Review

Algae, a Hope for Sustainable Living

Abstract

An alga is a microorganism that comes in the context of both present and future sustainable living in this present world at large. It has come a long way. Algae can be also a macro-organism, such as many Chlorophyta, Rhodophyta and Ochrophyta. Previously, alga was referred to as a pollutant, a menace in the society and the environment. However, now with the advent of great discoveries and biotechnological advancement of Algae, significant t benefits can be achieved. Cultivation of algae is not only safe but also requires less space, is capable more production and yield as well as being cost-effective, Algae have the ability to power a whole building, be used as biofuels for vehicles, for electrical purposes, for decorations and as health supplement for both humans and animals. The production of biofuels from algae has a good impact in the environment considering the problems experienced in the conventional fuels from hydrocarbons. The aquatics are not left out because they serve as great feeds for fishes and other aquatic livestock. Algae is the way forward when it comes to sustainable living.

Introduction

Algae are microscopic organisms that carry out photosynthesis andpossess photosynthetic pigments which helpin their nutrition. They can tolerate a wide range of temperatures, salinities, and pH values; different light intensities; and conditions in reservoirs or deserts and can grow alone or in symbiosis with other organisms [1] Algae are broadly classified base on their pigmentation as in Rhodophyta (red algae), Ochrophyta (brown algae), and Chlorophyta (green algae) and classified by size as macroalgae or microalgae. Macro-algae (seaweed) are multicellular, large-size algae, visible with the naked eye, while microalgae are single microscopic cells and may be prokaryotic or eukaryotic. Microalgae can be used in the production of in bio-fuels, health supplements, pharmaceuticals, and cosmetics [2]. They are also said to be used in treating waste water and atmospheric CO_2 mitigation. Microalgae are being use by various industries in the production of bio-products, including polysaccharides, lipids, pigments, proteins, vitamins, bioactive compounds, and antioxidants [3]. The bio-refineries have developed interest in the use of microalgae as a renewable and sustainable feedstock for bio-fuels production. Growth enhancement techniques and genetic engineering may be used to improve their potential as a future source of renewable bio-products. The positive impact of nutritious foods on the human health has been long realized, which has led to the development of several innovative functional ingredients and functional food products. Algae derived nutrients and bioactive compounds are being investigated for their potential biological activities [4,5]

The algal metabolites are promising sources of ingredients for the development of novel food products they are also good sources of proteins, minerals, vitamins, amino acids, lipids, fatty acids, polysaccharides, nucleic acid, and carotenoids etc which are of immense value as nutritional supplements [6, 7]. In view of this, in recent years, a lot of research has been carried out on the development of novel health foods from algal biomass. Algal biomass and extracts are used extensively in the formulations of gels, capsules, tablets, gums, bars, snacks, kinds of pasta, drinks, and beverages [8]. Algal biomass production can be improved through adopting innovative methods of enhancing biomass coupled to technological interventions for functional food application.

According to Plaza *et al*.,[9], it has been reported that industrial cultivation of microalgae to produce bio-products are on the increase since the past decade. Algae are sold directly as food and nutrient supplements, while their processed products or extracts are used in biopharmaceuticals and cosmetics [10, 11, 12].The main applications of microalgae for aquaculture are associated with nutrition as the sole component or as a food additive to essentialnutrients and for inducing other biological activities. Microalgae are required for larval nutrition either for direct consumption in the case of mollusks and penaeid shrimp or can be fed indirectly as food for the live prey fed to small fish larvae [13]. A combination of different algal species provides balanced nutrition and improves animal growth better than a diet composed of only one algal species [14]. In order to be used in aquaculture, a micro algal strain has to meet various criteria, such as ease of culture, lack of toxicity, high nutritional value with correct cell size and shape and a digestible cell wall to make nutrients available [15, 16]. The significant role of microalgae in aquaculture hatcheries include the cultivation of micro algal strains for brood stock conditioning, larval rearing and feeding of newly settled spat, as all developmental stages of bivalve molluscs are directly dependant on microalgae as a feed source. The planktonic larval stages of commercially important crustaceans are initially fed on microalgae. Farmed gastropod molluscs and sea urchins require a diet of benthic diatoms when they first settle out from the plankton, before transferring to their juvenile diet of macro-algae. The small larvae of most marine finfish species and some freshwater fish species also initially receive live prey in the presence of microalgae. These microalgae are allowed to bloom within the fish larval rearing tanks (green water) or are added from external cultures (pseudo-green water). Microbial conditioning by microalgae may extend to prevent cell-to-cell signalling (quorum sensing) by bacterial pathogens. In a laboratory screening study focused on micro algal strains commonly used in aquaculture, several of the tested strains interrupted signaling by pathogenic *Vibrio harveyii*, proving that such microalgae offer potential as aquaculture bio-control agents.

Benefits of algae

Microalgae have the potential to meet the populations need when it comes to food. It shows an advantageous effect on protein supply than currently used raw materials in an environmental point of view. Microalgae produce bioactive compounds with potential benefits for human health. Microalgae exploitation as a source of protein (bulk protein) and other valuable products within the food industry still face some challenges, mainly because of the underdeveloped technologies and processes currently available for microalgae processing. However, systematic improvement of the technology readiness level (TRL) could help improve the current situation if applied to microalgae cultivation and processing. Microalgae-derived compounds such as peptides have been said to have

Antioxidative, antihypertensive, immunomodulatory, anti-cancerogenic, hepato-protective, and anticoagulant activities. Nevertheless, research work on this topic is scarce, and the evidence on potential health benefits is not strong.

As mentioned above, plant-based proteins are currently the main source of protein for food and feed. Expanding the cultivation area, changing the cropping frequency, and boosting yields could help meet the increasing food demand; however, crop production may be approaching a ceiling in terms of optimization. The practicality of the methods could worsen the environmental problems arising from current methods of cultivation, i.e., land degradation, loss of biodiversity, and deforestation [17]. Animal-based proteins depend on the supply of appropriate and cost-effective plant-based proteins for feeds [17]. Microalgae have arisen as a promising sustainable alternative protein source. However, aspects related to food safety of algae are not well-known, namely the presence of contaminants, allergens, or hazardous substances generated during microalgae processing. Hence, the estimated time to market of microalgae and other protein sources differs [18]

Nostoc, Arthrospira (usually denoted as *Spirulina* in the market), and *Aphanizomenon* are protein-rich microalgae that have been part of the human diet [14]. Spanish chroniclers observed Aztecs consuming a blue-green cake made from *Arthrospira* [17]. During the Algae Mass-Culture Symposium in 1952, it was suggested to exploit microalgae for food and biochemical applications, even if some progress had been made in the early 1940s. *Chlorella* was first produced commercially in Japan, whereas Mexico pioneered *Arthrospira* cultivation in the 1970s [14]. Although the number of microalgae species in nature is estimated between 200,000 and 800,000, only a few are used in food applications.

Microalgae-based proteins could significantly contribute to meet the populations need for protein, with several advantages over other currently used protein sources. Microalgae-based proteins have low land requirements for cultivation compared to animal-based proteins: <2.5 m^2 per kg of protein [19] compared to 47–64 m^2 for pork, 42–52 m^2 for chicken, and 144–258 m^2 for beef production [20]. Land requirements are also lower than for some other plant-based proteins used for food and feed, such as soybean meal, pea protein meal, and others [21]. Furthermore, there are certain advantages of algae over other plant-based protein sources and they include usage of non-arable land for cultivation, minimal freshwater consumption [17]. When it comes to quality, *Chlorella* and *Arthrospira* accumulate high-quality proteins; hence, both species possess well-balanced amino acid profiles according to the WHO/FAO/UNU recommendations regarding human requirements of essential amino acids (EAAs) [22, 23]. The amino acid profiles of both species are similar to other conventional protein sources such as eggs and soybean [22]. In general, microalgae as plants are deficient in sulfur-containing amino acids methionine and cysteine [22]; however, some microalgae supplements showed to be deficient in other amino acids [24]. A comparison between the amino acid profiles of several algal products, including commercially available products such as *Chlorella* pills and *Arthrospira* flakes, showed that some supplements couldprovide high amounts of EAAs. It is worth mentioning that the cultivation conditions or sources of the biomass used for these products can lead to differences in the amino acid profiles of the products [24]. Nevertheless, during consumption, protein bioavailability becomes important. At this point, three different concepts need to be explained: bioaccessibility, bioavailability, and bioactivity [25]. The bioaccessibility are usually evaluated by *in vitro* tests. It represents the portion of the compound released from the food matrix becoming available for absorption. Afterward, the compounds may reach the systemic circulation and being utilized, which is referred to as bioavailability. The bioavailability is determined by *in vivo* tests. Finally, the bioactivity of a compound describes the physiological response, e.g., antioxidative, antihypertensive, or anti-cancerogenic activities. The bioactivity can be evaluated *in vivo, ex vivo,* and *in vitro*. Based on these definitions, a compound can be considered bioaccessible, but not necessarily bioactive. Protein bioavailability from whole microalgae cells could be improved by applying pre-treatments to disrupt cell walls, which hinder degradation [23].

There are other valuable compounds with health benefits that can be sourced from microalgae apart from proteins such as carbohydrates, polyunsaturated fatty acids, essential minerals, and vitamins [22,25,26], which can increase the nutritional value of food products upon incorporating. Polysaccharides and oligosaccharides are promising compounds with potential health benefits, arising interests in terms of prebiotic applications [27, 28, 29]. Gibson and Roberfroidefined as "non-digestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, and thus improves host health [28]. *Arthrospira, Chlorella* ,and*Nannochloropsis* are not only a good source of proteins, but have been reported as important [26, 27, 28]. Lipids, in particular long-chain polyunsaturated omega-3 fatty acids (ω-3 PUFAs), have also been suggested as valuable compounds with health benefits that can be incorporated into food products. α-linolenic acid (ALA; 18:3 n-3), eicosapentaenoic acid (EPA; 20:5 n-3), docosapentaenoic acid (22:5 n-3) and docosahexaenoic acid (DHA; 22:6 n-3) are some of the most important ω-3 PUFAs with health benefits for humans [26]. EPA and DHA aids in prevention or amelioration of cardiovascular or renal diseases. These long-chain EPA and DHA, considered as essential dietary nutrients, can be produced only by plants, thus, consumers must incorporate them into their die [30]. Microalgae are a valuable source of ω-3 PUFAs. *Arthrospira, Chlorella, Dunaliella, Haematococcus, Schizochytrium, Porphyridiumcruentum,* and *Crypthecodiniumcohnii* have GRAS status [31]. Most of the commercially available biomass is marketed as pills and capsules. *Arthrospira* and *Chlorella* are commonly consumed as food supplements, *Tetraselmischuii* as seafood flavouring agent, and the diatom *Odontellaaurita* is consumed as a food supplement as it is rich in EPA [19]. Some microalgae-derived products marketed are: β-carotene from*Dunaliella*, DHA from *C. cohnii*, and the blue colorant phycocyanin from *Arthrospira* [31, 32]. Table 1 below shows the common benefits of algae in food production industries.

Table 1: Some Common Benefits of Algae in Food Production Industries [33]

Product	**Microalgal incorporation**	**Addition**	**Benefit**
Oil/water emulsion	*Chorella vulgaris* green and *C. vulgaris* orange (after carotenogenesis)	2% w/w	Techno-functionalproperties
Oil/water emulsion	*Chorella vulgaris* green,*C. vulgaris* orange (after carotenogenesis) and *Haemtococcuspluvalis* (red, after carotognesis)	*C. vulgaris*:0.25-2.00%w/w *H. pluvalis* : 0.05-2.00 w/w	Colouring and nutritional properties (antioxidant activity)
Vegetarian food gels	*C. vulgaris, H. pluvalis, Aerodramu maxima, Dicroenmavlkanum*	0.75%w/w	Techno-functional and nutritional properties (antioxidant activity, ω-3PUFA)
Vegetarian food gels	*A. maxima, D. vlkanum*	0.1%w/w	Techno-functional and nutritional properties (ω-3PUFA)
Vegetarian food gels	*H. pluvalis*and *A. maxima*	0.75%w/w	Techno-functional properties
Frozen yoghurt	*Athrospirasp*	2-8%w/w	Nutritional properties
Dairy products (fermented milk)	*A.platensis*	3g/l	Nutritional properties
Natural and probiotic yoghurt	*A.platensis*	0.1-0.8%w/w	Techno-functional and nutritional properties
Yoghurt	*Chlorella sp.*	0.25w/w extract powder and 2.5-10.0% extract liquid	Techno-functional and nutritional properties
Processed cheese	*Chlorella sp.*	0.5 and 1.0% w/w	Techno-functional and nutritional properties

Cookies	*C. vulgaris*	0.5,1.0,2.0,3.0% w/w	Colouring agent
Biscuits	*Isochrysisgalbana*	1 and 3% w/w	Techno-functional and nutritional properties (ω-3PUFA)
Biscuits	*A.platensis*	*A.platensis:*0.3, 0.6 and 0.9% phycocyanin extract 0.3%w/w to wheat flour	Nutritional properties
Biscuits	*A.platensis*	1.63, 3.5, 7, 8.36% w/w	Techno-functional and nutritional properties (proteins, fibre contents and anti-oxidation)
Biscuits	*A.platensis, C. vulgaris, Tetraselmissuecica, Phaeodactylumtricornutum*	2 and 6%w/w	Techno-functional and nutritional properties (antioxidant activity)
Cookies	*H. pluvalis*	Asthaxanthin powder 5, 10 and 15%ww/w	Techno-fuctional and nutritional properties (antioxidant activity)
Bread	*Dunaliellasp*	Whole biomass, biomass after b-carotene extraction an biomass after b-carotene and glycerol extraction: 10.0 %w/w	Nutritional properties (protein content)
Bread	*A.fusiformis*	1 and 3% w/w in flour	Nutritional properties (protein and mineral content)

Bread	*I.galbana, T. suecica, Scenedesmusalimeriensis, Nannochloropsisgaditana*	0.47%w/w in flour	Techno-functional properties
Gluten free bread	*A.platensis*	2,3,4 and 5%w/w in flour	Nutritional properties (protein content)
Extruded snacks	*Athrospirasp*	0.4, 1.0, 1.8,2.6 and 3.2%w/w	Techno-functional and nutritional properties (protein content)
Pasta	*Chorella vulgaris* green, *C. vulgaris* orange (after carotenogenesis), *A. maxima*	0.5,1.0 and 2.0% w/w in flour	Techno-functional and nutritional properties
Pasta	*I.galbana, Dicroenmavlkanum*	0.5, 1.0, and 2.0 %w/w in dry weight	Techno-functional and nutritional properties (ω-3PUFA)
Pasta	*A.platensis*	5,10 and 20%w/w in flour	Techno-fuctional and nutritional properties (antioxidantactivity)
Pasta	*Dunalielasalina*	1,2 and 3%w/w in flour	Techno-functional and nutritional properties

Recent Innovations of Algae for Sustainable Living

Algae was usually associated with green sum left on neglected fish tank or smelly pond but these green organisms found in these waste water are now being exploited for the purpose of sustainable living [34]

Humanity is beginning to channel its interest in accessing biomass fuels as a way of dealing with its dwindling energy reserves. These fuels, such as algae, are made through a process similar to the conversion of oil from organic materials. The main difference is that biomass fuels a shorter period of time. With algae, there is a potential for rapid production, as well as potential to produce an infinite amount of biomass, which can lead to a theoretically infinite energy source [35].

An alga, microalgae, in particular, carries out photosynthesis so as to derive energy, just like plants and in that process they utilise atmospheric CO_2 and release oxygen hence making it ideal for correcting the mess made by fossil fuels. But the real lure of microalgae is its ability to produce fuelsSome of these microorganisms store energy by producing oils, and if these oils can be exploited, they can be used to fuel cars. Algae are very good protein sources as previously mention[34].

Though microalgae looks like green scum or strands of hair floating on the water, they areactually made up of microscopic, single-celled organisms capable of photosynthesis. They slurp in sunlight and convert it to energy. They suck up carbon dioxide emitted by power plants and cars, turning it into oxygen. So, they run on solar power, and they scrub the air, both of which are very appealing qualities for a post-oil world. Scientists can convert that oil into fuel for cars, trucks, trains, and planes. This is better for the environment than fossil fuels because its carbon neutral.

Algae-Powered Vehicles

The handmade wooden motorcycle by Ritsert Mans and Peter Mooijuses natural materials for its production and also being powered using algae oil. The energy-producing capabilities of microalgae make it possess a potential to fuel our vehicles and are already being widely recognized. Algae, the plug-in hybrid Toyota Prius in 2009 was just the beginning. In 2011, United Airlines introduced the first algae-powered passenger flight from Chicago to Houston. Japan has already considered developing a fleet of buses powered by algal oil , and energy companies are already working on ways to produce algae biofuel at a lower cost to serve as an alternative to conventional petroleum products [34].

Algae Furnishings

The project "Living Things"is an effort in the direction that celebrates the beauty and qualities of microalgae. It shows the creation of symbiotic relationship between humans and microorganisms within the built environment. It consists of custom glass bioreactors designed as household furnishings; the project demonstrates three vignettes that function differently in each space by cultivating*Spirulina* algae. These furnishings also function as lighting and heating elements for the occupants and simultaneously provide heat, light, and air supply for the microorganism living inside [34]

Algae-Powered Buildings

The world's first algae-powered building dubbed as BIQ House was developed by the international design firm Arup, Germany's SSC Strategic Science Consultants and Austria's Splitterwerk. The features of this building includes a bio-adaptive algae façade that not only helps in maintaining the required amount of solar shading, but it also captures solar thermal heat and biomass that can be used to power the building [34]

Algae-Powered Street Lamps

Pierre Calleja developedAlgae-Powered Street Lamps that utilizes the energy-producing capabilities of microalgae to offer light through a natural process and simultaneously absorb CO_2 from the surroundings. Utilizes the energy-producing capabilities of microalgae to offer light through a natural process and simultaneously absorb CO_2 from the surroundings. The lamp does not use electricity but uses the energy produced by algae's photosynthesis process. Pierra explains in his TED Talk that a single lamp has the capability to absorb at least a ton of carbon from the air in a single year, while illuminating the low-light areas [34].

Biodegradable Algae Water Bottles

Algae aren't just restricted to be used as a biofuel or CO_2 absorber;it is equally useful in developing sustainable materials. Ari Jonsson developed a biodegradable water bottle. It uses a mixture of powdered agar and water with thecapability to break down once it is empty. Being an all-natural alternative to plastic, drinkers can also chew the bottle if they like the taste and is safe for both humans and the environment [34].

Algae as Health Food Supplement

Microalgae are already successful in the specialty food market. They have some nutritional value, hence, can be used as a health supplement *Spirulina*, one of the types of alga, is gaining popularity as a health food supplement. It is also marketed as an alternative to fish oil since fish gets the omegas by eating plankton by extracting omega-3, omega-7 fatty acids directly from the crops. Microalgae are also seen as a livestock feed for animals due to theirvaluable nutrient composition [34].

Algae-Powered Eco City

The co-founders of ecoLogicStudio, Claudia Pasquero and Marco Polletohave already envisioned an eco-friendly city. They are experimenting with the possibilities of building an entire town in Simrishamn, Sweden, which will be centred on algae production and research that would eventually drive tourism. The project aims to harvest the algae for energy and food while keeping the environment pollution-free[34].

Algae Bulbs

Designer GyulaBodonyi has harnessed the power of green algae in a light bulb. Bodonyi's concept brings green power to the public on a more user-friendly scale. With the Algae bulb, algae powers a single LED activated by a tiny air pump and hydrophobic material able to create a teeny-tiny power house for light [36]. Although small in size, if Algae Bulb is employed on a large scale, it holds the potential to save a significant amount of energy. Aside from providing a light source with renewables, the bulb also sucks up carbon dioxide, helping to alleviate greenhouse gases one bulb at a time [36]. The tear-shaped bulb is made up of an air pump, LED, hidrophobic container, PC Shell, and air outlet. The system sucks in carbon dioxide and water through the pump near the E27 screw-top, and as the air passes through the bulb. While **algae flourishes**, it gives off oxygen, which in turn powers the tiny LED inside.When the AlgaeBulb is not illuminated, it appears to be a dark green; a result of the colony of microalgae living within. When illuminated, it gives off a slightly green tinge on the interior, making for a green bulb that is literally "green."

The Future Use of Microalgae in Hatcheries

The high production cost of microalgae remains a limitation to many hatcheries. A good selection of microalgal species is also available to support the aquaculture industries [37]. Apart from improvements in the cost-effectiveness of on-site algal production, an alternative is the centralization of algal production at specialized mass culture facilities using heterotrophic methods or photo bioreactors to produce cheaper algal biomass. These technologies could be combined with post-harvest processing such as spray drying or algal concentration to develop off-the-shelf algal biomass for distribution to hatcheries [37]. Although genetically engineered microalgae havebeen studied in its application for biofuel production and bioremediation of heavy metals, there is less research on its application in aquaculture. The insertion of genes determining the nutritional parameters into microalgae can increase the quality of fish in aquaculture [38]. A combined effort to standardize a genetically modified micro algae aided with a controlled bioprocess system will lead to an improvement in the status of aquaculture

Conclusion

Algae, which were previously seen as a pollutant or a menace in the environment, have now been further researched, and the result is alarming. It has been discovered that these organisms can be very useful in protection, survival in future on earth. Ranging from its importance in the production of biodiesel which is environmentally friendly too their use in powering certain appliances and even a building not to mention nutritional benefits. These organisms can be seen to help control the greenhouse effect, which we are currently facing on earth. It's potential in increasing the nutrient qualities of food and can serve as supplements must not cease to be mentioned. Algae are of great importance, and their commercialization will go a long way to boost the economy.

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