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Energy and Food Security from Macroalgae

Deepthi Hebbale[1,2], M. D. Subash Chandran[1], N. V. Joshi[1] and T. V. Ramachandra[1,2*]

[1]Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012, Karnataka, India
[2]Centre for Sustainable Technologies, Indian Institute of Science, Bangalore 560 012, Karnataka, India

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ABSTRACT Macroscopic marine macroalgae is on the verge of becoming popular due to its suitability as potential feedstock for biofuel production as well as supplements for food items. Seaweeds are rich in protein, dietary fibres and phytochemicals used to enhance the nutritional quality of the food products. The increasing demand over renewable and sustainable energy source without compromising on food and land resources can be fulfilled by seaweeds as they are fast growing, high biomass yielding with higher productivity compared to other conventional biomass feedstock. Exploratory survey in the Aghanashini estuary, West Coast of India, has revealed the potential of seaweeds as raw material for both food and energy security in the country. Indian peninsula, with its large coastline, attempts of seaweed cultivation would aid as an important opportunity for better livelihood and income. Unexplored potentials of seaweed resources are to be realised in coastal regions of Karnataka state.

INTRODUCTION

A major global concern today is that one in seven people today do not have access to sufficient protein and energy in their diet and several more suffer from micronutrient malnourishment as well (FAO 2016; Godfray et al. 2010). Burgeoning population with an increase in the wealthy and their higher purchasing power are instrumental in emerging scenario of conspicuous consumption patterns, more production of processed food, meat, dairy and fish, all cumulatively exerting tremendous pressure on basic food production systems. The food producers are experiencing increasing competition for land, water and energy while intensive agriculture, livestock ranging and increasing reliance on aqua-culturing systems for fish, shrimp etc. pose seemingly unsolvable problems on the quality of land, water and air. Godfray et al. (2010) explicitly stated the world in the throes of a threefold challenge:

- Matching the rising demand for food from a large and more affluent population to food production and supply systems.
- Evolving environmentally and socially sustainable production and supply processes.
- Ensuring that world's poorest people are not hungrier and are wholesomely fed.

*Address for correspondence

In the absence of addressing these challenges, about 2 billion of the global population of over 7 billion will face severe food crisis (Wheeler and Braun 2013). In India large fragment of the population suffers with burgeoning population from under nutrition, unplanned urbanisation, increased consumerism (by few with their higher purchasing power) are instrumental in emerging scenario of conspicuous consumption and shifting patterns to more high value (50% increase by 2030) agricultural commodities (Wheeler and Braun 2013) and production of processed food, meat, dairy and fish, etc. These would cumulatively exert tremendous pressure on the sustainability of natural resources. India with the score of 28.5 ranks at 97 among 118 developing countries on Global Hunger Index (2016) compared to counterparts Nepal (GHI score 21.9 ranking 72) and Bangladesh (GHI score 27.1 ranking 90). This highlights the widespread persistence and prevalence of food insecurity due to lack of vision in the planning process. Overcoming malnutrition and hunger in the 21st century necessitates adequate quantity of quality food, and transforming food production systems with the sustainable, efficient and environmentally safer processes (Braun 2007).

Along with food, energy plays a very pivotal role in the welfare of the society. A country's prosperity and welfare depends on the accessibility to reliable and secure supply of energy in any form - oil, gasoline or electricity (Oh et al. 2010). Perishing stock of fossil fuels with higher GHG (Greenhouse gas) footprint and increasing CO_2 levels in the atmosphere to alarming levels have contributed to changes in the climate in the planet. According to International Energy Agency, Global energy consumption is estimated to increase by 53 percent by 2030, with 70 percent of the demand from developing countries. Exploitation of natural resources and consumption of large amounts of fossil fuels have resulted in the production of toxic waste, pollutants, endangering flora and fauna with increased global warming. This has necessitated exploration of technically feasible, economically viable, socially acceptable and environmentally sound energy alternatives to complement or replace fossil fuels (Ramachandra and Deepthi 2016; Posten and Schaub 2009; Borines et al. 2011; Kumar and Sahoo 2012). The current research focusses on the prospects of biofuel from algae.

Algae form the diverse group of organisms, due to their morphotypes, cellular structures, and their proportion ranging from several cm to tens of meters (Misurcova 2011). The macroalgae, occurring in greater abundance in seas and oceans, commonly known as seaweeds, are macroscopic multicellular marine algae, broadly categorised in to three groups based on the colour of the pigment; viz. Green, Red and Brown algae. These groups contain specific polysaccharides (agar, algin, and carrageenan) and phytochemicals (sulphated polysaccharides, polyphenolic compounds and antioxidant enzymes) missing in terrestrial plants (Pereira and Neto 2014).

In conformity with the Declaration by world summit to meet target of (FAO 2015) 70 percent more food by 2050 and on framing policies towards substantial reduction (Kyoto protocol 5.6% by the year 2012) in GHG emissions through increased introductions of renewable as well as more sustainable biofuels the search is already on for sourcing such fuels from marine macroalgae or seaweeds, which are hitherto underexplored, but abundantly available and often cultivable (Tester and Langridge 2010; Forster and Radulovich, 2015).

Seaweed polysaccharides are extensively used as thickening agents in sweet and savoury sauces and condiments, to stabilise food products against degradation, staling and heating or cooling/freezing, also used as fat replacers in a range of food applications (Forster and Radulovich 2015). The market price of one of the phytochemicals, carrageenan was estimated to be $720.3 million in the year 2013, at 5.3 percent rise annually which is projected to reach $931.6 million by the end of 2018.

Carrageenan accounts for 13.3 percent share of the global food and beverage hydrocolloids market. These phytochemical compounds form a part of healthy balanced diet. While protein content of seaweeds is higher than other food materials (Table 1) such as cereals, eggs and fish they are also excellent sources of vitamins A, Bl, B12, C, D and E, riboflavin, niacin, pantothanic acid and folic acid as well as minerals such as Ca, P, Na, K. The known uses of seaweeds as food, date back to 300 BC in China and Japan (Ortiz et al. 2006; FAO 2009; Collins et al. 2016) and these countries are still in the forefront of seaweed cultivation, and consumption in the world. Seaweed variants have been successfully included as an ingredient in the number of food applications. Dried seaweed is high in dietary fibre, along with a range of other potentially bioactive components, its addition has the potential to enhance the nutritional quality of a product (Kim et al. 2008). The pharmaceutical industry is evincing considerable interest in seaweed phytochemicals towards development

Table 1: Nutritive values of some seaweeds in relation to cereals and pulses (in percent)

Seaweeds[1, 5]	*Protein*	*Lipid*	*Carbo-hydrates*	*Ash*
Ulva sp.	26.1	2.1	42.0	7.8
Enteromorpha sp.	19.5	0.3	64.9	15.2
Sargassum sp.	19.0	2.9	33.0	16.2
Padina sp.	18.81	1.7	31.6	10.3
Gracilaria sp.	24.37	1.8	61.75	11.3
Cereals[2, 3]				
Sorghum	8.3	3.9	62.9	2.6
Brown rice	7.3	2.2	64.3	1.4
Maize	9.8	4.9	63.6	1.4
Rice	7.7	2.2	73.7	-
Wheat	11.3	1.8	59.4	1.4
Corn	8.8	3.8	65	-
Millet	10.5	3.9	68.2	-
Oats	10.8	7.2	56.2	2.3
Pulses[4, 5]				
Chickpea	21.2	5.4	45.5	5.4
Lentils	25.4	1.8	53	1.8
Black gram	25.2	1.64	45.5	1.64
Red kidney beans	22.5	1.06	37	1.06

References: [1]Forster and Radulovich 2015; [2]Haard 1999; [3]Koehler and Wieser 2013, [4]FAO 2016, [5]Ramachandra and Deepthi 2016 of novel drugs. Seaweeds antioxidant capability is verified which protect the human body from free radicals and retard the progress of many chronic diseases such as hypertension, heart diseases, diabetes and cancer (Kokabi et al. 2013; Kolanjinathan et al. 2014; Collins et al. 2016). Though the current utilisation of seaweeds, in terms of global food production, is on a very modest scale, they are recognized as wholesome, healthful, and tasty foods.

Food Security

Seaweeds are readily available food sources that have been consumed by coastal communities, particularly in Asia (Table 2), may be from pre historical times. Their popularity through centuries, especially in East and South-east Asian cuisine, has captured global attention and currently seaweed based dishes adorn the menu of most of Europe and America. If tastier, easy to prepare, and moderately priced seaweed products become a reality in rest of Asia and in the West, certainly the seaweeds stand great potential as important component of the world's vegetable diets, embarking a flourishing seaweed farming industry in the imminent future (Forster and Radulovich 2015). Such developments would herald a new era of greater certainty in supplementing or augmenting our existing food supplies, most based on irrigated crops, livestock, and cultured fishery, at great cost to environment and collectively leaving behind enormous carbon foot prints. Seaweeds also provide an edge against possible crop failures.

Table 2: World food production

Food commodity	*Million tons/ year*	*Total %*
Cereals and pulses	2858	32.3
Sugar crops	2103	23.8
Vegetables and fruits (includes tree nuts)	1757	19.9
Roots and tubers	809	9.2
Dairy and eggs	824	9.3
Meat	302	3.4
Fisheries (marine, 79.7 Mt; freshwater, 11.6 Mt)	91	1.0
Aquaculture (marine, 24.7 Mt; freshwater, 41.7 Mt)	67	0.8
Seaweed (farmed, 95.6%; capture, 4.4%)	25	0.3
Total	8836	100

References: Forster and Radulovich 2015; Ramachandra and Deepthi 2016; FAO 2016

There is a growing belief in coastal region that continued growth in aquaculture will automatically relieve pressure on depletion of wild fish stocks, allowing their populations to recover while supplying an ever-increasing demand for protein to nourish a growing human population. However current trends in the world aquaculture industry do not support such belief. Problems have been cropping up from increased feed input, with small oceanic fish for fish meal production bearing the brunt of heavy fishing pressure, while depleting the food source for other carnivorous fish such as tuna as well as for seals and dolphins. Despite rising appreciation of the role of mangroves in coastal ecology, paradoxically enough, 50 percent of world's mangroves have been cleared for establishment of brackish water shrimp farming.

Against such a dismal backdrop, the prospects of seaweed cultivation (unlike shrimp or fish farming), raises a hopeful situation of a net gain, surpassing the constraints of shrimp farming, since seaweeds need nothing more than sunlight energy to convert water, carbon dioxide (available in surplus, as the planet's greenhouse carbon-enriched atmosphere is threatening "ocean acidification" as well), and inorganic nutrients, into sugars that then provide the chemical energy and intermediaries to synthesize more complex carbohydrates, proteins, fats, and other organic nutrients (Kumar and Sahoo 2012). Nutrient upwelling process being closer to shores than open ocean seaweeds are mainly confined to continental shelves. Near-shore waters worldwide are over enriched with inorganic nutrients like nitrate and phosphates due to upwelling and terrestrial runoff causing algal blooms of both micro and macroalgae. Hence a study was undertaken on seaweeds along the coast of Uttara Kannada district towards the centre of Indian west coast in the highly productive and biologically rich Aghanashini estuary. Hundreds of families residing along the estuarine shores are dependent on the estuary for their livelihood through fishing, including collection of bivalves and capture of crabs, shrimp aquaculture and raising of salt tolerant rice crops and capture fishery in the traditional *gazni* rice fields. Mining of molluscan shells, salt production, sand removal, water transportation etc. are other enterprises associated with the estuary (Subash Chandran et al. 2012). Culturing of economically important seaweed resources, especially some of those already present in the estuary (Table 3), could be a good option for harnessing additional resources while minimising the existing extractive pressure on the estuary.

In India, although seaweeds are seldom used for food, their cultivation as sources of raw material for phycocolloids industry is gaining importance. The present state of seaweed underutilisation can be changed through promotion of seaweed farming and popularisation of newer, nutrient rich foods to dispel hidden hunger latent in bulk of the country's population. Seaweed-based enterprises, while generating more income and self-sustaining jobs for especially the farmers and fishers of the densely populated estuarine zone can be a promising economic activity particularly empowering womenfolk (Rao and Mantri 2006; Radhika and Gayathri 2014; Reddy et al. 2014), who are facing crisis as their traditional livelihood sources especially related to bivalve and shrimp fishery, drying and trade, are getting out of gear due to a host of detrimental and exhaustive commercial uses of estuary beyond their control. Seaweed cultivation in estuarine region and processing can emerge as a less taxing but more promising alternatives to redeem the currently emerging bleak situation, which has, has obviously afflicted most other estuaries of the Indian west coast already. Seaweed cultivation is less demanding as regards resource and manpower inputs are concerned unlike organizing fishing and other agricultural activities. Seaweeds based foods could turn out to be more affordable and promising in future, at least in the coastal zones. High-valued seaweed species has promising potential markets in Europe, USA, Japan etc. Consumption of certain algae (*Undaria* or *Sargassum* of marine and *Spirulina* of fresh water sources) is associated with decreased rates of HIV infection (after controlling for important covariates) (Teas et al. 2004). Improvements in farm efficiency and techniques related to seawards can bring to the doorsteps easily affordable and nutritionally rich seaweed products. Seaweed cultivation is in its formative and experimental stage in India, initially seaweeds were over exploited from natural resources, depleting the supply of raw materials. In order to stop this, edible and pharmaceutically important seaweeds such as *Enetromorpha* and *Ulva* and economically important seaweeds such as *Sargassum, Cystoseira and Hypnea, Gelidiella* and *Gracillaria* were attempted at large scale cultivation (Rao and Mantri 2006; Chanakya et al. 2012; Reddy et al. 2014).

Energy Security

Renewable energy has been making strident progress in India in recent times (Garg 2012; TERI 2010; Ramachandra and Ganesh 2015), evident from the fivefold renewable grid capacity increase in a span of 8 years (2002-2010) compared to European Union (EU) and USA. This growth is largely based on thermal energy, with other sources making important contributions. The conventional sectors are starting to face problems such as mining and import of coal, logistics and transport issues, limited extractable coal reserves and other environmental and climate change threats making project clearances difficult to obtain.

Biomass based energy accounts roughly for a quarter of India's energy consumption, by far the largest share of which is the traditional use of biomass for cooking in households (Fig. 1). Largest share of biomass such as Bagasse (a by-product of sugarcane processing) have been utilized for 7 GW of power generation capacity in 2014 (Briol 2015; Ramachandra and Hegde 2015; TERI 2010), and a smaller share is cogeneration based on other agricultural residues. Other biomass based energy such as syngas and small scale thermal gasifiers are obtained via a range of gasification technologies.

Table 3: Current uses of seaweed species found in Aghanashini Estuary

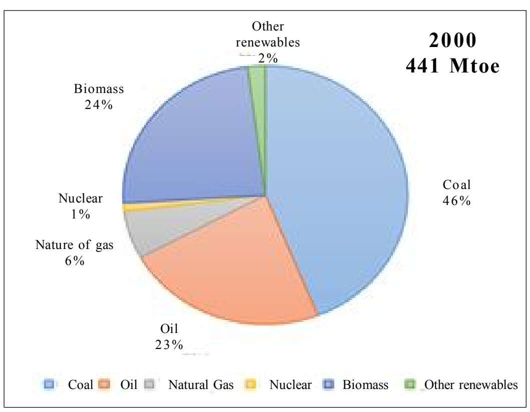
S. No.	*Species*	*Food*	*Feed*	*Industrial uses*	*Medicine*	*Fertilizer*	*Biofuel*
1.	*Ulva lactuca*	+	+	-	+	-	+
2.	*Enteromorpha intestinalis*	+	+	-	+	-	-
3.	*Padina tetrastromatica*	-	-	+	-	+	+
4.	*Gracillaria corticata*	+	+	+	-	-	+
5.	*Grateloupia lithophila*						+
6.	*Gelidium pusillum*			+			+

In India, energy from biomass constitutes only a small share of energy use at present, which has led to recognition of National Bioenergy Mission – the potential of biomass based energy to become a larger part energy requirement in rural, providing additional source of income to farmers, as well as power and process heat for consumers. In the year 2009, an ambitious biofuel blending mandate was supported with 20 percent share for bioethanol and biodiesel by 2017. Though implementation has been slower (bioethanol from sugarcane being well under 5%), due to concerns such as adequacy of supply: land, water and fertilisers for biofuels cultivation that may be limited and is required in other sectors (Kumar and Sahoo 2012; Briol 2015). Hence, one of the prime economic and developmental challenges for the country is the need for secure, affordable and environmentally sustainable energy.

In overall primary energy consumption, fossil fuels account for 88 percent, oil (35%), coal (29%) and natural gas (24%) while nuclear and hydroelectricity account for 5 percent and 6 percent respectively (TERI 2010). Given the current technological progress, potential reserves, and increased exploitation of newer unconventional reserves (such as natural gas, solar energy), it is probable that fossil fuels will be available at relatively lower costs for longer times than feared. On the flip side of such complacency is the gloomy scenario of rising greenhouse gases (GHGs) from fossil fuels, which necessitate alternative technologies and unconventional fuel sources, integral to ensure future energy security and reduction of GHGs. Introduction of biomass based biofuels certainly should signal a perceptible shift from hydrocarbon to carbon based economy.

India's current energy requirements are met by fossil fuels to an extent of 70 percent (Yanagisawa et al. 2011; Ramachandra and Ganesh 2015). Being one of the world's fastest growing energy markets and due to its rapid economic expansion, it is expected to be the second-largest contributor to the increase in global energy demand by 2035, accounting for 18 percent of the rise in global energy consumption. As recent times are witnessing high degree of geopolitical volatility in Middle East and North Africa (suppliers of oil to India up to 60%) crude oil production shows uncertain trends causing increased prices and inflation in India.

India has limited domestic fossil fuel reserves and the country needs to expand its renewable and sustainable fuel program. While renewable sources like solar, wind, and hydro energies may generate electricity or heat either directly or indirectly, biomass is the only renewable energy source useful for producing liquid fuels (biofuels) mainly for transportation. As currently used bioethanol feedstock like sugarcane, maize, and wheat and all land-based crops, their continued and increased use, results in the major "food versus fuels" (Posten and Schaub 2009; Brennan and Owende 2010; Kumar and Sahoo 2012; Chanakya et al. 2012) debate especially as the proportion of land to be used for such biomass crops is concerned, whereas seaweeds are beyond such constrains, not needing farmlands,



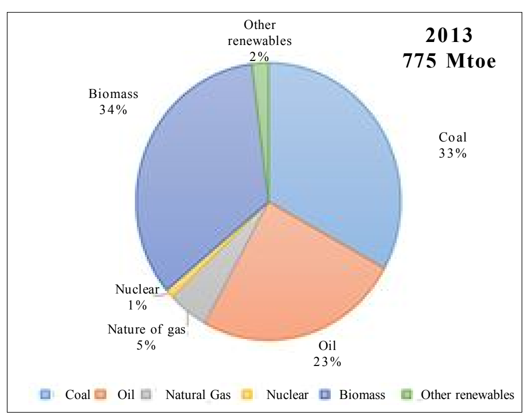


Fig 1. Primary fuel energy demand in India
Source: Author

but only underused coastal brackish or salt water bodies.

Therefore, studies focusing on marine sources of biomass, as a feedstock for future bioethanol generation, are gaining importance. Macroalgae due to their fast growth rate, large biomass yield, and higher productivity as compared to many terrestrial crops, make promising bioethanol feedstocks for the future. Their physical support being furnished by water, seaweeds needn't invest energy and material in lignified tissues. Their entire surface area being permeable to mineral nutrients, and photosynthetic pigments dispersed through the entire exposed surfaces they have insignificant energy needs for internal nutrient transport, all contributing to their high biomass production potential (Kumar and Sahoo 2012). Seaweed biomass accumulates large amount of carbohydrate, which are broken down to simple reducing sugars through acid or enzymatic treatments, these reducing sugars are subjected to fermentation using yeast microorganism as illustrated in Figure 2.

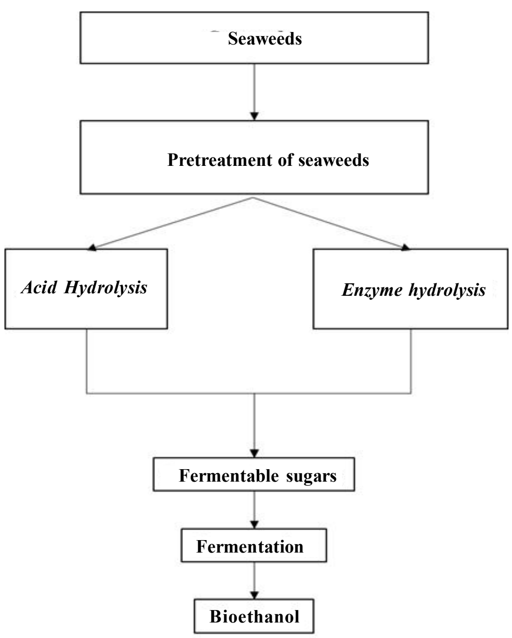


Fig. 2. General schematic of bioethanol from Seaweeds
Source: Author

The Indian Peninsula, enveloped by an extensive coast line from Kutch to Cape Comorin and beyond into the Sunderbans (apart from the coasts of Lakshadweep and Andaman and Nicobar Islands), has immense potential for seaweed production. In earlier reports (Reddy et al. 2014) a standing crop of 258,715 tons wet weight of seaweeds has been estimated from the intertidal and shallow sub-tidal waters of India. A total of 60 commercially important seaweeds have been recorded from Indian waters. Their current utilisation is mainly confined to production of commercially and industrially important phycocolloids. Raw materials are harvested manually, bringing additional source of income to over 10,000 coastal fisher folks (Reddy et al. 2014). Seaweed farming in India is currently in its infantile stage is poised for a due to primitive measures for cultivation and harvest strategies for sustainable production and utilization. The Central Marine Fisheries Research Institute (CMFRI) of India has developed and perfected techniques for culturing *Acanthophora spicifera Gelidiella acerosa, Gracilaria edulis and Hypnea musciformis*, and now attempts are being made to find improved techniques for propagation and large scale culture of other economically important seaweeds. The Pepsi Foods Ltd. (PFL) has initiated cultivation of *Kappaphycus alvarezii*, an exotic seaweed, along a 10 km stretch of the Palk Bay side towards Mandapam in Tamil Nadu, with technical support from Marine Algal Research Centre, CSMCRI, Mandapam. The species is cultivated in 100 hectares through a contract farming system in which seaweeds are grown in individual plots of 0.25 ha (40 m x 60 m). Each harvest cycle takes 45 days with an annual yield of 100 tons (wet weight) per hectare, which makes 10 tons of dry seaweed enough for production of 2.5-3 tons of carrageenan (Radhika and Gayathri 2014; Reddy et al. 2014). The company has ambitious plans for expansion of seaweed cultivation. The seaweed industry is certainly on its way towards establishing itself well in India, for mainly production of agar and algin.

Recent research progress in India has unravelled the potential of the green seaweed Enteromorpha *compressa* in curing various types of allergies (Ramachandra and Deepthi 2016; Rao and Mantri 2006). Algal *Enteromorpha* is an edible alga successfully being cultivated in Okha, Gujarat. *E. intestinalis* was selected as a source of carotenoid for inclusion in the formulated diet of shrimp *Penaeus monodon.* In the Sundarbans, its cultivation is undertaken mainly for use as mineral rich manure. Nutritionally Ulva is a rich source of iodine, aluminium, manganese, magnesium, sodium, potassium, copper, zinc, trace elements and ash. It is high in iron (15 times greater than egg yolk) and calcium. Rich in protein is comprised of all 9 essential amino acids including Lysine which is the amino acid that is typically deficient in most vegetarian diets. It is rich in vitamins and antioxidants. High concentration of Beta carotene makes consumption of Ulva good for eye, health and as antioxidant. Ulva can be eaten raw in salads but it also used in cooking, soups, with meats and fish (Forster and Radulovich 2015).

Introduction of Seaweed farming by integrated coastal management projects has been initiated in India to raise the socioeconomic status of coastal communities as well as to provide an alternative income for fisher folks. Small scale algal cultivation requires little technical knowhow and almost no start-up costs. Biofuel from seaweeds could be a potential source of renewable energy, without any taxing on farmland resources, and promises new vistas in the agricultural marketing scenario of India. India, rich in seaweed diversity, has also suitable areas for mass cultivation. The Kharlands or *gazani* of Karnataka, *bheris* of West Bengal, *gheris* of Orissa, pokkali rice fields of Kerala are prospective areas for cultivation of appropriate seaweed species.

In Aghanashini estuary, *gazani* fields were traditionally being utilized for cultivation of salt tolerant 'Kagga rice'. After harvest of rice towards the end of south-west monsoon, the fields used to be flooded with the water from the rising tide of the estuary, and used for fishery purpose. Parts of this estuary is currently being utilized for especially shrimp culturing. These *gaznis*, during the post-monsoon are essential locations for seaweed cultivation, at least in small parts, with only beneficial output towards fishery as well. Algal cultivation during post-harvest season of fisheries offers promises to the local communities in attaining an alternative and a self-sustained income generating job (Ramachandra and Deepthi 2016).

METHODOLOGY

Collection of Algal Sample

Seaweeds are collected from Aghnashini estuary and washed thoroughly with tap water to remove salts, epiphytes and debris. Shade dried or oven dried to a constant weight at temperature of 50°C. After drying, the seaweed samples are powdered using grinder for chemical composition analysis.

Chemical Composition of Seaweed

Seaweeds chemical composition analysis includes the determination of protein, carbohydrate, lipid, cellulose content and reducing sugars following the method as per standard protocol (Lowry et al. 1951; Dubois et al. 1956; Folch et al. 1957; Updegroff 1969; Miller 1959).

Pre-treatment Method

Seaweed carbohydrates are broken down to simple sugars for bioethanol production. These sugars are firstly released from the biomass using pre-treatment methods such as dilute acid and enzyme hydrolysis. In dilute acid pre-treatment method complex carbohydrates of seaweed is broken down to simple sugars (disaccharides), enzyme hydrolysis further breaks down these sugars to fermentable sugars.

Mineral acids such as H_2SO_4 and HCL of various concentration are used for acid hydrolysis. Enzyme hydrolysis is carried out using different enzymes as they are highly substrate specific. Since major portion of seaweed cell wall is composed of cellulose, to break down cellulose *cellulase* enzyme is employed at different dosage and incubation period for the maximum yield of fermentable sugars. Similarly, *agarases* for agar, *alginases* for alginate, *carrageenase* for carrageenan, *laminarases* for laminarin. Compounds with rigid structures are hydrolyses using bioengineered genes.

Fermentation

Fermentable sugars are utilised by yeast microorganisms and ethanol is obtained as by product. Favourable thermal conditions to convert fermentable sugars into ethanol is around 35-40°C. Most common organism such as *Saccharomyces cerevisiae* (ethanol tolerant species) are used for fermentation process to convert fermentable sugars into ethanol, these microorganisms are highly specific to hexose sugars. In case of certain pentose sugars, specific organisms like *Pichia angophorae*, *Zymobacter palmae, Pichia stipitis* are employed for fermentation

(Horn et al. 2000; Yeon et al. 2011; Lee et al. 2013; Cho et al. 2013, Trivedi et al. 2015).

$$\begin{array}{ccccccc} \text{Glucose} & & \text{Ethanol} & & \text{Carbon dioxide} & & \\ C_6H_{12}O & \longrightarrow & C_2H_5OH & + & CO_2 & + & \text{Heat} \\ 1\text{kg} & \longrightarrow & 511\text{g} & + & 489\text{g} & + & 147\text{ Kcal} \end{array}$$

Above equation shows the basic biological reaction in the conversion by fermentation of one kilogram of glucose to ethanol, carbon dioxide, and heat. Theoretically, the maximum conversion efficiency of glucose to ethanol is 51 percent on the weight basis. However, some glucose is used by the yeast for the production of cell mass and for metabolic products other than ethanol. Therefore, only 40 to 48 percent of glucose is converted to ethanol with a 45-percent fermentation efficiency, 1,000 kilograms of fermentable sugar produce about 570 L of pure ethanol. Economically feasible ethanol concentration for distillation should be around 4-5 percent.

RESULTS AND DISCUSSION

Table 4 gives biofuel production from different types of seaweeds based on literature review (Yanagisawa et al. 2013 Trivedi et al. 2015; Ramachandra and Deepthi 2016; Troell et al. 2006). Cellulosic rich seaweeds are easily hydrolysed by both acid and enzyme treatment resulting in higher yields of ethanol. Not all the sugars that are present in seaweeds are fermentable, Sugar alcohols like mannitol, sulphated polysaccharides like carrageenan, ulvan and alginate needs to be broken down into simpler sugars to achieve higher ethanol yield. Thus, the production of high concentrations of ethanol from seaweeds requires the conversion of all major carbohydrates into ethanol (Ramachandra and Deepthi 2016; Yanagisawa et al. 2013)

Suitability of Macroalgae as Feedstock for Biofuel Production

Microalgae as feedstock for biofuel production is appropriate due to

- Higher productivity - mass productivity of Macroalgae is 13.1 kg dry weight m^{-2} over a seven-month growth period, compared to terrestrial plants (0.5–4.4 kg dry weight m^{-2} per year);
- entire cell mass is utilized for biofuel production compared to terrestrial biomass feedstock, wherein only a part is economically useful for biofuel production;
- cultivating macroalgae in waste water, brackish water, and saline water do not pose threat to food security.

CONCLUSION

The vast stretches of coastal wetlands and the offshore regions that envelope Peninsular Indian subcontinent, has immense, but poorly realised potential for seaweed production. The increasing problems with conventional land-based agricultural systems are ridden with problems of varied sorts, and attractive prices for their products are seldom realized by the bulk of

Table 4: Bioethanol from seaweeds

Seaweeds	*Ethanol yield g/l*	*References*
Ulva pertusa	7.2	Yanagisawa et al. 2011
Ulva fasciata	0.45g/g RS	Trivedi et al. 2013
Ulva reticulate	90 L/t	Yoza and Masutani 2013
Undaria pinnatifida	9.42	Cho et al. 2013
	12.98	Kim et al. 2008
Saccharina japonica	6.65	Lee et al. 2013
Laminaria japonica	2.9	Lee et al. 2013
	0.41	Kim et al. 2008
Saccharina latissimi	0.45%	Ramachandra and Deepthi 2016
Alaria crassifolia	0.244	Yanagisawa et al. 2013
Kappaphycus alvarezi	64.3	Hargreaves et al. 2013
	0.147 L per kg granules	Khambhaty et al. 2012
	0.369 g/g RS	
Gelidium elegans	55	Yanagisawa et al. 2011
Gracillaria verrucosa	0.43 g/g RS	Kumar et al. 2013
Saccharina japonica	0.41 g/g RS	Wargacki et al. 2012
Sargassum sagamianum	0.386 g/g RS	Yeon et al. 2011
Laminaria hyperborean	0.43 g/g RS	Horn et al. 2000

these coastal farmers. In this scenario the seaweed cultivation and uses promise unexplored vistas especially in the coastal scenario of Karnataka State. From the point of elevating the nutritional and economic status of the coastal communities much research work is needed on several seaweeds. Further field investigations with optimisation technquies are required to realise bio-energy production from abundantly available algae, especially of Enteromorpha spp. which grows in brackish water.

RECOMMENDATIONS

Seaweeds are promising resources in terms of achieving the food and energy security in India, though the developments have been made in food industry but yet to achieve complete hydrolysis of seaweed carbohydrate. Introduction of seaweed based food items into world's vegetable diets, augments our existing food supplies with greater nutritive value, and also provides an edge against possible crop failures. Seaweed harvest from wild stocks is sustainable practice only in certain parts of the world where natural biomass is considered to have been triggered due to nutrient pollution of natural marine systems, or if the species is a pest. Large scale harvesting in wild is regarded as undesirable as it causes significant environmental impacts for associated marine fauna. Therefore, in India cultivation of seaweeds to be practiced in large expanses of flood plains in estuaries and development of cost-effective methods to transport, and process macroalgae for various industrial applications is the most crucial. Locating suitable sites for seaweed cultivation, and employing fisher folks especially women, to take up seaweed farming during off-season while not meddling into their conventional fishing activities.

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