Journal of
Bioremediation & Biodegradation

Rajkumar and Takriff, J Bioremediat Biodegrad 2016, 7:1
DOI: 10.4172/2155-6199.1000321

Review Article

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Prospects of Algae and their Environmental Applications in Malaysia: A Case Study

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Abstract

Algae are gaining wide attention in the recent times energy scenario as an alternative renewable source of biomass due to the increased awareness of finite fossil-fuel resources and the associated problems. From the environmental aspects, algae could be used to produce biofuel, to remove nutrients and other pollutant from wastewaters, to maintain water quality, as indicators of environmental change and as CO_2 sequester. The present review discusses an overview of micro and macroalgae resources and their environmental application includes wastewater treatment, CO_2 sequestration and biofuel production are highlighted. Several recommendations are added from the author's point of view regarding the prospects of Malaysia becoming a leading figure in algae utilization. It is hope that Malaysia's progress in algae products industry will not only benefit itself but rather as the role model to catalyst the development of global algae industry as a whole.

Keywords: Biofuel production; CO_2 sequestration; Microalgae; Macroalgae; Wastewater treatment

Introduction

The photosynthetic organisms considered in this review are macroalgae and microalgae growing in aquatic environments. Macroalgae or "seaweeds" are multicellular organisms and belong to the lower plants, consisting of a leaf-like thallus instead of leaves, stems and roots [1,2]. On the contrary, microalgae are microscopic organisms that can grow rapidly and live in salt or fresh water environments [3]. It extends to extreme environments such as ice or hot springs pose no obstacle to them. At present over 100,000 algae species are known. However, some 400,000 species of algal exist worldwide according to the general estimates [4]. In Malaysia have the vast algae resources and the author Mazlan et al. [5] estimates number of known species of marine algae in Malaysia and the world (Table 1).

Malaysia has an excellent of algal experience in the academic side as well as in industry, relevant to the use of algae in environmental and other higher value applications. Great profits could be resulted from integrating this expertise to a better extent. In Malaysia, algae research is actually not a new topic as evident from the several publications. The main contributors of initial development of algae research in Malaysia including scientific expeditions to the east comprising mainly of the "Preussische Expedition nach Ost-Asien from 1859 to 1863, the British H.M.S. Challenger Expedition in 1874, the Dutch Siboga Expedition from 1899 to 1900 and the "Deutsche Limnologische sunda Expedition" in 1929 [6]. As these expeditions shown that the algae were mostly collected from marine habitat of Malaysia was being enumerated and published [7,8]. Malaysia and the UK was jointly founded the Tropical Fish Culture Research Institute in Malacca during 1957 to conduct combined research project on the taxonomy, distribution and ecology of freshwater algae in Malaysia. In 1982, United Nations was also supported for further research on unicellular algae as aquaculture food source. Since then, several algae research findings have been published [9,10].

Extensive coastline surrounded by numerous islands which can offer variety of ideal habitats for the feasibility of algae mass cultivation in Malaysia. Apart from these, Malaysia with a lot of under-utilized rice land is also an ideal choice for growing algae. Those secondary lands are infertile since infiltration salt water and farmers are searching for other choices. Totally, marine algae in Malaysia now stands at 375 specific and intra-specific taxa with reference to the regular collections and documentations of algae strains can be dated back to the year of 1859 [9]. In Malaysia, past algae research mainly focused on identification of native microalgae strains, utilized in wastewater treatment, bio-indicators of heavy metal pollution and control of mosquito breeding [6]. The fundamental studies in algae research have shown in many publications of checklists and monographs that recorded the microalgae diversity in Malaysia [11-13].

Algae are produced a wide range of commercial metabolites with

Major categories	Groups	Estimates of number of known species of marine algae in Malaysia	Estimates of number of known species of marine algae in the world
Seaweed and other algae	Chlorophytes	78	800
	Rhodophytes	69	4000
	Phaeophytes	49	1500
	Cyanophytes	13	1500
Phytoplankton	Diatoms	70	4200
	Dinoflagellates	30	1200

Table 1: Estimates of number of known species of marine algae in Malaysia and the world as reported by Mazlan et al [5].

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Received October 29, 2015; **Accepted** December 02, 2015; **Published** January 04, 2016

Citation: Rajkumar R, Takriff MS (2016) Prospects of Algae and their Environmental Applications in Malaysia: A Case Study. J Bioremediat Biodegrad 7: 321. doi:10.4172/2155-6199.1000321

various bioactivities that are yet to be completely exploited [14]. Figure 1 illustrates schematic diagram for microalgae potential applications. Microalgae were isolated from different habitats in Malaysia and screened for these commercial values [15]. Algae Culture Collection, University of Malaya (UMACC) was established for the repository of microalgal cultures [6]. More than150 microalgal isolates holds by the UMACC and is the biggest microalgae culture collection in Malaysia [16].

The carbon cycle has changed globally because of extensive use of fossil fuels, coal etc. This leads to increase the emission of CO_2, and other gases in to the environment. In order to achieve environmental sustainability, carbon neutral and renewable fuels are essential that are also capable of sequestering CO_2. In this both micro and macroalgae perform to be a main resource that can replace fossil fuels and sequester high level of CO_2. Algae utilize large amounts of nitrogen, phosphate, and CO_2 that are converted into biomass thus making these species attractive for CO_2 sequestering and pollutants reduction of waterways [17,18]. Algae utilize CO_2 as well as water and convert them into lipid, carbohydrates and other commercial products. Both algae groups will be considered in this review, but as there is lot of research, applied experience, culture and more biofuel routes from algae, these will require a bigger share in this review.

General properties of algae

Generally, algae are categorized into two groups microalgae and macroalgae based on their morphological features and size. The number of algae species has been calculated to be one to ten million, most of which are microalgae. Microalgae are thought to be one of the most primitive life forms on earth [19] and growing very fast in the world. They are able to grow in various extreme conditions (high temperatures and pH) since they can inhabit diverse ecological habitats. These abilities make microalgae the most abundant living organisms on earth. The frequently used micro-algae are classified under four main groups i.e., Cyanophyceae (blue-green algae), Chlorophyceae (green algae), Bacillariophyceae (including the diatoms) and Chrysophyceae (including golden algae) [3]. The microalgae such as *Arthrospira* (*Spirulina*), *Chaetoceros*, *Chlorella, Dunaliella* and *Isochrysis* are the dominating genera in commercial scale cultivation [20]. Ecological surveys of microalgae were recorded on varies aspects covering distribution, zonation, water quality, frequency in different places in Malaysia. The microalgal populations of Malaysia are summarized in Table 2. This feature provides competitive advantage under the local geographical, climatic and ecological conditions that these algae species have considerable potential for offering new bioactive compounds, chemicals, materials. Currently, 31 countries and territories are recorded with algae farming production, and 99.6% of global cultivated algae production comes only from eight countries. Among these, Malaysia produced 1.1% (207,900 tons) of cultivated microalgae (Figure 2). The microalgae vast biodiversity creates the discovery of new products very likely. The proteins, carbohydrates and lipids composition of microalgae biomass is varied as shown in Table 3 [21-23]. It is essential to pay special attention for the selection of suitable species and cultivation

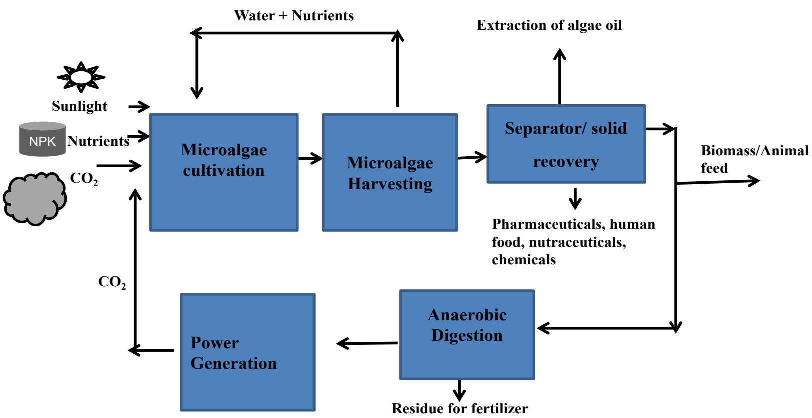

Figure 1: Schematic diagram for algae applications.

Study area	Microalgae species detected	Group	Reference
Jeli, Gunung Stong, Kelantan (Fresh water)	*Achnanthes oblongella; A. exigua; Amphora bitumida; Cocconeis* sp. *Cymbella gracilia; C. naviculiformis; Eunotia* sp.; *Fragilaria pinnata Frustulia* sp.; *Gomphonema* sp.; *Navicula* sp.; *Navicula radiosa Navicula rhynchocephala; Pinnularia microstauron; Surirella* sp.; *Synedra ulna*	Bacillariopyceae	[100]
	Anabaena sp.; *Bangia* sp.; *Lyngbya* sp.; *Oscillatoria agardhii; Scytonema* sp.	Cyanophyceae	[100]
	Ankistrodesmus sp.; *Mougeotia* sp.; *Spirogyra* sp.; *Zygnema* sp.	Chlorophyceae	[100]
Bukit Jalil, Kuala Lumpur (Airborne)	*Phormidium tenue*	Cyanobacteria	[100]
Tasek Bera (Lake Bera), Ampang Park in the city of Kuala Lumpur, peninsular Malaysia (Fresh water)	*Batrachospermum phangii* sp. nov.; *Sirodotia delicatula; Balliopsis prieurii; Batrachospermum beraense* Kumano; *Batrachospermum cylindrocellulare* Kumano; *Balliopsis macrosporum; Compsopogon caeruleus*	Red algae	[102]
local freshwater located at Penang, Malaysia (Fresh water)	*Chlorella vulgaris*	Chlorophyceae	[103]

Table 2: The list of some species of microalgae reported from the study area in Malaysia.

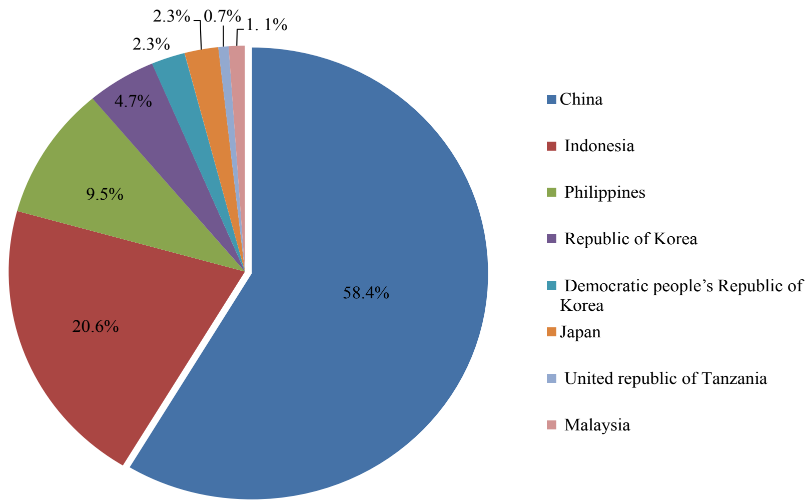

Figure 2: Malaysia annual microalgal production in comparison to major algae producing countries [36].

Microalgae	Protein (%)	Carbohydrate (%)	Lipid (%)
Anabaena cylindrical	43–56	25–30	4–7
Aphanizomenon flos-aquae	62	23	3
Arthrospira maxima	60–71	13–16	6–7
Botryococus braunii	8–17	8–20	21
Chlamydomonas rheinhardii	48	17	21
Chlorella pyrenoidosa	57	26	2
Chlorella vulgaris	51–58	12–17	14–22
Dunaliella bioculata	49	4	8
Dunaliella salina	57	32	6
Euglena gracilis	39-61	14-18	14-20
Isochrysis sp.	31–51	11–14	20–22
Neochloris oleoabundans	20–60	20–60	35–54
Porphyridium cruentum	28–39	40–57	9–14
Prymnesium parvum	28–45	25–33	22–38
Scenedesmus obliquus	50–56	10–17	12–14
Spirogyra sp.	6–20	33–64	11–21
Spirulina maxima	60–71	13–16	6–7
Spirulina platensis	46–63	8–14	4–9
Synechococcus sp.	63	15	11
Tetraselmis maculata	52	15	3

Table 3: Chemical compositions of algae biomass based on dry matter [21,22,23].

types to achieve the maximum benefits from microalgae biomass. The cultivation of microalgae is composed of a single specific strain that is accurately selected for producing the target product and the most beneficial outcome of the cultivation process.

Macroalgae are classified as brown, red and green algae, based on the thallus color originated from natural pigments and chlorophylls [24]. Brown algae are known as Phaeophyceae under phylum Chrysophyta. The molecules such as chlorophyll a and c, b-carotene, and other xanthophylls are the principal photosynthetic pigments in brown algae [24]. It has 1500–2000 species exist [25]. Red algae are all included in a single class of Rhodophyceae consisting of two subclasses (i.e., Bangiophycidae and Florideophycidae). The red color pigment is produced from chlorophyll a, phycocyanin and phycoerythrin [24-26]. There are 4000–6000 red algae species in over 600 genera, and most of them presented in tropical marine environments [27]. Green algae belong to phylum Chlorophyta, which contain the same ratio of chlorophyll pigment *a* to *b* as land based plants [26]. In addition, herbaceous green plants had evolved from green algae as reported by Lewis and McCourt [28]. Even though that is still controversial, there is no doubt that biochemical components of land plants are similar to green algae. There are about 4500 green algae species containing 3050 algae species of freshwater-favorable (class Trebouxiophyceae and Chlorophyceae) and 1500 algae species of saltwater favourable (class *Bryopsidophyceae, Dasycladophyceae, Siphoncladophyceae, and Ulvophyceae)* [29]. The macroalgal populations of Malaysia are summarized in Table 4. The macroalgae growth rate is significantly affected by their environmental factors such as temperature, light, salinity, nutrient, pollution and water motion, mostly depending on their species like *Enteromorpha*, *Porphyra, Laminaria, Sargassum, Gelidium* and *Ulva* spp [2]. Among the factors, light is the most principal contributor. Therefore, the

Study area	Macroalgae species detected	Group	Reference
Kuala Similajau, Sarawak	*Anadyomene plicata* C. Agardh, *Acetabularia major* C. Agardh, *Avrainvillea obscura* (C. Agardh) J. Agardh, *Cladophora prolifera* (Roth) Kutzing, *Ulva clathrata* (Roth) Greville, *Ulva intestinalis* (Linnaeus) Nees, *Valonia aegagropila* C. Agardh	Chlorophyta	[104]
	Dictyota sp., *Lobophora variegata* (Lamouroux) Womersley ex Oliveira, *Sargassum* sp., *Padina minor* Yamada	Phaeophyta	[104]
	Acanthophora spicifera (Vahl) Borgesen, *Amphiroa fragilissima* (Linnaeus) Lamouroux, *Gelidiella acerosa* (Forsskal) Feldmann & Hamel, *Gracilaria salicornia* (C. Agardh) Dawson, *Hydropuntia edulis* (S. G. Gmelin) P. C. Silva, *Laurencia papillosa* (C. Agardh) Greville, *Laurencia* sp., *Ceramium* sp., *Pterocladia* sp.	Rhodophyta	[104]
Lawas mangrove forests, Miri, Sarawak	*Enteromorpha* spp. and *Rhizoclonium* sp.	Chlorophyta	[105]
	Bostrychia spp., *Caloglossa* spp., *Catenella* sp.	Rhodophyta	[105]
Pulau Gedung, Penang	*Acanthophora spicifera* (Vahl) Borgesen	Rhodophyta	[106]
Pantai Morib, Selangor	*Gracilaria (G.) changii* B.M. Xia & I.A. Abbott	Rhodophyta	[107]
Pulau Gedung, Pulau Pinang	*Acanthophora spicifera* (Vahl) Borgesen	Rhodophyta	[106]
Semporna, Sabah	*Kappaphycus alvarezii*	Rhodophyta	[108]
Pulau Dinawan, Kota Kinabalu, Sabah	*Cryptonemia crenulata* (J. Agardh) J. Agardh	Rhodophyta	[109]
Pulau Tikus; Sandakan; Pulau Bai, Sabah	*Solieria anastomosa* P. Gabrielson *et* Kraft	Rhodophyta	
Pulau Sapangar Kota Kinabalu; Tanjung Kaitan, Kota Kinabalu, Sabah	*Kappaphycus cottonii* (Weber-van Bosse) Doty *ex* P. Silva *in* P. Silva	Rhodophyta	
Sungai Batu; Batu Ferringhi; Pasir Pandak; Pasir Panjang; Teluk Kerachut, Penang	*Gracilaria multifurcata* Borgesen	Rhodophyta	
Kuah, Langkawi, Kedah	*Gracilaria tenuistipitata* Chang *et* Xia	Rhodophyta	
Tanjung Aru, Pulau Labuan, Sabah	*Gracilaria firma* Chang *et* Xia	Rhodophyta	
An island in the Middle Banks, Penang; Pulau Bai, Sandakan, Sabah	*Gracilariopsis bailiniae* (as *bailinae*) Zhang *et* Xia	Rhodophyta	

Table 4: The list of some species of macroalgae reported at various locations in Malaysia.

Group	Name of the strain	Biomass production	Total in percentage
Macroalgae[a]	-	-	-
Brown algae	*Laminaria japonica*	5,146,883	32.61
Red algae	*Eucheuma* spp.	3,489,388	22.11
Red algae	*Kappaphycus alvarezii*	1,875,277	11.88

Table 5: World production of algae biomass [106].

classes of macroalgae are distributed vertically from the upper layer to the lower sublittoral layer [2]. This is because macroalgae have their pigments, which selectively absorb the light with particular wavelengths [29]. For example, while most macroalgae live in the littoral zone near coastal area, some red algae like *Gelidium* sp. grow the deep sea zone where the availability of sunlight is limited [30]. *Gelidium* sp. contains phycoerythrin and phycocyanin pigments, which can absorb light efficiently with wavelengths of photosynthetically active radiation (PAR) that can penetrate seawater to the deep zone [30]. As such, the surroundings factors affect the chemical components, growth rates, size and weight [31].

Based on current farming technology, macroalgae are cultivated in mass scale in all over the world. Among over 20000 species reported, only a dozen of algae are commercially cultivated [32]. Over the last 10 years, the amount of mass cultivation of macroalgae has continuously increased in the world at an average of amount is 10% [33]. The cultivation of brown and red algae is higher than green algae. It is understood that the red algae production extremely increased and the brown algae production reached to 15.8 million wet tons, which were collected from aquaculture farms and wild habitats in 2010 [33]. Table 5 shows the amount of the mass-cultivated macroalgae is 4 and 6 orders of magnitude larger than for the biomass of microalgae and lignocellulosic plant, respectively. These reports suggest that macroalgae can be mass-cultivated in more to supply feedstocks with current farming technology. Figure 3 shows the most promising macroalgae feedstock. For brown algae, *L. japonica* and *U. pinnatifida* account for over 40% of the total of only these two species. Red algae, *Eucheuma, Gracilaria* spp., and *Kappaphycus* account for about 40%. In contrast, the amount of green algae production is negligible.

Depending on macroalgae cultivation and market demand, utilizing brown and red algae needs to be focused rather than green algae. To rise the amount of macroalgal biomass production globally, international cooperation would be required to distribute and expand the farming technology and experience of the East Asian countries (i.e., China, Japan, Korea, Indonesia, Malaysia and the Philippines), which are the main producers [33]. Due to the several habitat conditions, major species are cultivated in the countries are different. China cultivated 85% of *L. japonica* and Korea cultivated 30% of *U. pinnatifida* of the total

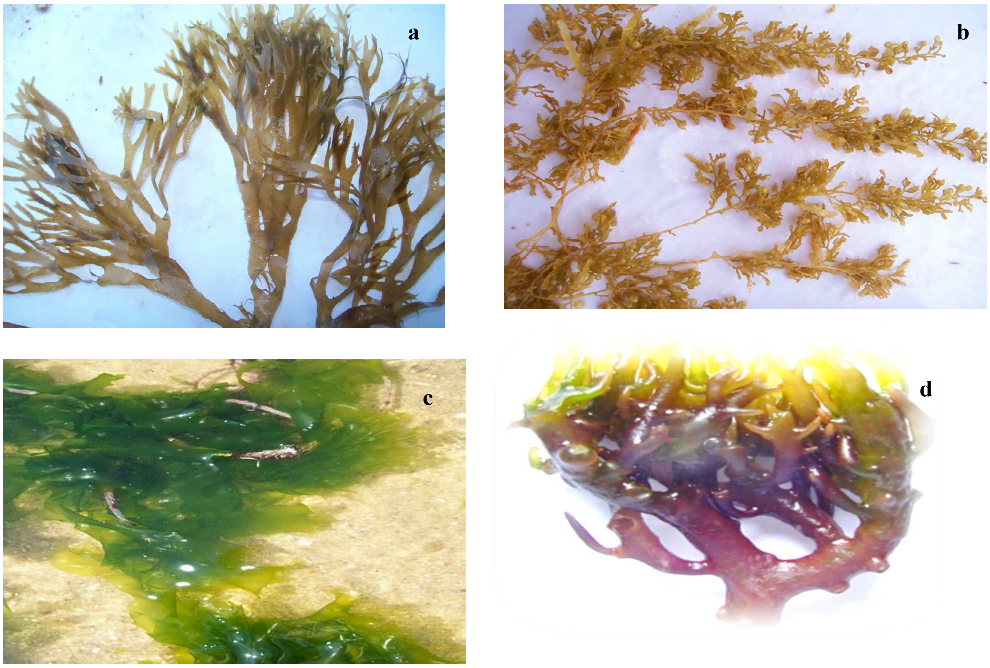

Figure 3: Macroalgae production; a) *Gracilaria corticata* (J.Agardh) J.Agardh; b) *Sargassum plagiophyllum* C.Agardh; c) *Ulva lactuca* Linnaeus; d) *Kappaphycus alvarezii* (Doty) Doty ex Silva.

world production [33]. While Japan was primarily produced *Porphyra* sp. and the other countries, Indonesia and the Philippines produced mainly in red algae [33,34]. *Eucheuma* sp. and *Kappaphycus alvarezii* are most often cultivated in the Philippines, Indonesia and Tanzania whereas *Gracilaria* species have also been cultivated in Chile, China and Indonesia. In the late 1970s, seaweed farming was introduced in Malaysia and started the commercial cultivation few years after, with the culture of *Eucheuma* in North Borneo and *Gracilaria* in Peninsula Malaysia. At present, after almost 35 years, *Eucheuma* and *Kappaphycus* are cultivated intensively in two locations; Semporna (East Coast of Borneo), and Kudat (North Borneo) [35]. Among these species, *Eucheuma* spp. is one of the most abundant species along the coastal region. The East Asian countries would have major role in increasing the amount of macroalgae production globally due to their extensive farming technology and experience built up over decades [36].

Since the algae performances are influenced by chemical compositions, researchers need to understand what contents of chemical resources are available in macroalgal biomass. That kind of information would be useful to understand what biomaterials can be used economically and converted into valuable products. For instance, information on the macroalgae biomass has the high amounts of water (70-90% fresh wt.) and minerals such as alikali metals (10-50% dry wt.) compared to the terrestrial plant biomass [37]. In contrast, macroalgae have the low amounts of lipids (1-5% dry wt.) and protein (7-15% dry wt.) [38], while most of the microalgae species have the high amounts of intermediate lipids (20-50% dry wt) [39,40] and protein (40-60% dry wt.) [41]. Macroalgae contains high amount of carbohydrate compounds. The amount of carbohydrate in green, red, and brown algae is 25-50%, 30-60%, and 30-50% dry wt., respectively [37,38,41]. Depending on their species, macroalgae have the variety of carbohydrates and the information on their compositions is necessary to effectively utilize them as carbon sources for biofuel production.

Environmental applications

Biological tool for measurement of environmental toxicants: Microalgae have been used as a biological tool for measurement of environmental toxicants [14]. The changes of natural environment in Malaysia were mostly regulated by the continued eco-social development and industrialization whereby the coastal area is the mainly affected region. The coastal region of Malaysia experiences the most dense peoples activity, where a highest population percentage, industries, ports, tourism constructions as well as agriculture, fisheries, aquaculture, mineral and exploitation of oil and gas, transportation and discharge of sewage result in many contradictory activities in that area [42]. These activities may be contributing to the discharge of pollutants to the coastal zone. The discharge of pollutants arises due to man-made sources, and to the natural activities. The living organisms, either animal or plant, can be used as indicators of bio-monitoring in the coastal area and open sea. The population, abundance and species composition of microalgae can be used as environmental indicators because of their sensitivity to environmental changes [43]. There are two main reasons for efficient focus on microalgae in order to evaluate and predict the environmental impacts of land-use activities on the coastal area. Firstly, microalgae composition and structure are basic indicators of environmental status. Secondly, microalgae are very sensitive to ecological changes at small spatial scales. Microalgae mainly act as primary producers, forming the basis of the food chain. These assemblages reveal excellent continuity in the course of time with water quality changes [42].

Changes of microalgae species can happen under various circumstances with response to a diverse of irritants. Marine microalgae assays are helpful in the assessment of the toxicity of agricultural, industrial and municipal wastewater effluents [44], so researchers used microalgae as indicators of water quality changes and pollution in their projects. Din and Brooks [45] observed the responses of marine centric diatoms to the chemical pollutants discharged place. Marine microalgae were used as an indicator of pesticides and industrial wastes by Walsh [46,47] studied some microalgal species as indicators of heavy metals contamination since of their aptitude to concentrate and accumulate heavy metals.

Microalgae were used as an indicator of organic and inorganic pollutants and monitoring of water quality by many researchers in Malaysia. For example, Wan Maznah and Mansor [48] studied in the water quality status of Penang River by using periphytic algal and physico-chemical parameters as indicators. Nather Khan [49] also used the diatom community structure and species distribution for the biological assessment of water pollution in the Linggi River Basin (Malaysia). Microalgae were used as indicator for biological monitoring of water quality changes and pollution study because very little research has been conducted on marine microalgae around Penang, Malaysia [50].

Wastewater treatment, bifuel production and carbon dioxide fixation: Malaysia is endowed with abundant algal resources that are yet to be fully exploited for commercial applications. The aim of this section is to give an overview of the wastewater treatment, carbon dioxide fixation and bifuel production of algae, as well as to trace the developments of algal research in Malaysia. For microalgae, it has been cited as one of the potential feedstock for wastewater treatment, carbon dioxide fixation and bifuel production due to the numerous distinct advantages as listed below.

1. Microalgae utilize the nutrients from various wastewater sources such as industrial and municipal wastewaters, agricultural run-off and concentrated animal feed operations giving the additional benefit of wastewater treatment [51].
2. Microalgae sequester carbon dioxide from flue gases released from fossil fuel-fired power plants and other industrial sources, thus reducing major greenhouse gas emissions 1 kg of algal biomass needed about 1.8 kg of carbon dioxide [52].
3. Higher oil productivity (at least 15 times higher oil productivity per hectare than conventional plants such as jatropha, palm and rapeseed). For instance, table 6 shows the land requirement comparison on biodiesel feedstock's for Malaysia's B5 mandate [53].
4. Fast reproduction ability (biomass doubling within 3.5 h during exponential growth). Microalgae are fast-growing unicellular microorganism that able to divide their cells within 3-4 h, but mostly divide every 1-2 days under favourable growing conditions [54].
5. Non-food resource.
6. Not necessary fresh water and arable land.
7. Microalgae produce value-added (e.g., pigments, bio polymers, polysaccharides, proteins, animal feed and fertilizer) and do not require pesticide and herbicide [51].
8. Cultivation of microlalgae in suitable culture vessels (photobioreactors) throughout the year with higher annual biomass yield on an area basis [51].
9. Due to their simple cell structure and fast growth rate, microalgae are expected to have CO_2 bio-fixation efficiency of 10-50 times higher than terrestrial plants [51,55].

The previous research in malaysia mainly focused on the use of microalgae for agro-industrial wastewater treatment [56]. Table 7 shows various research work done on different wastewater treatment by microalgae in Malaysia. Efficient nitrogen removal in palm oil mill effluent (POME) was achieved using such a system. Subsequent this, the HRAP process was resulted to be useful for the treatment of agro-industrial wastewaters such as sago starch factory wastewater [57], rubber wastewater [58], textile wastewater [59] and landfill leachate [60].

Blue green algae were utilized effectively for removing of organic pollutants in paper industrial wastewater [61]. Further, microalgae are reported to be used for treatment of heavy metals in industrial wastewater. The heavy metals such as cadmium, nickel, and zinc in monometallic solutions were removed effectively by brown alga, *Ascophyllum nodosum* when compared to green and red algae [62]. Similarly, brown alga *Fucus vesiculosus* was recorded the maximum removal efficiency of chromium (III) at high initial metal concentrations [63]. In addition to this, algae species, *Scenedesmus obliquus* was performed up to 90% of cyanide degradation in mining process wastewaters after introduction of algae into the system [64]. *Rhizoclonium hieroglyphicum* and *Spirogyra condensata* also involved to remove chromium from tannery wastewater [64]. The concentration of algae and pH were observed to have significant role on chromium removal and thus indicating potential of algae for removing hazardous heavy metals in wastewater [64]. In addition, *Chlorella vulgaris* UMACC 001 [16] has great potential applications in wastewater treatment and removal of heavy metals, and it also grows well on organic carbon source and at high nitrogen concentrations.

The use of microalgae as a potential feedstock for biofuel production has been receiving a lot of interest in recent years. They are still infancy in Malaysia. Recently, many studies have been conducted to identify the suitable algae species to be a source of alternative fuel. Much effort also has been undertaken in order to produce algae biodiesel mainly in Sabah and Sarawak area. Algae is a promising source for biofuel production as it will not compromise to the food, fodder and other products derived from crop plants [65]. Palm oil also has been the major raw material in Malaysia for biodiesel production; nevertheless, the production of palm oil is not enough to meet the current demand. There is issue that there may not be sufficient palm oil left for food production if it

Crop	Oil productivity (kg/ha/year)	Conversion (%)	Biodiesel productivity (kg/ha/year)	Land area needed (thousand ha)	Percentage of arable land in Malaysia (%)
Soybean	375	95	356	1235	68.3
Rapeseed	1000	95	950	463	25.6
Jatropha	2000	98	1960	224	12.4
Palm oil	5000	94	4700	93	5.1
Algae[a]	75,000	80	60,000	7	0.4

[a] 50% oil (by wt) in algae biomass.

Table 6: Comparison of land dependent biodiesel production efficiencies from crop oils for Malaysia's B5 mandate [53].

Name of the species	Wastewaters	Notes	References
Spirulina platensis	Sago starch factory wastewater, factory at Batu Pahat, Johore	Using High Rate Algal Pond (HRAP), the reduction of COD, ammoniacal-nitrogen and phosphate levels of the digested effluent reached 98.0%, 99.9% and 99.4% respectively	[57]
Algae consortia	POME, Anaerobic liquor pond	Algae pond system was used in secondary treatment of digested POME for the gross biomass productivities	[56]
Chlorella spp.	Rubber mill effluent, Malaysia rubber factories	In this study, *Chlorella* spp. isolated from rubber effluent ponds, and the algae revealed high hetero-trophic and mixotrophic abilities. It was noted that the organic carbon compounds from rubber effluent was removed by *Chlorella* spp. in an oxidation pond system	[118]
Characium sp.	POME, Sime Darby East Mill, Carey Island, Selangor	The study examines the efficiency of nutrients removal in anaerobically treated POME by a locally isolated microalga *Characium* sp. from POME treatment pond. The results showed that the level of COD, ammoniacal nitrogen, ammonia, ammonium, total nitrogen of POME was reduced up to 45.41%, 90.35%, 86.9%, 87% and 88.6% respectively. This alga was also found to remove up to 99.1% of phosphate and 99.5% of phosphorus.	[119]
S. platensis, S. dimorphus	POME, Sime Darby East Mill, Carey Island, Selangor	Experiment was conducted in outdoor raceway pond reactor to evaluate nutrient removal efficiency in anaerobically treated POME. *S. platensis* was having best nutrient removal efficiency compare than *S. dimorphus.* Results showed that *S. platensis* were effective in reduction of BOD (78.3%), COD (84.9%), Total Nitrogen (91%), ammonia Nitrogen (93.8%) and phosphorus (96.8%)	[120]
S. platensis	POME, Sime Darby East Mill, Carey Island, Selangor	The experiments were conducted on the orbital shaker. It was observed that *S. platensis* able to reduced 90% of COD. Ammoniacal nitrogen and Total phosphorus was removed up to 87% and 80% respectively.	[121]
C. vulgaris UMACC 078	Sewage treatment plant located at International Islamic University Malaysia campus	Total phosphorus and COD was removed up to 40.7% and 35.3% respectively. Total Nitrogen was removed the maximum which is about 45.8-77.8% by the growth of *C. vulgaris*	[122]
C. vulgaris, C. pyrenoidosa, C. sorokiniana, Botryococcus sudeticus, and *Tetraselmis* sp.	POME, Bukit Besar, Johor Bahru	POME was used as carbon source to increase the lipid content by limiting algae growth rate	[123]
Isochrysis, Chaetoceros sp., *Tetraselmis* sp. (marine algae)	POME, Sabah	Use of both photobioreactor and outdoor system in digested secondary treated POME. It was noted that 5% POME with 0.075% of inorganic NPK fertilizer in seawater gives optimum algae growth rate and the biomass showed the increment of lipid and fatty acids. The pollutants such as Orthophosphate (87%), Nitrate (38%), Total Nitrogen (39%), and BOD (21.3%) was reduced	[124]
Nannochloropsis sp., Chlorella sp., Isochrysis sp., Tetraselmis sp. and *Pavlova sp.*	Leachate ponds at the Pulau Burung Sanitary Landfill, Pulau Pinang	Using leachate from a landfill as a low cost growth medium for the production of algae biomass	[125]
C. vulgaris	POME	The raw, filtered and sterilized POME was used by culturing *C. vulgaris* in 5L tanks. From this study, the maximum NH_3-N and TP removal was obtained in the sterilized POME which is about 82.1% (NH_3-N) and 88.3% (TP) with the shortest cultivation time (10 days). The filtered POME and the raw POME also succeeded to remove the NH_3-N and TP up to 90% when the cultivation time was extended further two to three times. These findings proposed that the POME from secondary treatment pond could be used for microalgae cultivation to remove excessive nutrients in POME	[126]
C. vulgaris UMACC 001, *Chlorella* UMACC 236, *Scenedesmus* UMACC 099, *Ankistrodesmus convolutus* UMACC 101, *Euglena UMACC 058* and 4 strains of *S. platensis*, namely UMACC 159, 160, 161 and 162	Textile wastewater (TW), garment factory located at Senawang Industrial Estate, Negeri Sembilan	Among the various algae cultures tested, *C. vulgaris* UMACC 001 was performed well in HRAP. The nutrients such as NH_4-N, PO_4-P, and COD were removed up to 44.4-45.1%, 33.1-33.3% and 38.3-62.3% in TW, respectively. It was concluded that *C. vulgaris* using HRAP offers a viable system for the polishing of TW before final discharge.	[59]

Table 7: Work done on different wastewater treatment by microalgae, Malaysia.

is utilized for biodiesel production. Microalgae emerge to be the only source of biodiesel that has huge potential to replace diesel from fossil source [66]. The oil productivity from microalgae biomass can attain up to 136,900 L/ha compared to other crops, which range between 172 and 5950 L/ha [67]. The priority areas include screening of microalgal strains for high lipid producers, and the use of different nutrient sources and environmental conditions can further enhance the lipid content in biomass.

In fact, many literatures shows on growing various microalgae species for biodiesel production has further open the opportunity of carbon dioxide fixation as this significance to a new milestone. There are several laboratory experiments have proven positive effect of cultivating microalgae with pure form of carbon dioxide, real or simulated flue gas towards carbon bio-fixation rate and biomass productivity [22,68-70]. The microalgae growth rate was increased due to the addition of higher concentration of carbon dioxide (1-15%) compared to atmospheric air (0.04% CO_2), recorded to higher biomass productivity in a relative short cultivation period [71]. Microalgae have ability to convert CO_2 into biomass, fatty acids and lipids [70,72]. The accumulated lipid in microalgae cells could be further converted into biodiesel. This concept offers a sustainable carbon cycle as carbon dioxide released from burning the biodiesel is absorbed back by microalgae growing and therefore, the level of carbon dioxide is maintaining continuously in the atmosphere.

Various Malaysian research programs concern on the negative effect of climate change towards human and environment has synergized the improvement of carbon dioxide capture technologies. The capturing of carbon dioxide by growing microalgae has increased a massive thrust due to their high photosynthetic rate that allows more efficient carbon dioxide fixation than terrestrial plants. In addition, microalgae biomass contain the lipid could be processed to biodiesel; a renewable biofuel that releases very less carbon dioxide compared to fossil-fuel when combusted.

A large pilot scale plant had been built in Kuala Lumpur, Malaysia for utilizing CO_2 from flue gases for growing algae in ponds and photobioreactor and is expected to be completed in 2009 [53]. Moreover, coal and natural gas is the main power stations in Malaysia and has generated the electrical energy with a lot of CO_2 and this offers an excellent supply for mass cultivation of algae. This process can assist to sequester atmospheric carbon dioxide emission and thus enable Malaysia to withstand the regulations set in Kyoto Protocol to decrease greenhouse gases emissions [53]. There are several data shows on microalgae strains for CO_2 removal efficiency. From this data, *Botryococcus braunii, Chlorella* sp., *Chlorella vulgaris*, *Scenedesmus obliquus, Scenedesmus* sp., have been identified as potential microalgae strains that are able to assimilate high amount of CO_2 and concurrently producing considerable quantity of lipid for biodiesel production.

In general, 1-20% of CO_2 supplement is suitable to grow microalgae and the CO_2 amount is varied basis on microalgae strain. If the amount of CO_2 supplement is very less (e.g., CO_2 absorbed from air), more energy will be utilized to distribute the CO_2 to microalgae growing system and then decrease the life cycle energy efficiency in making algae biodiesel [73]. It was calculated that CO_2 procurement supported approximately 40% of the total energy utilization and 30% of the total greenhouse gas emission throughout the microalgae cultivation time [73]. This is combined with the low mass transfer amount of CO_2 in water and hence, more energy is needed to manage the air pump [74]. Thus, it is highly advised to place microalgae farm nearby coal-fired power plant station so that the release flue gas could be easily consumed as a promising carbon source to cultivate microalgae. As per the recent report of Stephenson et al. [75], if the concentration of CO_2 is increased in flue gas ranged from 5% to 12.5%, the overall fossil-energy input in raceway system to make biodiesel from microalgae would reduce considerably from 23.7 GJ/tonne of biodiesel to 6.5 GJ/tonne of biodiesel; a difference of reduction rate of 72.6%. This result indicates the significance of utilizing flue gas in decreasing the energy trouble in a typical microalgae growing farm and subsequently, the microalgae can work as a carbon sink to avoid CO_2 direct emission to the atmosphere. This study was also supported to be practical as microalgae can efficiently absorb flue gas under certain growing environmental conditions. Yoo et al. [70] reported that the *Botryococcus braunii* and *Scenedesmus* sp. and growth rates were increased using real flue gas (5.5% of CO_2) when compared to enriched air with 10% CO_2. Similarly, Li et al. [76] studied that *Scenedesmus obliquus* was capable to grow up to 12% CO_2 in industrial flue gas with 67% of optimal removal efficiency in a 100 L air-lift photobioreactor.

Apart from the more amount of CO_2, flue gas can have up to 142 various compounds, such as NOx, SOx, HCl, O_2, H_2O, CO, particulate matter (PM), heavy metals, etc. [77,78]. Depending on the source of flue gas, these compound concentrations can be varied. For example, pulverized coal-fired boiler emitted the flue gas contains 10-16% (v/v) CO_2, 100-2000 ppmv SO_2 and 100-1000 ppmv NO. Cement kiln emitted the flue gas includes 14-33% (v/v) CO_2, 10-2500 ppmv SO_2 and 475-1900 ppmv NO [79]. The influence of NOx and SOx on microalgae growth is mainly based on the type of strains. For example, *Synechococcus nidulans* was completely inhibited with the presence of NOx and SOx in the flue gas whereas the growth of *Chlorella* sp. can survive. Further, isolating microalgae strains that succeeds around coal fired power plants is a novel approach to enhance CO_2 fixation efficiency by microalgae [80]. It is well understood that these local microalgae strains are higher tendency to adapt local conditions of surrounding power stations and have more tolerant in the presence flue gas. Radmann *et al.* [81] studied the strain *Chlorella vulgaris* LEB-106 was isolated from a pond close to a thermoelectricity plant could tolerate their growth with the additional concentration of 100 ppm NO and 60 ppm SO_2 while the growth of commercial strain, *Chlorella vulgaris* LEB-104 was inhibited with the additional concentration of 30 ppm SO_2.

In theoretical view, algae do promise many advantages but various difficulties will still require to be overcome in practical view. Low cost effectiveness and technological obstacles are some of the limitations to industrial scale algae-biodiesel production. Particularly in Malaysia, scarcity of environmental information on Malaysian algae strains has to be overcome by motivating scientific evaluation and phenological studies on potential native algae strains. As other countries have been encouraging the usage of algae biodiesel production, Malaysia should not be left behind as well [53].

The Research and Development Efforts on Algae for Environmental Applications in Malaysia

Malaysia has the vast potential as a sustainable algae resource for various industrial applications. Particularly, research on the production of microalgae biofuels is in the beginning stages and there is an urgent need for conducting more research on algae biofuels related to economic issues. Geographically, the South China Sea borders Peninsular Malaysia in the east and both Sarawak and Sabah in the north that has natural advantages for algae culture. Malaysia has various salt lakes that offer researchers advance algae-based technology. Authors of this review paper recommend to government and private institutes to investigate the following chart in order to make industrial sites for biofuels with their close to the lakes, have the potential to be algal fuel in Malaysia. The research efforts can be classified into several areas [82];

1. Selection of new algae strains with more oil content or Improving oil content of existing algae strains
2. Increasing the algae growth rate
3. Development of vigorous algal cultivation systems in either closed or open-air environmental conditions
4. Producing by-products other than oil
5. Utilization of algae for waste water treatment and
6. Developing a finest oil-extraction technique.

A number of challenges have hindered for the progress of microalgae biofuels to become commercially viable technology. Of these and based on recent publications, the most important points as reported in the review of Ribeiro and da Silva [83] are: The selected algae species must equalize the requirements for biofuel production and extraction of commercial by products [84]. Constant improvement of production systems can reach more photosynthetic efficiency through microalgae [85]. Technology development for cultivating a single algae species, decreasing a losses due to diffusion and evaporation rate of CO_2 [86]. Selection of microalgae strains that need freshwater to cultivate could be unsustainable for operation on a mass scale and exacerbate scarcity of freshwater [87]. There is a dearth of details on mass cultivation for some commercial cultivating"farms" [88]. With the presence of toxic compounds such as NOx and SOx, there is not possible of launching high amount of flue gas, [89]. Present methods of dewatering and harvest are still standing additional energy intensive [1]. Algae biofuels containing meagre energy or greenhouse gas profits as shown some recent lifecycle analyses (LCAs) project [90]. One more unacceptable issue that may happen is the insufficient places with suitable resources of land, temperature, water, and CO_2, all located in one site [90]. Supplying CO_2 cost is very high, because of high cost of capital and operational setup and costs for piping CO_2 to, and relocating it into, the ponds [90]. The goals listed above can achieve when the algal species are genetically and metabolically alter & to improve new cultivating technologies or to develop existing ones.

Mass cultivation of algae for biodiesel production is still in the progress stage and it is very expensive to be commercialized. The following approaches may improve that long term potential technology [91].

1. Algae should be identified and developed basis on cost saving growth technologies of highest oil producer
2. For reducing the cost of production, integrated bio-refineries can be applied to produce animal feed, biodiesel, biogas and electrical power.
3. Improving algal biotechnology by genetic engineering and metabolic alteration has the high impact on enhancing the economic value of algae biodiesel.
4. For capturing CO_2 from industrial power plants, area efficient technology to be identified and developed
5. Recycled nutrients are required from municipal sewage and industrial wastes to reduce the demand of fertilizers to cultivate algae.
6. Microalgae biomass production can be developed economically through extra incomes benefit in green- house gas abatement and wastewater treatment.

This review paper reported that there is a considerable potential for the utilization of algae for the production of biodiesel in Malaysia. Authors are strongly recommended these techniques so Malaysia can reduce import of algae diesel fuel. Sure, there is a substantial need for more research to study the other economically related issue.

With the drive towards achieving the industrialized Malaysia nation status by the year 2020, the quality of the environment is extent to threaten [92]. Although the immediate ecological issue, in specific those pertaining to industrial effluents and sewage, are being dealt with the introduction of integrated algae treatment systems such as the proposed bio-refinery approach, future environmental management strategies need to be considered. For the installation of suitable treatment systems, long term solution will cover to minimize the waste by the launching of sound technology as an integral part of the manufacturing operation, recycling of wastes and by-products of algae treatment systems. In addition to the regular monitoring of natural habitat by the Department of Environment, there is a need to undertake the bio resources in the ecosystem as the amount of industrial effluents increases. Besides, whilst point-sources of contamination are generally quite clear and readily identifiable, there is a need to analyze and control the pollution load from non-point sources [92].

Algae production and use extend across the entire process chain is having numerous challenges. It includes the selection of suitable algal phyla, cultivation, and extraction of the biomass from the suspension, through to optimal benefit of the obtained biomass. The suitability of algae biomass for energy supply and material use has been revealed in a large number of studies [4]. Various research projects are concerned with identifying the optimal processes to enable its extensive implementation. Algae biomass contains of a large number of materials in relation to the physical and chemical properties. They may be converted into energy by a variety of different means depending on its origins. Various conversion technologies are available for the purpose. Malaysia is often situated in regions which are geographically interesting for algae cultivation (favorable climatic conditions, cheap labor and underdeveloped land). It includes physical, biochemical and biological treatments to generate energy-rich products from the source of algae biomass [4].

Research and commercial applications of algae have gained more interest during the last few years in Malaysia. Macroalgae have long been utilized for the phycocolloids production i.e., alginates, carrageenans or agars [93-95]. *Laminaria*, *Macrocystis* and *Ascophyllum* was used for alginates production. Different species of the genus *Eucheuma*, *Kappaphycus alvarezii* (cottonii), *Gigartina stellate* and *Chondrus crispus* were used for the carrageenan production. The productions of carrageenan are growing very fast in Malaysia. For instance, Malaysia has taken a great interest to produce k-carrageenan from *E. cottonii*. It has been widely cultivated on the east coast of Sabah, Malaysia for the last three decades [96]. In the year of 1970s, *E. cottonii* was manufactured as a component of preserved pet food. Then it was exported as food grade k-carrageenan in 1980s [96]. Tawau, Sabah state is the first food-grade natural k-carrageenan producer in Malaysia [97]. Research on algae biodiesel production has started to emerge in Malaysia among academic researchers [98] and also private companies. For example, University of Malaya conducts various research projects in algae technology. Some on-going projects carried out in the University Kebangsaan Malaysia include studies on the isolation and identification native microalgae for Palm oil mill effluent treatment and CO_2 sequestration studies. Figure 4 shows researches on microalgae cultivation are conducted at University Kebangsaan Malaysia. Algaetech company is involved into the microalgal research, development and consultancy as well as production and marketing of renewable energy and commercial value products since 2004 [99]. In addition, the authors are referred to the list of some research publications and internet resources on algae from the various Malaysian universities such as University Putra Malaysia, University Science Malaysia, University Putra Malaysia and University Malaysia Sabah.

Conclusion

This review has given an overview of current and past algal activity in Malaysia both in the academic and industrial researchers. Currently, Malaysia has a diverse knowledge based on algae, with more strength in biotechnology and bioengineering. Industrial activity is also increasing slowly. Most of the active companies have valuable contributions and some existing collaborations with Malaysia universities; this inspires the interpretation of breakthroughs in academic fundamental research into industrial scale applications. Step changes would be expected If the expertise of the industrial and academic societies were to come together to use their knowledge under a planned agenda. In order to start with the society's experience, increased utilization of renewable energy resources, in particular algae resources are viable as it can contribute to the country's sustainability of energy supply while reducing the adverse impacts of energy production on the environment.

It can also clear the agriculture disposal problem in an eco-friendly manner while recovering energy and greater value chemicals for commercial applications like biofuel in assisting the government to succeed its duty to prolong the fossil fuel reserves. This should also comprise improving its development by giving good incentives to encourage the use of algae biomass and encouraging joint efforts between private agencies and government institutions and to implement the commercial approach of its assignment which include further research development of algae biomass.

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