bathula C, Sharma G. Production and harvesting of microalgae and an efficient operational approach to biofuel production for a sustainable environment. Fuel. 2022 March 311:122543

102. Khan, M. I., Shin, J. H., & Kim, J. D. (2018). The promising future of microalgae: current status, challenges, and optimization of a sustainable and renewable industry for biofuels, feed, and other products. *Microbial cell factories*, *17*(1), 1-21.

103. Khozin-Goldberg, I. (2016). Lipid metabolism in microalgae. In *The physiology of microalgae* (pp. 413-484). Springer, Cham.

104. Kim GV, Choi W, Kang D, Lee S, Lee H. Enhancement of biodiesel production from marine alga, *Scenedesmus* sp.through in situ transesterification process associated with acidic catalyst. *BioMed Res. Int.* 2014;2014:391542.

105. Kolev Slavov A. General characteristics and treatment possibilities of dairy wastewater–a review. Food technology and biotechnology. 2017 Mar 23;55(1):14-28.

106. Kothari R, Prasad R, Kumar V, Singh DP. Production of biodiesel from microalgae Chlamydomonas polypyrenoideum grown on dairy industry wastewater. Bioresource technology. 2013 Sep 1;144:499-503.

107. Kothari, R., Pandey, A., Kumar, V., & Tyagi, V. V. (2015). Algae-Based Biohydrogen: Current Status of Bioprocess Routes, Economical Assessment, and Major Bottlenecks. *Algae and Environmental Sustainability*, 77-86.

108. Kumar N, Banerjee C, Jagadevan S. Identification, characterization, and lipid profiling of microalgae Scenedesmus sp. NC1, isolated from coal mine effluent with potential for biofuel production. Biotechnology Reports. 2021 Jun 1;30:00621.

109. Kumar, G., Shobana, S., Chen, W. H., Bach, Q. V., Kim, S. H., Atabani, A. E., & Chang, J. S. (2017). A review of thermochemical conversion of microalgal biomass for biofuels: chemistry and processes. *Green Chemistry*, *19*(1), 44-67.

110. Kumari S, Nasr M, Kumar S. Technological advances in biohydrogen production from microalgae. In: Gupta SK, Malik A, Bux F, eds. Algal biofuels: Recent advances and future prospects. Durban: Springer International Publishing; 2017. p. 347-360.

111. Kuravi SD, Mohan SV. Mixotrophic cultivation of Monoraphidium sp. In dairy wastewater using Flat-Panel photobioreactor and photosynthetic performance. Bioresource Technology. 2022 Jan 348:126671

112. Kushwaha, J. P., Srivastava, V. C., & Mall, I. D. (2011). An overview of various technologies for the treatment of dairy wastewaters. *Critical reviews in food science and nutrition*, *51*(5), 442-452.

113. Kusmayadi A, Lu PH, Huang CY, Leong YK, Yen HW, Chang JS. Integrating anaerobic digestion and microalgae cultivation for dairy wastewater treatment and potential biochemicals production from the harvested microalgal biomass. Chemosphere. 2022 March 291(1):133057

114. Laurens LM. State of Technology Review—Algae Bioenergy. Golden: IEA Bioenergy. 2017.

115. Lee CH, Chae HS, Lee SH, Kim HS. Growth characteristics and lipid content of three Korean isolates of Botryococcusbraunii (Trebouxiophyceae). Journal of Ecology and Environment. 2015;38(1):67-74.

116. Lee, S. Y., Sankaran, R., Chew, K. W., Tan, C. H., Krishnamoorthy, R., Chu, D. T., & Show, P. L. (2019). Waste to bioenergy: a review on the recent conversion technologies. *Bmc Energy*, *1*(1), 1-22.

117. Lei, Y. J., Tian, Y., Zhang, J., Sun, L., Kong, X. W., Zuo, W., & Kong, L. C. (2018). Microalgae cultivation and nutrients removal from sewage sludge after ozonizing in algal-bacteria system. *Ecotoxicology and Environmental Safety*, *165*, 107-114.

118. Limongi, A. R., Viviano, E., De Luca, M., Radice, R. P., Bianco, G., & Martelli, G. (2021). Biohydrogen from microalgae: production and applications. *Applied Sciences*, *11*(4), 1616.

119. Lin, T. S., & Wu, J. Y. (2015). Effect of carbon sources on growth and lipid accumulation of newly isolated microalgae cultured under mixotrophic condition. *Bioresource technology*, *184*, 100-107.

120. Liu R, Li S, Tu Y, Hao X, Qiu F. Recovery of value-added products by mining microalgae. Journal of Environmental Management. 2022 Apr 307:114512

121. Lv, X., Zou, L., Sun, B., Wang, J., & Sun, M. Y. (2010). Variations in lipid yields and compositions of marine microalgae during cell growth and respiration, and within intracellular structures. *Journal of Experimental Marine Biology and Ecology*, *391*(1-2), 73-83.

122. Ma, X. N., Chen, T. P., Yang, B., Liu, J., & Chen, F. (2016). Lipid production from Nannochloropsis. *Marine drugs*, *14*(4), 61.

123. Mahapatra DM, Ramachandra TV. Algal biofuel: bountiful lipid from Chlorococcum sp. proliferating in municipal wastewater. Current science. 2013 Jul 10:47-55

124. Maltsev, Y.; Maltseva, K. Fatty Acids of Microalgae: Diversity and Applications; Springer: Dordrecht, The Netherlands, 2021; Volume 3, ISBN 0123456789.

125. Mata M, Melo A, Meireles S, Mendes A, Martins A, Caetan N. Potential of microalgae *Scenedesmus obliquus* grown in brewery wastewater for biodiesel production. *Chem. Eng.Trans.* 2013;32:901-906.

126. Mata TM, Martins AA, Caetano NS. Microalgae for biodiesel production and other applications: a review. Renewable and sustainable energy reviews. 2010 Jan 1;14(1):217-32.

127. Mathushika, J., & Gomes, C. (2021). Development of microalgae-based biofuels as a viable green energy source: challenges and future perspectives. *Biointerface Res Appl Chem*, *12*, 3849-82.

128. Matos J, Cardoso C, Bandarra N. M, Afonso C.Bhalamurugan GL, Valerie O, Mark L. Valuable bioproducts obtained from microalgal biomass and their commercial applications: A review. Environmental Engineering Research. 2018;23(3):229-41.

129. Mehrotra R, Trivedi A, Mazumdar SK. Study on characterisation of indian dairy wastewater. International Journal of Engineering Applied Sciences and Technology. 2016;1(11):77-88.

130. Menegazzo, M. L., & Fonseca, G. G. (2019). Biomass recovery and lipid extraction processes for microalgae biofuels production: A review. *Renewable and Sustainable Energy Reviews*, *107*, 87-107.

131. Mimouni, V., Couzinet-Mossion, A., Ulmann, L., & Wielgosz-Collin, G. (2018). Lipids from microalgae. In *Microalgae in health and disease prevention* (pp. 109-131). Academic Press.

132. Minhas AK, Hodgson P, Barrow CJ, Adholeya A. A review on the assessment of stress conditions for simultaneous production of microalgal lipids and carotenoids. Frontiers in microbiology. 2016 May 3;7:546.

133. Mirizadeh, S., Casazza, A. A., Converti, A., Nosrati, M., & Shojaosadati, S. A. (2021). Repetitive non-destructive extraction of lipids from Chlorella vulgaris grown under stress conditions. *Bioresource Technology*, *326*, 124798.

134. Mofijur M, Rahman SMA, Nguyen LN, Mahlia TMI, Nghiem LD. Selection of microalgae strains for sustainable production of aviation biofuel. Bioresource Technology. 2022 February 345:126408

135. Mondal M, Goswami S, Ghosh A, et al. Production of biodiesel from microalgae through biological carbon capture: A review *3 Biotech* 2017;7:1-21.

136. Mondal, M., & Khan, A. A. (2021). Immobilized Microalgae for Removing Industrial Pollutants: A Greener Technique. In *Wastewater Treatment* (pp. 367-384). Elsevier.

137. Morando-Grijalva CA, Vázquez-Larios AL, Alcántara-Hernández RJ, Ortega-Clemente LA, Robledo-Narváez PN. Isolation of a freshwater microalgae and its application for the treatment of wastewater and obtaining fatty acids from tilapia cultivation. Environmental Science and Pollution Research. 2020 Mar 24:1-10.

138. Moshood, T. D., Nawanir, G., & Mahmud, F. (2021). Microalgae biofuels production: A systematic review on socioeconomic prospects of microalgae biofuels and policy implications. *Environmental Challenges*, *5*, 100207.

139. Mozaffarian, D.; Wu, J.H.Y. Omega-3 fatty acids and cardiovascular disease: Effects on risk factors, molecular pathways, and clinical events. J. Am. Coll. Cardiol. 2011, 58, 2047–2067. [CrossRef] [PubMed]

140. Msanne J, Xu D, Konda AR, Casas-Mollano JA, Awada T, Cahoon EB, Cerutti H. Metabolic and gene expression changes triggered by nitrogen deprivation in the photoautotrophically grown microalgae Chlamydomonas reinhardtii and Coccomyxa sp. C-169. Phytochemistry. 2012 Mar 1;75:50-9.

141. Mwangi, J. K., Lee, W. J., Whang, L. M., Wu, T. S., Chen, W. H., Chang, J. S., ... & Chen, C. L. (2015). Microalgae oil: Algae cultivation and harvest, algae residue torrefaction and diesel engine emissions tests. *Aerosol and air quality research*, *15*(1), 81-98.

142. Nguyen, L. N., Aditya, L., Vu, H. P., Johir, A. H., Bennar, L., Ralph, P., ... & Nghiem, L. D. (2022). Nutrient Removal by Algae-Based Wastewater Treatment. *Current Pollution Reports*, 1-15.

143. Nomanbhay, S., Purvunathan, P., & Yin, O. M. (2017). Enhancement of Bio-Hydrogen Production in Chlamydomonas Reinhardtii by Immobilization and Co-Culturing. *International Journal of Bio-Science and Bio-Technology*, *9*(1), 35-52.

144. Novoveská L, Ross ME, Stanley MS, Pradelles R, Wasiolek V, Sassi JF. Microalgal carotenoids: A review of production, current markets, regulations, and future direction. Marine drugs. 2019 Nov;17(11):640.

145. Ordóñez, Y. D. J. T., Gutiérrez, B. A. A., Marin, A. R., Ordóñez, F. A. T., Davila, I. M. M. M., González, L. R., ... & Ordoñez, M. C. T. (2021). Transcription of the Hydrogenase Gene during H2 Production in Scenedesmus Obliquus and Chlorella Vulgaris.

146. Osman, A. I., Mehta, N., Elgarahy, A. M., Al-Hinai, A., Al-Muhtaseb, A. A. H., & Rooney, D. W. (2021). Conversion of biomass to biofuels and life cycle assessment: a review. *Environmental Chemistry Letters*, *19*(6), 4075-4118.

147. Pandey, A., Srivastava, S., & Kumar, S. (2019). Isolation, screening and comprehensive characterization of candidate microalgae for biofuel feedstock production and dairy effluent treatment: a sustainable approach. *Bioresource technology*, *293*, 121998.

148. Pang, N., Bergeron, A. D., Gu, X., Fu, X., Dong, T., Yao, Y., & Chen, S. (2020). Recycling of nutrients from dairy wastewater by extremophilic microalgae with high ammonia tolerance. *Environmental science & technology*, *54*(23), 15366-15375.

149. Park, S., Ahn, Y., Pandi, K., Ji, M. K., Yun, H. S., & Choi, J. Y. (2019). Microalgae cultivation in pilot scale for biomass production using exhaust gas from thermal power plants. *Energies*, *12*(18), 3497.

150. Patel AK, Joun J, Sim SJ. A sustainable mixotrophic microalgae cultivation from dairy wastes for carbon credit, bioremediation and lucrative biofuels. Bioresource technology. 2020 Oct 1;313:1236-81.

151. Patel, P., Patel, S., & Krishnamurthy, R. (2016). Microalgae: future biofuel.

152. Patnaik, R., & Mallick, N. (2021). Microalgal biodiesel production: realizing the sustainability index. *Frontiers in Bioengineering and Biotechnology*, *9*, 620777.

153. Pohl CH, Kock JL. Oxidized fatty acids as inter-kingdom signaling molecules. Molecules. 2014 Jan;19(1):1273-85.

154. Porwal HJ, Mane AV, Velhal SG. Biodegradation of dairy effluent by using microbial isolates obtained from activated sludge. Water Resources and Industry. 2015 Mar 1;9:1-5.

155. Prazeres, A. R., Carvalho, F., & Rivas, J. (2012). Cheese whey management: A review. *Journal of environmental management*, *110*, 48-68.

156. Qadir, M., Drechsel, P., Jiménez Cisneros, B., Kim, Y., Pramanik, A., Mehta, P., & Olaniyan, O. (2020, February). Global and regional potential of wastewater as a water, nutrient and energy source. In *Natural resources forum* (Vol. 44, No. 1, pp. 40-51). Oxford, UK: Blackwell Publishing Ltd.

157. Radakovits R, Jinkerson RE, Darzins A, Posewitz MC. Genetic engineering of algae for enhanced biofuel production. Eukaryotic cell. 2010 Apr;9(4):486-501.

158. Raghunath, B. V., Punnagaiarasi, A., Rajarajan, G., Irshad, A., & Elango, A. (2016). Impact of dairy effluent on environment—a review. *Integrated Waste Management in India*, 239-249.

159. Raheem, A., Azlina, W. W., Yap, Y. T., Danquah, M. K., & Harun, R. (2015). Thermochemical conversion of microalgal biomass for biofuel production. *Renewable and Sustainable Energy Reviews*, *49*, 990-999.

160. Randhir, A., Laird, D. W., Maker, G., Trengove, R., & Moheimani, N. R. (2020). Microalgae: a potential sustainable commercial source of sterols. *Algal Research*, *46*, 101772.

161. Rani AS, Rao HG, Kumar AB, Shruthi M. Eco-Friendly Approach for Treating Dairy Effluent and Lipid Estimation Using Microalgae. Biotechnology Journal International. 2015 Apr 1:33-39.

162. Rawat, J., Gupta, P. K., Pandit, S., Priya, K., Agarwal, D., Pant, M., ... & Pande, V. (2022). Latest Expansions in Lipid Enhancement of Microalgae for Biodiesel Production: An Update. *Energies*, *15*(4), 1550. .

163. Rodolfi L, ChiniZittelli G, Bassi N, Padovani G, Biondi N, Bonini G, Tredici MR. Microalgae for oil: Strain selection, induction of lipid synthesis and outdoor mass cultivation in a low-cost photobioreactor. Biotechnology and bioengineering. 2009 Jan 1;102(1):100-12.

164. Saifuddin N, Priatharsini P. Developments in bio-hydrogen production from algae: A review. *Res. J. Appl. Sci. Eng.Technol.* 2016;12:968-982.

165. Sajjadi, B., Chen, W. Y., Raman, A. A. A., & Ibrahim, S. (2018). Microalgae lipid and biomass for biofuel production: A comprehensive review on lipid enhancement strategies and their effects on fatty acid composition. *Renewable and Sustainable Energy Reviews*, *97*, 200-232.

166. Santhosh S, Dhandapani R, Hemalatha N. Bioactive compounds from microalgae and its different applications – A review. *Adv. Appl. Sci. Res.* 2016;7:153-158.

167. Scaife MA, Nguyen J, Rico D, Lambert K, Helliwell E, SmithAG. Establishing Chlamydomonas reinhardtii as an industrial biotechnology host. *Plant J.* 2015;82:532-546.

168. Schlagermann P, Göttlicher G, Dillschneider R, Rosello-Sastre R, Posten C. Composition of algal oil and its potential as biofuel. Journal of combustion. 2012 Oct;2012.

169. Shah GC, Yadav M, Tiwari A. Assessment for the higherproduction of biodiesel from *Scenedesmus dimorphus*algal species using different methods. *J. Biofuels* 2011;2:91-97.

170. Shahid, A., Rehman, A. U., Usman, M., Ashraf, M. U. F., Javed, M. R., Khan, A. Z., ... & Mehmood, M. A. (2020). Engineering the metabolic pathways of lipid biosynthesis to develop robust microalgal strains for biodiesel production. *Biotechnology and Applied Biochemistry*, *67*(1), 41-51.

171. Shaishav S, Singh R, Satyendra T. Biohydrogen from algae:Fuel of the future. *Int. Res. J. Environ. Sci.* 2013;2:44-47.

172. Sharma R, Mishra A, Pant D, Malaviya P. Recent advances in microalgae-based remediation of industrial and non-industrial wastewaters with simultaneous recovery of value-added products. Bioresource Technology. 2022 Jan 344(Pt B):126129

173. Sharma, P. K., Saharia, M., Srivstava, R., Kumar, S., & Sahoo, L. (2018). Tailoring microalgae for efficient biofuel production. *Frontiers in Marine Science*, *5*, 382.

174. Shenbaga Devi A, Santhanam P, Rekha V, et al. Culture and biofuel producing efficacy of marine microalgae *Dunaliella salina* and *Nannochloropsis*sp. *J. Algal Biomass Utln.* 2012;3:38-44.

175. Shete BS, Shinkar NP. Dairy industry wastewater sources, characteristics and its effects on environment. International Journal of Current Engineering and Technology. 2013 Dec;3(5):1611-5.

176. Shi, T.Q.; Wang, L.R.; Zhang, Z.X.; Sun, X.M.; Huang, H. Stresses as First-Line Tools for Enhancing Lipid and Carotenoid Production in Microalgae. Front. Bioeng. Biotechnol. 2020, 8, 1–9. [CrossRef]

177. Shin DY, Cho HU, Utomo JC, Choi YN, Xu X, Park JM. Biodiesel production from *Scenedesmus bijuga*grown in anaerobically digested food wastewater effluent. *Bioresour.Technol.* 2015;184:215-221.

178. Shokravi, Z., Shokravi, H., Chyuan, O. H., Lau, W. J., Koloor, S. S. R., Petrů, M., & Ismail, A. F. (2020). Improving 'lipid productivity'in microalgae by bilateral enhancement of biomass and lipid contents: a review. *Sustainability*, *12*(21), 9083.

179. Siaut M, Cuiné S, Cagnon C, Fessler B, Nguyen M, Carrier P, Beyly A, Beisson F, Triantaphylidès C, Li-Beisson Y, Peltier G. Oil accumulation in the model green alga *Chlamydomonas reinhardtii*: characterization, variability between common laboratory strains and relationship with starch reserves. BMC biotechnology. 2011 Dec;11(1):1-5.

180. Sibi, G., Shetty, V., & Mokashi, K. (2016). Enhanced lipid productivity approaches in microalgae as an alternate for fossil fuels–A review. *Journal of the Energy Institute*, *89*(3), 330-334.

181. Singh, H., & Das, D. (2018). Biofuels from microalgae: biohydrogen. In *Energy from microalgae* (pp. 201-228). Springer, Cham.

182. Sirohi R, Joun J, Hong ME, Gaur V, Sim SJ (2021a) Algal glycol biotechnology: omics approaches for strain improvement. Microbial Cell Fact 21(1):163. https://doi.org/10.1186/ s12934-021-01656-6

183. Sirohi R, Lee JS, Yu BS, Roh H, Sim SJ (2021b) Sustainable production of polyhydroxybutyrate from autotrophs using CO2 as feedstock: challenges and opportunities. Bioresour Technol 341:125751. https://doi.org/10.1016/j.biortech.2021.125751

184. Skjånes K, Rebours C, Lindblad P. Potential for green microalgae to produce hydrogen, pharmaceuticals and other high value products in a combined process. *Crit. Rev. Biotechnol.* 2013;33:172-215.

185. Slavov, A. K. (2017). General characteristics and treatment possibilities of dairy wastewater–a review. *Food technology and biotechnology*, *55*(1), 14.

186. Subash chandrabose, S. R., Ramakrishnan, B., Megharaj, M., Venkateswarlu, K., & Naidu, R. (2013). Mixotrophic cyanobacteria and microalgae as distinctive biological agents for organic pollutant degradation. *Environment international*, *51*, 59-72.

187. Sulochana, S. B., & Arumugam, M. (2020). Targeted metabolomic and biochemical changes during nitrogen stress mediated lipid accumulation in Scenedesmus quadricauda CASA CC202. *Frontiers in bioengineering and biotechnology*, *8*, 585632.

188. Sun, X. M., Ren, L. J., Zhao, Q. Y., Ji, X. J., & Huang, H. (2018). Microalgae for the production of lipid and carotenoids: a review with focus on stress regulation and adaptation. *Biotechnology for biofuels*, *11*(1), 1-16.

189. Sun, X. M., Ren, L. J., Zhao, Q. Y., Ji, X. J., & Huang, H. (2019). Enhancement of lipid accumulation in microalgae by metabolic engineering. *Biochimica et Biophysica Acta (BBA)-Molecular and Cell Biology of Lipids*, *1864*(4), 552-566.

190. Swain P, Tiwari A, Pandey A. Enhanced lipid production in Tetraselmis sp. by two stage process optimization using simulated dairy wastewater as feedstock. Biomass and Bioenergy. 2020 Aug 1;139:105643.

191. Tan, X. B., Lam, M. K., Uemura, Y., Lim, J. W., Wong, C. Y., & Lee, K. T. (2018). Cultivation of microalgae for biodiesel production: a review on upstream and downstream processing. *Chinese Journal of Chemical Engineering*, *26*(1), 17-30.

192. Thomas NV, and Kim SK2013 Beneficial effects of marine algal compounds in cosmeceuticals. *Mar. Drugs* 2013;11:146-164.

193. Torzillo, G., Scoma, A., Faraloni, C., & Giannelli, L. (2015). Advances in the biotechnology of hydrogen production with the microalga Chlamydomonas reinhardtii. *Critical reviews in biotechnology*, *35*(4), 485-496.

194. Udayan, A., Pandey, A. K., Sharma, P., Sreekumar, N., & Kumar, S. (2021). Emerging industrial applications of microalgae: challenges and future perspectives. *Systems Microbiology and Biomanufacturing*, *1*(4), 411-431.

195. Udayan, A., Pandey, A. K., Sirohi, R., Sreekumar, N., Sang, B. I., Sim, S. J., ... & Pandey, A. (2022). Production of microalgae with high lipid content and their potential as sources of nutraceuticals. *Phytochemistry Reviews*, 1-28.

196. Ummalyma SB, Sukumaran RK. Cultivation of microalgae in dairy effluent for oil production and removal of organic pollution load. Bioresource technology. 2014 Aug 1;165:295-301.

197. Ummalyma, S. B., Sahoo, D., & Pandey, A. (2021). Resource recovery through bioremediation of wastewaters and waste carbon by microalgae: a circular bioeconomy approach. *Environmental Science and Pollution Research*, *28*(42), 58837-58856.

198. Ummalyma, S. B., Sirohi, R., Udayan, A., Yadav, P., Raj, A., Sim, S. J., & Pandey, A. (2022). Sustainable microalgal biomass production in food industry wastewater for low-cost biorefinery products: a review. *Phytochemistry Reviews*, 1-23.

199. Unpaprom Y, Tipnee S, Ramaraj R. Biodiesel from green alga *Scenedesmus acuminatus*. *Int. J. Sust. Green Energ.*2015;4:1-6.

200. Valdez-Ojeda, R., González-Muñoz, M., Us-Vázquez, R., Narváez-Zapata, J., Chavarria-Hernandez, J. C., López-Adrián, S., ... & Medrano, R. M. E. G. (2015). Characterization of five fresh water microalgae with potential for biodiesel production. *Algal Research*, *7*, 33-44.

201. Vargas, S. R., Zaiat, M., & do Carmo Calijuri, M. (2021). Chlamydomonas strains respond differently to photoproduction of hydrogen and by-products and nutrient uptake in sulfur-deprived cultures. *Journal of Environmental Chemical Engineering*, *9*(5), 105930.

202. Vidya, D., Nayana, K., Sreelakshmi, M., Keerthi, K. V., Mohan, K. S., Sudhakar, M. P., & Arunkumar, K. (2021). A sustainable cultivation of microalgae using dairy and fish wastes for enhanced biomass and bio-product production. *Biomass Conversion and Biorefinery*, 1-15.

203. Wang L, Li Y, Chen P, Min M, Chen Y, Zhu J, Ruan RR. Anaerobic digested dairy manure as a nutrient supplement for cultivation of oil-rich green microalgae Chlorella sp. Bioresource technology. 2010 Apr 1;101(8):2623-8.

204. Wijffels RH, Barbosa MJ. An outlook on microalgal biofuels. Science. 2010 Aug 13;329(5993):796-9.

205. Winwood RJ. Recent developments in the commercial production of DHA and EPA rich oils from micro-algae. *OCL* 2013;20:1-5.

206. Xia, L., Ge, H., Zhou, X., Zhang, D., & Hu, C. (2013). Photoautotrophic outdoor two-stage cultivation for oleaginous microalgae Scenedesmus obtusus XJ-15. *Bioresource technology*, *144*, 261-267.

207. Xing, C., Li, J., Yuan, H., & Yang, J. (2022). Physiological and transcription level responses of microalgae Auxenochlorella protothecoides to cold and heat induced oxidative stress. *Environmental Research*, *211*, 113023.

208. Xu L, Cheng X, Wang Q. Enhanced lipid production in Chlamydomonas reinhardtii by co-culturing with Azotobacter chroococcum. Frontiers in plant science. 2018 Jun 28; 9:741.

209. Xu, Y.; Qian, S.Y. Anti-cancer activities of ω-6 polyunsaturated fatty acids. Biomed. J. 2014, 37, 112–119. [CrossRef] [PubMed]

210. Yan N, Fan C, Chen Y, Hu Z. The potential for microalgae as bioreactors to produce pharmaceuticals. *Int. J. Mol. Sci.* 2016;17:1-24.

211. Yang, L., Chen, J., Qin, S., Zeng, M., Jiang, Y., Hu, L., ... & Wang, J. (2018). Growth and lipid accumulation by different nutrients in the microalga Chlamydomonas reinhardtii. *Biotechnology for biofuels*, *11*(1), 1-12.

212. Yang, M.; Zhou, M.; Song, L. A review of fatty acids influencing skin condition. J. Cosmet. Dermatol. 2020, 19, 3199–3204. [CrossRef] [PubMed] \

213. Yang, Y.H.; Du, L.; Hosokawa, M.; Miyashita, K.; Kokubun, Y.; Arai, H.; Taroda, H. Fatty acid and lipid class composition of the microalga Phaeodactylum tricornutum. J. Oleo Sci. 2017, 66, 363–368. [CrossRef] [PubMed]

214. Yao L, Gerde JA, Lee SL, Wang T, Harrata KA. Microalgae lipid characterization. Journal of agricultural and food chemistry. 2015 Feb 18; 63(6):1773-87.