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Overview: Exploring Seaweeds as Sustainable Alternatives for Bioplastics Production

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Abstract

From a historical perspective, the 20th century saw the fast expansion of the plastic production industry. Numerous uses are possible because of the low cost and adaptability of plastics. Bioplastics were developed because plastics are not biodegradable and have been shown to have harmful impacts on people, animals, and the environment. Bioplastics may be produced from renewable biological sources and are biodegradable. The same uses apply to bioplastics as to plastics. Bioplastics can come from a variety of sources, including plants, animals, and microorganisms, but they are limited in several ways, including the inability to get large biomass and the challenges associated with cultivation. When compared to other microbial sources that require a specific environment for cultivation, seaweeds have a high biomass, can grow in a variety of environments, and can be cultivated in the natural environment, making them one of the alternatives for the production of bioplastics in these situations. Seaweeds also have the advantages of being inexpensive, having little effect on the food chain, and not requiring any chemicals. It has been observed that seaweed-derived bioplastics are less brittle, more robust, and resistant to microwave radiation. Research is now underway to develop the technology needed to produce seaweed-based bioplastics, however it is anticipated that substantial progress in the bioplastics sector will enable the production of seaweed-based bioplastics in the future. As a practical substitute, fermentation and genetic engineering can lead the way in using cutting-edge methods to produce bioplastics from seaweeds. The significance, benefits, and uses of seaweeds as a substitute source of bioplastics are discussed in this paper.

Keywords: Plastics; Bioplastics; Seaweeds

Abbreviations: PHA: Polyhydroxyalkanoates; PGA: Polyglutamic Acid; BioPET: Bio-Polyethylene Terephthalate; BioPE: Bio-Polyethylene; BioPP: Bio-Polypropylene.

Introduction

Because of its many uses, plastic has long been regarded as a very valuable material. Plastics play a vital role in maintaining our daily well-being, security, and tranquilly.

Plastics are synthetic or semi-synthetic materials made mostly of high molecular mass polymers derived from natural gas and petroleum. Plastics are becoming increasingly popular because they are less expensive and have superior qualities including flexibility, stiffness, brittleness, and the capacity to be moulded into a wide range of forms. They are also lighter Plastics have a longer history than a century. Celluloid was the first semi-synthetic plastic substance to be utilised in the production of billiard balls and later in photographic films.

Since then, plastics have advanced tremendously; Figure 1 shows the evolution of plastics since that time.

Year	Name of the plastic	Uses
1862	Parkesine	Plastic rings, lucite rings, stone rings and other non-metal chunky cocktail rings
1870	Celluloid	Billiard balls, photographic films
Early 1900s	Cellulose acetate	Sunglasses, dresses, wedding and party attire, home furnishings, draperies, and slip covers
	Bakelite	saxophone mouthpieces, whistles, cameras, solid-body electric guitars, key ingredient in most of the weapons
1930	Polystyrene	Domestic purposes
	Polyvinyl chloride	Food packaging
	Polyamide	Automotive applications, electrical applications
1940–1968	Polyethylene, Polyester, PET, Silicones	Insulating material, bottles, fabric for T-shirts, athletic shoes, luggage

Figure 1: History of Plastic.

The development of plastics made life considerably more convenient due of its numerous uses. Plastics are utilised in building, cars, medical devices, household appliances, electrical equipment, and packaging in the modern world.

Because of their many uses and adaptability, plastics have become essential to human life. These plastics collect as garbage in the environment since they are not biodegradable and will take many years to totally decompose. It is exceedingly difficult to get rid of plastics since burning them releases dangerous compounds like dioxins that worsen global warming [1,2].

Figure 2 illustrates the significance and use of plastics in several industries from 2005 to 2009. This graphic illustrates how widely plastics have been utilised throughout a variety of industries, including exports, the building and construction industry, consumers, and the packaging business. Plastics utilised in the packaging industry, building and construction, consumer, and institutional sectors have been shown to gradually decline over time, but exports have significantly grown due to the growing demand for plastic items.

The total amount of plastic used between 2005 and 2009 is shown in Figure 2. It has been demonstrated that plastic use increased in 2006 but gradually decreased in the following years, suggesting that environmental concerns may be developing in an effort to reduce the negative consequences of plastic consumption. People are thus searching for a substitute that might lessen the issues that plastics present, and this substitute source could be polymers made from biologically renewable resources [3].

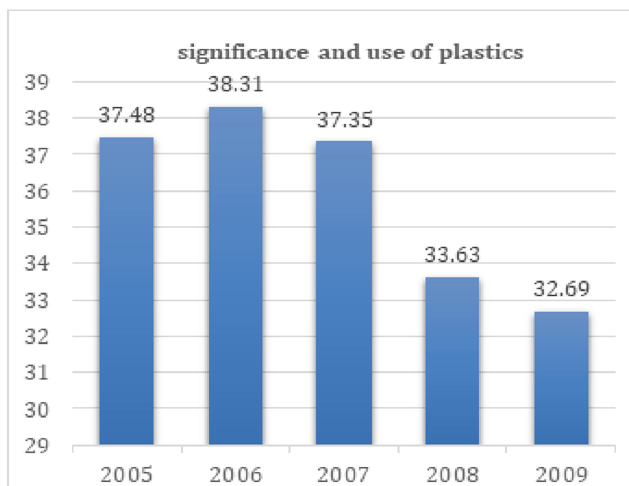

Figure 2: Illustrates the Significance and Use of Plastics in Several Industries.

Bioplastic

The quest for alternatives has been made possible by the environmental issues generated by synthetic plastics that are thrown away. Bioplastics are hailed as a potential new material to solve these issues since they are ecologically friendly and operate similarly to synthetic plastics. The word “bioplastics” refers to plastics that can either be biodegradable, like PCL or PBS, or can be made from renewable feedstock, such as vegetable oils, starch, cellulose, and vegetable fats, but may or may not be degradable [4,5].

Bio-based materials including potatoes, potato peels, corn, sugarcane, wheat, rice, banana peels, etc. are used to make io-plastics. Compared to plastics derived from petroleum, these polymers are safer, more environmentally friendly, and biodegradable. These biodegradable polymers decompose entirely into water, carbon dioxide, and inorganic chemicals [6]. All bioplastics, regardless of their biodegradability, require efficient end-of-life strategies for bioplastics waste to be implemented in tandem with their expanding production. Biodegradable bioplastics, for which biodegradation is frequently viewed as the only viable end-of-life option, present a different situation than biobased non-biodegradable bioplastics, such as bio-polyethylene terephthalate (BioPET), bio-polyethylene (BioPE), and bio-polypropylene (BioPP) [7].

Bioplastics have several benefits over traditional plastics, including a lower reliance on fossil fuels, non-toxicity, ease of recycling, lower energy consumption during production, renewable nature, and environmental friendliness. Since they were first developed in the early 19th century primarily for the purpose of wrapping candy, bioplastics are not new to the modern world. However, they did not become very important since they were costly and because they came from biological sources. Figure 3 provides an overview of the bioplastics’ future development [8].

Year	Development
1941	Henry Ford experimented with plastics made from soya beans and produced a plastic car. World war II played an important role in the development of bioplastics.
1992	Metabolix, a bioscience company provided solutions for worlds needs for plastics, chemicals and energy.
2000	Metabolix initiated the research programs for the development of engineered industrial crops for the production of bioplastics.
2005	Toyota began a pilot plant at Hirose plant in Toyota city, Japan to test the ease of producing bioplastics.
2006	LONDON-NEC corporation and Unitika Ltd had developed a bioplastic material reinforced with fibre from the Kenaf plant to reduce the environmental impact of mobile phones
2010	Cardia bioplastics Malaysia manufacturing(CBMM) was developed to manufacture bioplastics products

Figure 3: Provides an Overview of the Bioplastics’ Future Development.

Statistical Data of Bioplastics

It is projected that 327,000 tonnes of bioplastics can be produced globally, whereas 12.3 million tonnes are used globally. This suggests that the market for bioplastics is still in its infancy and that demand for them is greater than supply, which prevents them from fulfilling usage criteria.

By 2020, the bioplastics market is predicted to be valued $20 billion. Figure 4 displays the percentage of usage of bioplastics in different domains. It states that catering, vegetable packaging, and foil packaging are the industries that utilise bioplastics the most [9].

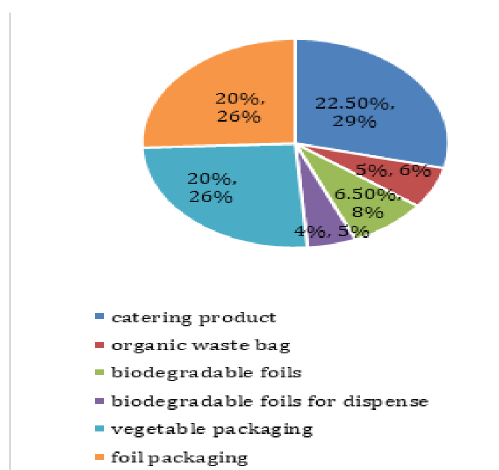

Figure 4: Displays the Percentage of Usage of Bioplastics in Different Domains.

Sources of Bioplastics

Algal, bacterial, and plant materials are used to make bioplastics [10].

Plant Sources: Approximately 80% of the market for bioplastics is made up of starch-based materials such as cellulose derivatives and wheat, maize starch, rice, sweet potatoes, barley and sorghum. One of the most popular types of bioplastics is thermoplastic starch. Pure starch is a great material to utilise in bioplastics for the production of medicine capsules since it can absorb humidity. Another usage for cane sugar is in the production of polylactic acid (PLA), a bioplastic.

Plants are being genetically engineered to manufacture next-generation bioplastics, such as genetically modified potatoes and maize, where the plastic is made directly within the plant. Apart from the benefits, limited biomass, impact on the human food chain, and longer production times are some of the drawbacks of plant-based bioplastics [10].

Bacterial Sources: Bioplastics, which are sustainable substitutes for conventional polymers derived from petroleum, may be produced using bacteria as a useful source. Polyhydroxyalkanoates (PHA), which are produced by a variety of bacteria including *Ralstonia eutropha* and *Cupriavidus necator*, are one important bacterial source. These bacteria have the ability to change renewable carbon sources like sugars and fats into PHA polymers, which are then granule-stored inside their cells. Bacillus subtilis is another potential bacterial choice; it is well-known for producing polyglutamic acid (PGA), a biodegradable polymer that finds use in bioplastics. Furthermore, the spectrum of bacterial sources for bioplastic synthesis has been further expanded by the genetic engineering of particular strains of Escherichia coli to make bioplastics. These bioplastics made from bacteria have the potential to lessen environmental damage and our dependency on non-renewable resources [11].

Algal Sources: The use of algae presents a viable avenue for the generation of bioplastics, owing to their fast proliferation, elevated lipid composition, and adaptability to various environmental circumstances. Microalgae, including species like Chlorella, Spirulina, and Nannochloropsis, are among the main contenders for the creation of bioplastics. These microalgae may collect lipids, especially triacylglycerides (TAGs), which can then be fermented by microbes to produce polyesters or other biodegradable polymers like polyhydroxyalkanoates (PHA). Furthermore, because macroalgae, sometimes referred to as seaweeds, contain a lot of cellulose and alginate, they have the potential to be sources of bioplastic. Scientists are investigating several techniques to separate and purify biopolymers from algae with the goal of creating environmentally friendly substitutes for traditional plastics. Bioplastics derived from algae have the potential to decrease carbon emissions, alleviate plastic waste, and encourage a more ecologically friendly [12].

Seaweeds

The three taxa that comprise seaweeds or macroalgae, are typically green, brown, and red algae. They are crucial to the preservation of the ocean's ecology and one of its most valuable bio resources. Food, fodder, bio fertilizers, food additives, paper production, and biobased fuels are all made from these marine algae. Many aspects of seaweed biology are explored in this chapter, such as their defence mechanisms against herbivory and predation, their function in maintaining ocean ecosystem, the life histories of significant seaweeds, and their economic uses [13].

- Brown seaweeds (Pheophyta): *Macrocystis integrifolia*
- Green seaweeds (Chlorophyta) – *Cordium fragile*
- Brown seaweeds (Pheophyta) – *Macrocystis integrifolia*
- Red seaweeds (Rhodophyta) – *Porphyra*

Bioplastics Making from Seaweeds

Seaweed manufacturing of bioplastics provides a long-term response to the environmental problems that traditional plastics bring. Seaweed is a common marine algae found in many parts of the world. It includes polysaccharides, such as cellulose and alginate, which may be collected and converted into biodegradable bioplastics. Innovative methods, such enzymatic or chemical treatments, may be used to convert seaweed-derived polymers into a variety of bioplastic products that are used in anything from packaging to medicinal materials. By using renewable marine resources, this strategy not only lessens dependency on fossil fuels but also helps to prevent plastic pollution and promote the circular economy. Bioplastics made from seaweed offer a viable way to develop environmentally acceptable substitutes for plastics in the market.

Bioplastics made from seaweed are dependent on polysaccharides such alginate, agar, carrageenan, and floridean starch. Seaweed is carefully harvested at the beginning of the quality control process, and then it is quickly dried and baled to maintain freshness. The dried seaweed is mechanically ground and sieved at the production location to get rid of debris like salt and sand, and it is then thoroughly cleaned to guarantee premium quality. Polysaccharide extraction is a heated technique that includes a two-stage clarifying step to get rid of smaller contaminants and dense cellulose particles. One of two techniques is then used to the concentrated polysaccharide solution during processing. First, a solution containing potassium chloride is added to raise the gelling temperature. Excess water is then removed by freezing and compression.

The second process involves precipitating the concentrated solution in isopropyl alcohol, which yields a coagulum that is compressed, vacuum-dried to eliminate alcohol, and then dried again using a belt drier. The generated polysaccharides are combined in a way that precisely satisfies the requirements for the final product [14].

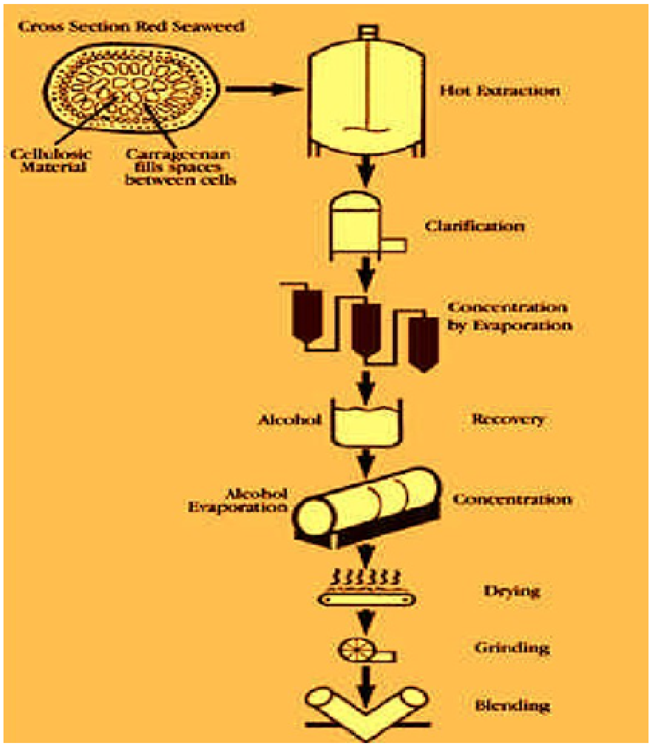

Figure 5: Manufacturing Process of Bioplastics from Seaweeds.

Cultivation of Seaweeds

Mariculture, another name for seaweed cultivation, is the carefully managed growth of seaweeds for a range of commercial, agricultural, and culinary uses. Seaweed cultivation starts with the gathering of spores or small seaweed fragments, which are then affixed to substrates like ropes, nets, or frames. Seaweed is often produced in coastal locations or in specially designated aquatic farms. These substrates are suspended in shallow coastal waters or the ocean, giving seaweeds a place to thrive. The kind of seaweed and the intended product determine the cultivation methods, which include carefully monitoring water depth, temperature, nutrient availability, and quality to maximise growth.

Seaweed farming is a sustainable supply of raw materials for a range of businesses and has several positive environmental effects, such as carbon sequestration, nitrogen absorption, and habitat provision for marine life [15,16].

Seaweeds in India

Seaweeds play a significant role in India, both ecologically and economically. India's vast coastline, spanning over 7,500 kilometres, provides abundant opportunities for seaweed cultivation and harvesting. Seaweeds are utilized in various sectors, including food and agriculture, pharmaceuticals, cosmetics, and biotechnology. In coastal regions such as Tamil Nadu, Gujarat, Maharashtra, and Andhra Pradesh, seaweed farming has become a source of livelihood for coastal communities. Species like *Kappaphycus* and *Gracilaria* are commonly cultivated for their agar and carrageenan content, used in food products, cosmetics, and pharmaceuticals. Additionally, seaweeds contribute to coastal biodiversity, acting as nurseries for marine life and providing crucial ecosystem services such as shoreline protection and nutrient cycling. With increasing recognition of the value of seaweeds, India is exploring ways to expand seaweed cultivation and harness its potential for sustainable economic development and environmental conservation [17,18].

Figure 6: Image of Seaweed.

Applications of Bioplastics

- **Packaging industry:** Bioplastics are favored in the packaging industry due to their biodegradability.
- **Catering products:** They are often utilised in catering items such as spoons, bowls, and disposable plates.
- **Gardening:** Mulch foils and flower pots made of biodegradable bioplastics are used in gardening and agriculture since they have customisable lifespans and don't leave behind any soil residue.
- **Medical products:** Because of their ability to absorb moisture, thermoplastic starch-based bioplastics, or polystarch, are used in the medical industry, especially in the manufacturing of pill capsules.
- **Automobiles:** With the goal of substituting seaweed-based bioplastics for oil-based carbon fibre in vehicle bodywork, Toyota is leading the way in the use of seaweed biomass for environmentally friendly automobiles.

By 2015, Toyota plans to release bioplastics made from seaweed for use in automobiles.

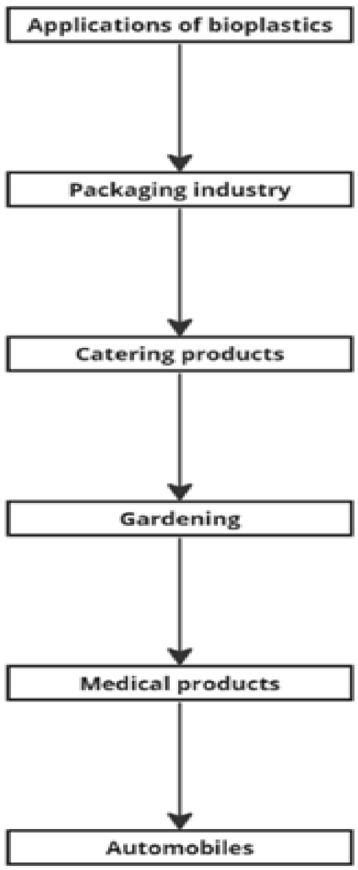

Figure 7: Application of Bioplastics.

Conclusion

Although the use of bioplastics is still in I its early stages, there is great potential for the development of sustainable plastics in the future. Fermentative PHA manufacture is expected to cost $2/kg, which is twice as much as polyethylene per unit polymer. Bioplastics are still seen as a potential solution to increase environmental sustainability despite their high cost. Although seaweed-derived bioplastics can be costly, their significance has grown recently due to their benefits over other biological sources that were previously discussed. When compared to traditional plastics, seaweed-based bioplastics are an environmentally benign and biodegradable substitute. Investigating the synthesis of bioplastics may have a significant impact on the profitability and viability of items made from seaweed. The utilisation of biotechnological and genetic engineering techniques is crucial in performing feasibility and sustainability studies of seaweed-based bioplastics, as the technical pathways for their manufacture are still being explored. It is envisaged that major developments in the bioplastics sector generally would help the seaweed-based bioplastics sector as well and eventually bring seaweed-based bioplastics to fruition.

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