Biofuel potential of aquatic weeds

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ABSTRACT

Dwindling of fossil fuel reserves and global climate change recently demand an alternative carbon neutral energy resources. To mitigate these global critical problems, scientists have paid much attention to the biomass feedstock as a reliable resource for producing the biofuel as carbon neutral energy resources. In this respect, tremendous biomass growth of aquatic weeds in nutrients enriched aquatic environment uptaking various pollutants has received considerable interest in applying as a potential feedstock for producing sustainable biofuels. Though, a number of studies recently demonstrated that biofuel can be produced from biomass of aquatic weeds, there is a lack of comprehensive account in this respect. Therefore, this review attempts to draw a brief account on biofuel potential of aquatic weeds. The present review documented that various macroalgae, water hyacinth (*Eichhornia* sp.*)*, duckweed (*Lemna* sp.), water lettuce (*Pistia* sp.) and some other aquatic weeds such as, *Azolla* sp. *Hydrilla* sp., *Alternanthera* sp., *Ipomoea* sp., etc. have been found to be potential candidates for generating the second and third generations biofuel. Though several aquatic weeds have biofuel potentiality, economical and industrial feasibilities of aquatic weed-based biofuel production should be considered in further researches in order to practical implementation.

1. Introduction

Global warming and climate change are critical challenges of global environment developed by green house gases emitted by fossil fuel (IPCC 2001, 2005). Both dwindling of fossil fuel and changing of global climate have sparked the global interest of alternative and renewable sources of energy. Recently, application of biomass generated fuel (i.e., biofuel) for supplying energy (i.e., bioenergy) is a growing concern, since it is playing a prime role among the most promising renewable energies (Goldemberg 2006; Demirbas 2008).

From the above points of view, there is a growing impetus in finding biomass for potential biofuel feedstock by characterizing qualitative and quantitative biofuel properties of biomass feedstock. Biofuels, such as bioethanol and biodiesel are commonly harnessed from various feedstock containing significant amounts of sugar, such as sugar cane or sugar beet, or starch, such as maize and wheat, and various crops which obviously requires huge lands for cultivation as well as food crops that can poses critical environmental and human food security risks (Donner and Kucharik 2008; Boddiger 2008).

In this respect, scientists have paid much attention for producing biofuel from biomass of grasses grown in cropland (Tilman et al. 2006; Schmer et al. 2008) and of microalgae grown in aquatic systems (Bhakta et al. 2015; Watanabe et al. 1993; Kodama et al. 1993; Hanagata et al. 1992; Takeuchi et al. 1992; Sung et al. 1999) as an alternative sources.

To avoid the problems of cropland and food security, recently, a number of studies have attempted to use biomass of aquatic vegetations/weeds as an alternative feedstock for producing biofuel. It is also widely known that biogas can be produced from aquatic weeds by well-established process of anaerobic digestion using methane-producing microbes (i.e., methanogens - *Methanobacterium* sp., *Methanococcus* sp.,

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Methanosarcina sp., *Methanothrix* sp., etc.) for using as biofuel. Though, several studies used biomass of aquatic weeds for producing biofuel, there is no such appreciable account in this respect to obtain the basic concept and present status of biofuel potentiality of aquatic weeds. The present review has attempted to deal and draw the clear picture of biofuel potentiality of aquatic weeds considering the biomass of various weeds, its biofuel content and advanced technological approaches employed.

2. Aquatic weeds

The vast aquatic environment is the habitat of vast array of aquatic plants. Aquatic weeds are those unabated plants which grow and complete their life cycle in water and directly cause harm to aquatic environment. They can easily grow and propagate in eutrophicated and polluted water environment. Due to these properties, it is applied for deeutrophication and reclamation of eutrophicated and contaminated water body using phytoremediation phenomenon (Singh et al. 2012; Dixit et al. 2011; Bhakta and Munekage 2008; Dunigan et al. 1975; Ornes et al. 1975). Aquatic weeds are of floating, submerged and emergent categories interfering with the static and flow water system (Fig. 1). Various macroalgae are blue-green algae (Cyanophyta/Cyanobacteria) - *Anabaena* sp., *Aphanizomenon* sp., *Microcystis* sp., *Planktothrix* sp., etc.; green algae - Chlorophyta; *Codium* sp., *Ulva* sp. (Fig. 1a), etc.; brown algae (Heterokontophyta) - *Dictyota bartaryesiana*, *Hormosira banksii*, *Ecklonia radiate*, etc.; and red algae (Rhodophyta) - *Cryptonemia* sp., *Augophyllum delicatum*, etc.). Water hyacinth (*Eichhornia* sp.) (Fig. 1b), duckweed (*Lemna* sp.) (Fig. 1c), water lettuce (*Pistia* sp.) (Fig. 1d), azolla (*Azolla* sp.) (Fig. 1e), etc are common floating aquatic weeds, whereas, hydrilla (*Hydrilla* sp.) (Fig. 1f), eel grass (*Vallisneria* sp.) curly-leaf pondweed (*Potamogeton* sp.), coontail (*Ceratophyllum* sp.), parrot feather (*Myriophyllum* sp.), elodea (Egeria sp.), etc belong to submerged weeds. The emergent weeds are water lily (*Nymphaea* sp.), water chestnut, water willow (*Justicia* sp.), water primrose (*Ludwigia* sp.) water shield, alligator weed (*Alternanthera* sp.), cattail (*Typha* sp.), purple loosestrife (*Lythrum* sp.), water pod (Hydrolea sp.), spike rush (*Eleocharis* sp.), pickerelweed (*Pontederia* sp.), smart weed (*Polygonum* sp.), pickerel weed (*Pontederia* sp.), soft rush (*Juncus* sp.), etc. These aquatic weeds generally have highly uncontrolled and tremendously prolific growth ability under favourable environmental conditions by uptaking nutrients as well as hazardous pollutants in wastewater.

3. Biofuel potential

As a result of rapid growth, the aquatic weeds apparently serve duel significantly beneficial ecosystem functions: (i) reclaim the aquatic ecosystem by uptaking nutrients as well as hazardous pollutants and (ii) produce profuse amount of biomass by harnessing nutrients in wastewater or using wetland. This aquatic plant biomass can be converted into various wrathful bioproducts, such as; biofuel which is one of the most important green bioproducts of biomass derived from aquatic weeds. Recently, several studies also revealed that the aquatic biomass has the potential to generate a new range of biofuels that is referred as "second and third generations' biofuel" (Fig. 2). As literature available, the biofuel potentiality of some aquatic weeds has been briefly summarized as follows:

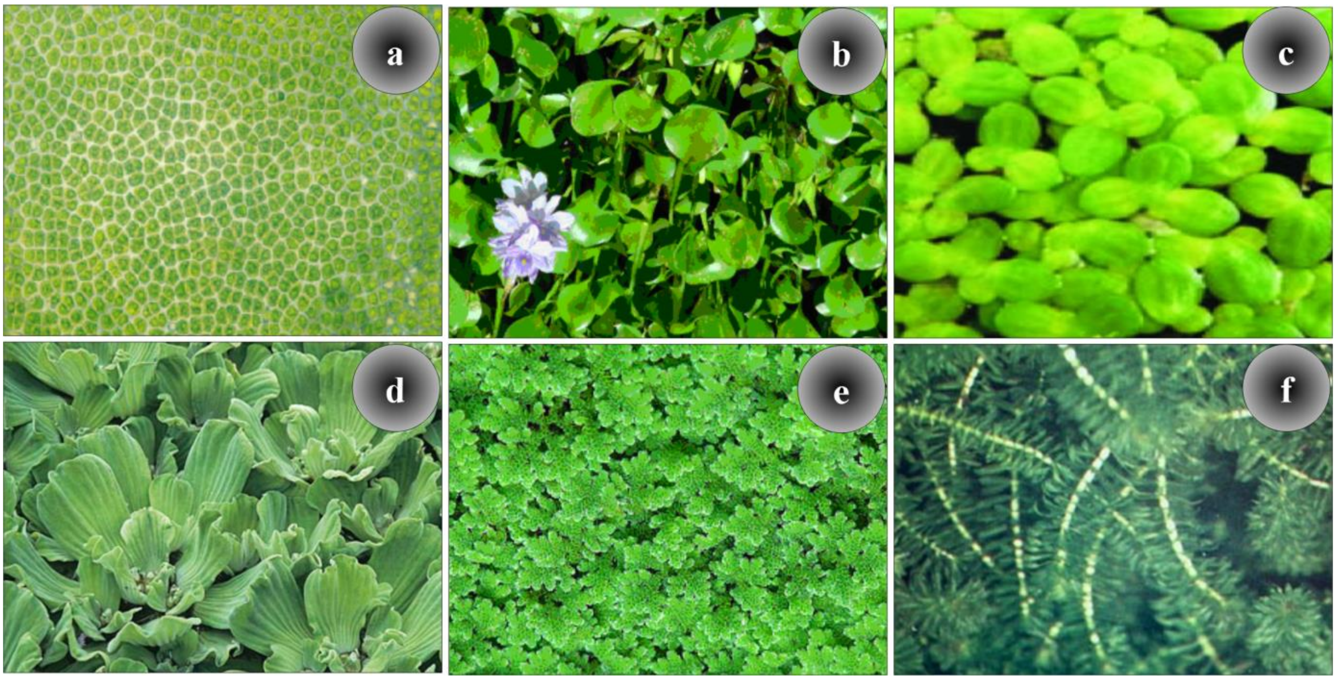

Fig. 1 Some common aquatic weeds of biofuel potential (a) *Ulva* sp., (b) *Eichhornia* sp., (c) *Lemna* sp., (d) *Pistia* sp., (e) *Azolla* sp. and (f) *Hydrilla* sp.

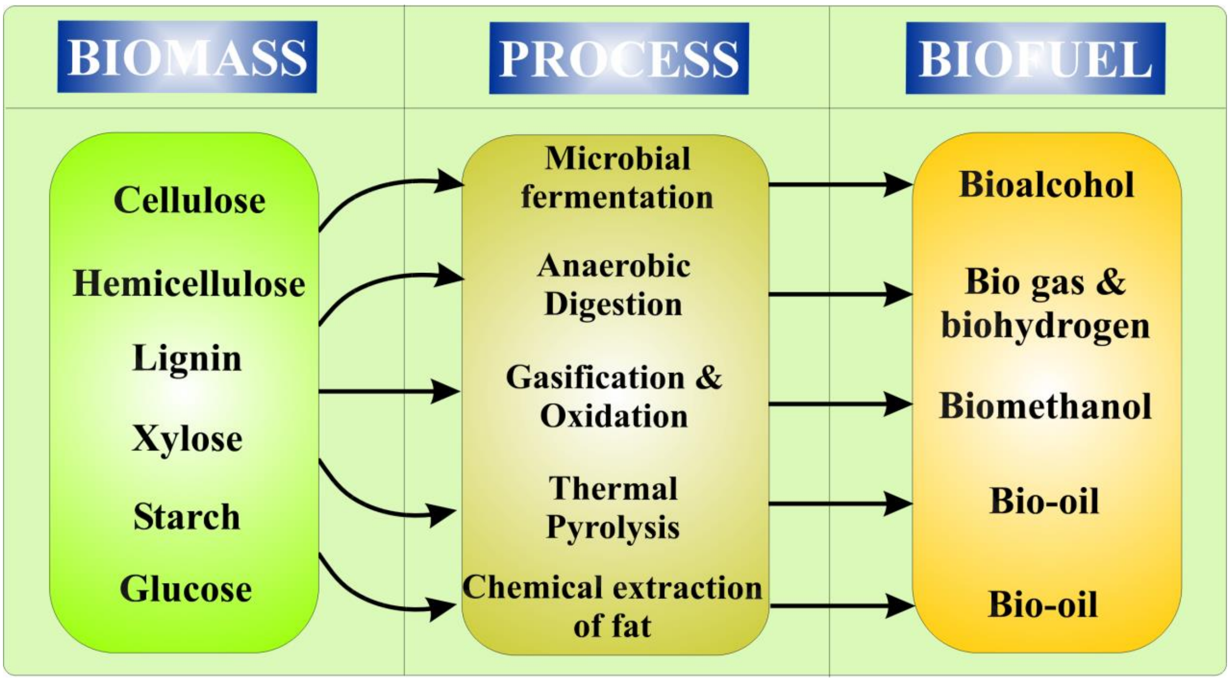

Fig. 2 Schematic diagram depicting some common production processes of second and third generations' biofuel from biomass feedstock of aquatic weeds.

3.1. Macroalgae

Macroalgae grows abundantly in aquatic environment. It is one of the promising sustainable fuel resources for producting renewable energy in terms of food security and environmental issues since it efficiently fixes the greenhouse gas (CO_2) by photosynthesis and does not compete with the production of food (Bharathiraja et al. 2015; Chen et al. 2015). Biofuels, such as biogas, bioethanol, biodiesel and bio-oils are produced from macroalgae (Fig. 2). The researches proved that biomass of macroalgae can be used as feedstock in anaerobic digestion, fermentation, trans-esterification, liquefaction and pyrolysis techniques in order to produce these biofuels (Chen et al. 2015; Milledge et al. 2014; Slade and Bauen 2013). Several investigations reviewed that energy is extract from dry macroalgal biomass by direct combustion, pyrolysis, gasification (conventional) and trans-esterification techniques, whereas hydrothermal treatments, fermentation to bioethanol or biobutanol and anaerobic digestion technology are employed in extracting biofuel from wet macroalgae. Macroalgal biomass typically contents 0.3% – 6% lipids. The study has suggested that high lipid content microalgal biomass is preferable in yielding high amount of biofuel. Biofuel production varies with different methods, such as, 11% biodiesel of the total dry biomass is produced from the macroalgae, *Chaetomorpha linum* (Aresta et al. 2005), *Ulva* sp. (Suganya et al. 2012) (Fig. 1a), *Enteromorpha* (Ulva) *compressa* (Suganya et al. 2013); Bio-oil yields from experimental hydrothermal liquefaction of microalgae, as percentage mass of original dry microalgal biomass, have been reported as: up to 41% for *Spirulina* (Jena and Das 2011), between 24%–45% for *Scenedesmus* (Vardon et al. 2012), 37% for *Dunaliella* (Minowa et al. 1995), and up to 49% for *Desmodesmus* or 75% recovery of the energy in the microalgal biomass as bio-oil (Alba et al. 2012).

Above all reports indicate that macroalgae would be potentially useful candidates which significantly take part a promising role in the field of biofuel production.

3.2. Water hyacinth

Water hyacinth is one of the fast growing tropical aquatic weed invasively distributed throughout the world posing sever environmental problems (Fig. 1b). High biomass productivity of water hyacinth has drawn the attention of researchers in using as suitable feedstock for biofuel production (Bhattacharya and Kumar 2010). Additionally, it consists of lignin (10%), cellulose (25%) and hemicellulose (35%) (Poddar et al. 1991) as potential compounds of biofuel. In addition, this research found that it has a fermentable glucose and xylose content in excess of 48% by dry weight which is suitable for bioethanol production (Malveaux 1995).

The bacterial (*Escherichia coli*, *Klebsiella oxytoca*, *Clostridium acetobutylicum*, *etc*.) and fungal (*Saccharomyces cerevisiae*, *Zymomonas mobilis*, *Aspergillus* sp. etc.) extracellular enzymetic conversion of water hyacinth into biogas or biomethanol, bioethanol and biobutanol, are well documented in a number of developing countries (Pothiraj et al. 2014; Bhattacharya and Kumar 2010; Alvi et al. 2014). Biohydrogen can be produced from microbial decomposition of water hyacinth (Bhattacharya and Kumar 2010).

Alvi et al. (2014) demonstrated that maximum 16.7 g bioethanol/100 g of water hyacinth is produced by *Aspergillus* sp. Water hyacinth was also used by Magdum et al. (2012) for ethanol production by using *Pichia stipitis* NCIM 3497 where a yield of 19.2 g/l was recorded. Malveaux (1995) reported that at a conservative biomass production rate of 0.26 metric tons of dry biomass per hectare per day under proven growing conditions in Louisiana these containment areas yielded 9.62 metric tons of dry biomass 42 per day thus producing 2020.2 kg of sugar for an experimental yield of 1131.3 liters of ethanol per day.

However, rapid growth rate of water hyacinth combined with its fermentable sugar concentration makes it a viable candidate for use as a source of biofuel and for environmental conservation.

3.3. Duckweed

Duckweed is another floating aquatic weeds exhibits rapid biomass growth in eutrophicated water body uptaking high rate of nutrients (Fig. 1c). The high biomass yield showed great potential as an alternative feedstock for the production of fuel ethanol, butanol and biogas (Cui and Cheng 2015). The elevated starch, low cellulose and lignin composition are the unique features of duckweed. Photosynthesis for starch generation and metabolism-related starch consumption are mainly two processes affecting the accumulation of starch in duckweed biomass. Several researches achieved the aims of inhibition of starch degradation as well as accumulation of starch in duckweed which characterized it as excellent candidate of bioproduct.

Due to these properties, its biomass shows great promise as a biofuel feedstock. Therefore, several researchers and private concerns have paid attention in biofuel production using duckweed biomass. Akinwole and Phillip (2014) extracted 5.0 ml oil from 100g duckweed biomass. According to Xu et al. (2012), 31.0 – 45.8% starch of dry weight can be stored by duckweed during 5 – 10 days period of nutrient starvation, and up to 94.7% of the starch could be converted to ethanol using the existing technologies for corn starch conversion. The biogas yield of duckweed is 176 m^3/t, while the yield of corn silage amounts to slightly higher 180 m^3/t (Kovačić et al. 2015).

Moreover, advantageous characteristics include rapid, clonal growth as small free-floating plants on nutrient-rich water; global adaptability across a broad range of climates; naturally high protein content; and inducible high starch content with low or no lignin, which enables other value-added products. Above merits obviously proven that biomass of duckweed is a promising feedstock for generating biofuel.

3.4. Some other aquatic weeds

In addition to above, several other aquatic weeds can be considered as potential bio resources which are effectively available for biofuel production. Aquatic weeds like *Alternanthera sessilis*, *Azolla* sp., *Hydrilla* sp., *Vallisneria* sp., *Typha latifolia*, *Baccopa monnieri*, *Ipomoea aquatica* and *Pistia stratiotes* are estimated for substantial carbohydrates content. That's why; biomass of these weeds is directly or indirectly subjected for potential feedstock to transform into biofuel. Most of them contains high amount of reducing sugar, for example, *Alternanthera sessilis* (296.8 µg/ml), total sugar in *Ipomoea aquatic* (880.00 mg/ml), starch in *Alternanthera sessilis* (57.13 mg/ml), cellulose in *Pistia stratiotes and Typha latifolia* (280.00 mg/ml), hemicellulose in *Typha latifolia* (26.85 mg/ml) (Sunil et al. 2015). Biomass of *Azolla filiculoides* contents high biodiesel producing compounds that indicates its high biofuel potentiality (Salehzadeh et al. 2014). The high amount of alcohol can be produced from the biomass of *Alternanthera sessilis* and *Typha latifolia* using physical (*A. sessilis* 160.5 and *T. latifolia* 115.4 µg/ml) and chemical (*A. sessilis* 387.1 and *T. latifolia* 69.63 µg/ml) methods (Sunil et al. 2015). Rezania et al. (2014) demonstrated that 1.019 g/L ethanol can be produced by biomass of *Pistia* sp. An experiment indicated that renewable value products such as bio-gas, carbon-rich bio-solids and liquid petrochemicals from biomass of water fern azolla, *A. filiculoides* and some other aquatic weeds collected from wastewater treatment system (Muradov et al. 2014). Hummel and Kiviat (2004) reported that *Trapa* sp. can be a source of biofuel in addition to its other significant importance.

However, above appraisal realistically indicated that several other aquatic weeds also have good potentiality in producing biofuel, therefore, biomass of these aquatic weeds would probably be a promising feedstock in the respect.

4. Conclusions

Despite various adverse environmental impacts, prolific growth performance of aquatic plants imparts significant roles in aquatic environment maintaining ecosystem balance minimizing the pollutants generated by various anthropogenic and geogenic activities. Application of aquatic weeds as potential candidates for bioremediation of polluted and contaminated environments is well known facts during last few decades. In addition to several medicinal and nutritional potentials, aquatic weeds recently have drawn much attention to the scientists for producing valuable bioproducts using its biomass as feedstock. It has been evidenced from the above discussion of biofuel production using biomass of aquatic weeds. The brief account on biofuel potential of aquatic weeds meticulously dealt in present review revealed the qualitative and quantitative potentialities of aquatic weeds in producing biofuel. Aquatic biomass has truly proven the biofuel potentiality; therefore, there is promising scope for partial meeting the present and future need of carbon neutral green fuel demanding for sustainable development and conservation of global environment in order to control the effects of climate change.

In spite of these, though several researches have been performed so far concerning the biofuel production using the biomass of aquatic weeds, it is still remain in it's infancy stage in respect to economic viability and feasibility concerning the industrial production of aquatic weed-based biofuel. It is pertinent to conclude herein that vigorous studies are required in the fields of identification of potential candidate from vast array of aquatic weeds in diversified ecosystems, characterizations of qualitatively and quantitatively high graded biofuel, and development as well as modification of economically feasible simple and cost effective methods for the extraction of biofuel in this respect.

Moreover, it can be reported that aquatic weeds would play dual significant roles for developing sustainable environment, primarily by generating valuable biofuel using available aquatic resources without competing the landcrop and secondarily by reclamation of polluted environment growing profuse biomass by harnessing pollutants.

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