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Review

Prospects, recent advancements and challenges of different wastewater streams for microalgal cultivation

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A B S T R A C T

Microalgae are recognized as one of the most powerful biotechnology platforms for many value added products including biofuels, bioactive compounds, animal and aquaculture feed etc. However, large scale production of microalgal biomass poses challenges due to the requirements of large amounts of water and nutrients for cultivation. Using wastewater for microalgal cultivation has emerged as a potential cost effective strategy for large scale microalgal biomass production. This approach also offers an efficient means to remove nutrients and metals from wastewater making wastewater treatment sustainable and energy efficient. Therefore, much research has been conducted in the recent years on utilizing various wastewater streams for microalgae cultivation. This review identifies and discusses the opportunities and challenges of different wastewater streams for microalgal cultivation. Many alternative routes for microalgal cultivation have been proposed to tackle some of the challenges that occur during microalgal cultivation in wastewater such as nutrient deficiency, substrate inhibition, toxicity etc. Scope and challenges of microalgal biomass grown on wastewater for various applications are also discussed along with the biorefinery approach.

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1. Introduction

Microalgal cells are renowned as a powerful biotechnology platform for the production of a wide range of value added products. These include biofuels, animal and aquaculture feeds as well as high value commercial products such as pigments, polysaccharides, bioplastic and organic compounds (Wolf et al., 2015). Microalgae have also been proposed for a biorefinery model where multiple compounds can be produced simultaneously from harvested microalgal biomass (Rahman et al., 2015). Microalgae cultivation requires large amounts of water and nutrient supply which consequently turns commercial scale microalgae cultivation to an economically inefficient process (Ebrahimian et al., 2014).

Cultivation of microalgae in wastewater has long been recognized as a viable option for sustainable biomass production and wastewater treatment (Batista et al., 2014; Brennan and Owende, 2010; Brown and Shilton, 2014; Pittman et al., 2011; Rawat et al., 2011; Ruiz-Martinez et al., 2012). The main nutritional requirement for algal growth includes nitrogen (N), phosphorous (P), and micronutrients such as iron (Fe), magnesium (Mg) and calcium (Ca) which are present in wastewater. Recent developments in microalgal research have demonstrated that microalgae have the required metabolic potential to effectively reduce high concentration of nutrients such as carbon (C), phosphorus (P) and nitrogen (N) present in different wastewater streams (Cai et al., 2013). Therefore, microalgae can be used to serve a dual purpose role for the treatment and polishing of the wastewater as well as generating biomass for various applications.

Various wastewater streams including municipal (Lee et al., 2015a; Selvaratnam et al., 2014), industrial (Dianursanti et al., 2014; Hernández et al., 2013; Kamyab et al., 2015; Pathak et al., 2015; Zhou et al., 2014), and agricultural wastewater (Chen et al., 2015; Cheng et al., 2013; Guldhe et al., 2017; Zhou et al., 2014) as well as primary and secondary effluent, centrate and anaerobic digestion effluent (Ji et al., 2014; Ramsundar et al., 2017; Yang et al., 2015) were exploited as suitable nutrient media for microalgae cultivation. Each wastewater stream has its own characteristics and challenges such as nutrient variability and the presence of potential inhibitors that could impact microalgal growth (Ji et al., 2014). Recently many researchers have developed strategies to overcome the challenges such as low nutrients, high turbidity, bacterial contamination and toxic materials associated with various wastewaters. The types of wastewater utilized for algae cultivation also affect the scope of biomass for various applications.

The basic aspects of algal cultivation in wastewater streams were discussed in detail in a number of papers (Cai et al., 2013; Rawat et al., 2011; Zhou et al., 2014). This review deals with the opportunities of using different wastewaters for microalgal cultivation. The paper critically evaluates the challenges associated with the different wastewaters which have not been given much emphasis in previous literature. The recent advancements are also discussed to overcome these challenges. The prospects and challenges of microalgal biomass grown on wastewater for various environmental and commercial applications have been critically discussed.

2. Prospects and challenges of different wastewaters for microalgal cultivation

2.1. Raw influent

The typical composition and characteristics of raw sewage/untreated effluent can vary depending on the source of wastewater and may contain essential nutrients required for microalgal growth (Komolafe et al., 2014). Successful cultivation of microalgae in different raw wastewater streams based on municipal, industrial and agricultural compositions were reported in recent years (Komolafe et al., 2014; Tsioptsias et al., 2016; Wang et al., 2010, 2013b) (Table 1). Komolafe et al. (2014) used raw domestic wastewater effectively for culturing microalgae (mixed and monoculture) with concentrations of N and P at 42.3 and 35.4 mgL^{-1}, respectively. Biomass yields observed in their study for the monoculture was 0.58 gL^{-1} and for the mixed culture was 0.45 gL^{-1}. They have reported a higher percentage of N (82%), ortho phosphate (61%) removal and total coliform removal (up to 99.8%) with mixed (*Oscillatoria* and *Arthrospira*) cultures compared to the mono culture of *Desmodesmus* sp. Wang et al. (2010) evaluated the growth of a green algae *Chlorella* sp. in wastewater after primary settling of a local municipal wastewater treatment plant and observed growth rate of 0.429 d^{-1} with excellent removal of ammonium (NH_4-N) (74.7%), P (90.6%) and chemical oxygen demand (COD) (56.5%).

Most of the available reports on microalgae cultivation using raw wastewater are based on lab scale observations which might not be a true reflection of the scale of events happening at a full scale level. The varying nature of influent wastewater, flow rate, nutrient composition, presence of heavy metals, microbial interactions, total suspended solids (TSS), and environmental factors such as light, pH and temperature are some of the challenges that might be encountered during large scale microalgal cultivation (Cai et al., 2013). Recently, Lu et al. (2015) evaluated the biomass productivity and nutrient removal capacity of *Chlorella* sp. in dairy raw wastewater using both indoor bench-scale and outdoor pilot-scale