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Seaweeds can be a new source for bioplastics

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ABSTRACT

The rapid growth of plastic production was a 20th century phenomenon on a historical scale. The low cost of plastics and its versatility have paved a way for a wide range of applications. As the plastics are non-biodegradable and found to have toxic effects on human, animals and environment, the bioplastics came into existence. Bioplastics are biodegradable and can be derived from renewable biological sources. Bioplastics have same applications as plastics. Although there are different sources of bioplastics like plants, animals and microbial sources, they have certain limitations such as non-availability of high biomass and difficulties involved in cultivation. In such cases, seaweeds can serve as one of the alternatives for the production of bioplastics because of its high biomass, its ability to grow in a wide range of environments and its cultivation in natural environment when compared to other microbial sources which require a specific environment for their cultivation. In addition to the above benefits, seaweeds are cost effective, minimize the impact on the food chain and are chemical-independent. Bioplastics from seaweeds are reported to be more resistant to microwave radiation, less brittle and durable. The technology development for the seaweeds-based bioplastics are still under the research phase and it is hoped that significant advancements would be made in the bioplastics industries and can make seaweed bioplastics a reality in future. Fermentation and genetic engineering can take the lead in using novel techniques to make bioplastics from seaweeds which would make them as a viable alternative. This review presents the importance, advantages and applications of seaweeds as an alternative source for bioplastics.

Key words: Plastics, bioplastics, seaweeds.

INTRODUCTION

Plastic has been a highly valued material on earth for its usefulness. Plastics contribute to our health, safety and peace of mind in our day to day life. Plastics are synthetic or semi-synthetic materials which are typically polymers of high molecular mass obtained from petroleum and natural gas. The phenomenal rise in the usage of plastics is due to their low cost and better properties which include flexibility, rigidness, brittleness, ability to be moulded into variety of shapes and lighter (Stevens, 2002). The history of plastics goes back more than 100 years. The first semi-synthetic plastic material used was celluloid which was used in the manufacture of billiard balls and later it was used in photographic films. Since then, there were tremendous amount of development in plastics and the history of development is presented in Table-1.

Table 1 History of plastics

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

(Source: American Chemistry Council).

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Life became much more convenient with the discovery of plastics because it has wide range of applications. In modern life, plastics are used in home appliances, electrical equipments, medical instruments, construction, automobiles and packaging.

Plastics became an integral part of human life due to their versatility and above mentioned applications. As these plastics are non-biodegradable it will take many years to completely get degraded, as a result they get accumulated

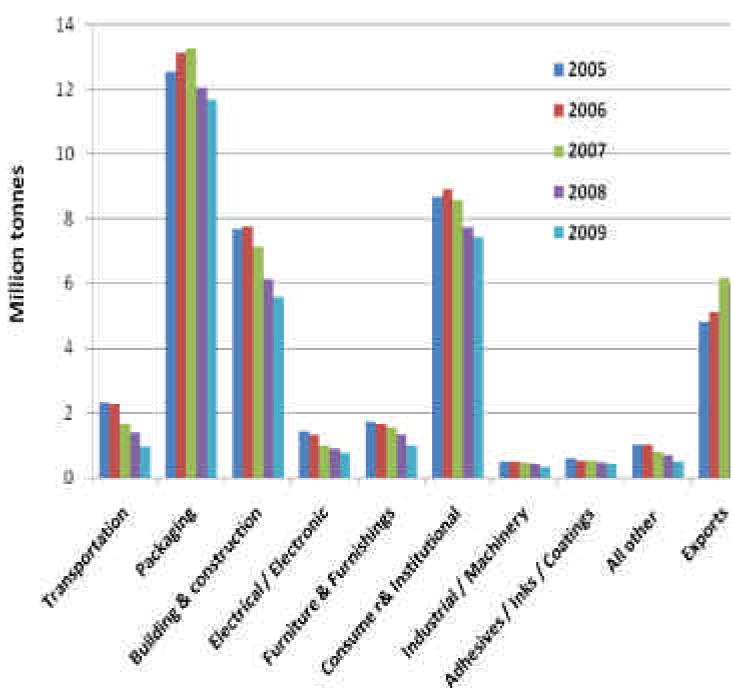

Fig. 1. Importance and usage of plastics during the year 2005–2009

in the environment as waste. Getting rid of the plastics is very difficult because burning of these plastics leads to harmful chemicals such as dioxins which contribute to global warming (Mary and Prieto, 2007; Song et al., 2009). Moreover recycling of plastics is difficult because different kinds of plastic has to be recycled by different processes and also involves high cost as the value of the material is low. Other limitations of plastics include release of toxic chemicals and carcinogens during manufacturing and also during incineration process resulting in pollution which in turn affects human health causing endocrine disruption, cancer, immune system suppression and various side effects. Although plastics are considered to be one of the greatest innovations ever, they also impose harmful effects to the environment and humans as mentioned above.

Figure 1 shows the importance and usage of plastics in different sectors during the year 2005–2009. This figure conveys the information that among the different sectors, plastics has been extensively used in packaging industry, building and construction, consumers and institutional, and exports. It is seen that the plastics used in packaging industry, building and construction, consumers and institutional showed gradual decrease whereas exports showed considerable increase with the time because of the increased demand for plastic goods.

Total usage of plastics during the year 2005–2009 was presented in Fig. 2. It has been shown that there is an increase in usage of plastics during the year 2006 but there is a gradual decrease in the later years, indicating that there may be a growing concern towards the environment in order to minimize the effects caused by the usage of plastics. Hence people are looking for an alternative that may reduce the problems posed by the plastics and this alternative source may be the plastics derived from renewable biological sources.

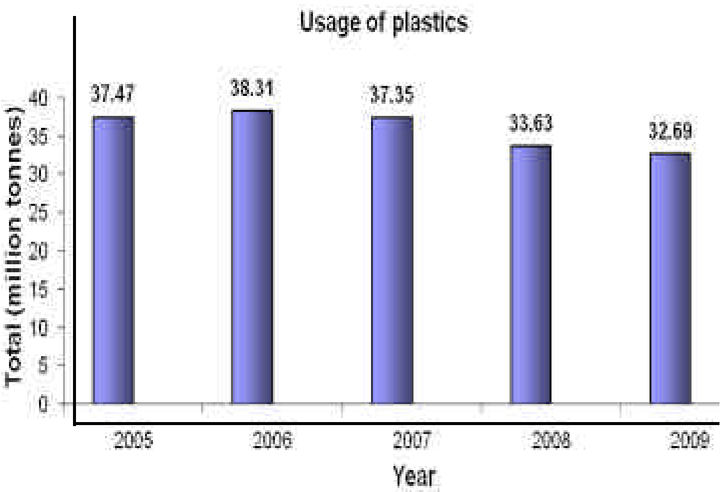

Fig. 2 Total usage of plastics during the year 2005–2009

Bioplastics

Bioplastics are the form of plastics derived from renewable biological sources such as plants, bacterial and algal sources. They can be degraded by microorganisms present in the soil such as bacteria and fungi without any release of pollutants. Moreover, the use of renewable sources in their manufacturing plays a key role in maintaining environment health. There are many advantages of bioplastics over conventional plastics such as reduced dependence on fossil fuels, non-toxic, easier to recycle, require less energy to produce, renewable and eco-friendly. Bioplastics are not new to the today's world as they were initially used only for wrapping candies during the early 19th century. But they did not gain significant importance as they were expensive and also due to its origin from biological sources. Further development of bioplastics has been described in Table 2.

Table 2. History of bioplastics

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

Statistical data of bioplastics

The global production capacity of bioplastics is estimated to be 327,000 tonnes and global consumption is around 12.3 million tonnes. This indicates that demand for the bioplastics is more compared to its production thus not meeting the requirements for their usage and it is still in infancy. It is estimated that the bioplastics industry could be worth $20 billion by 2020 (Beacham, 2010).

The information about the proportion of usage of bioplastics in various fields is shown in figure-3 which reports that among different sectors, bioplastics are predominantly used in catering, vegetable packaging and foil packaging.

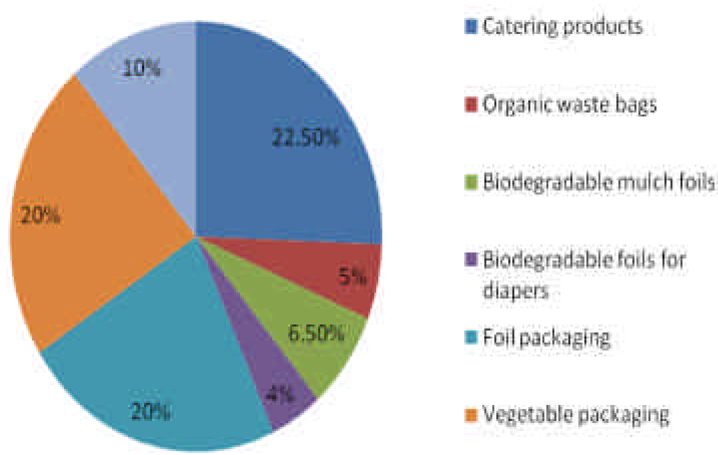

Fig. 3. Proportion of bioplastics in different sectors

Sources of bioplastics

Bioplastics are produced from plant, bacterial and algal sources.

Plant sources:

The different types of plant sources are starch based sources like wheat, corn starch, rice, sweet potato, barley, sorghum and cellulose derivatives which account for almost 80% of the bioplastics market. Thermoplastic starch is one of the most widely used bioplastics. Pure starch has the ability to absorb humidity, which makes it a suitable material to be used in bioplastics for the manufacture of drug capsules. Cane sugar is also used in the manufacture of bioplastics which is known as polylactic acid (PLA). Genetic engineering is being applied in plants to create next generation bioplastics in which the plastic is produced directly in the plant; genetically modified corn and potato serve as examples. In addition to the advantages bioplastics from plant source have certain limitations that include low biomass, affect the human food chain and consume more time for production.

Bacterial sources:

They are the most studied organisms for the production of bioplastics. Many bacterial species accumulate intracellular PHA granules as the energy and carbon reserves in their cells. PHA extracted from gram positive and gram negative bacterial cells show properties similar to polypropylene (Braun egg et al., 1998; Jose Luengo et al., 2003; Verlinden et al. 2007). PHA to be discovered and most studied is PHB. In their metabolism, bacteria produce acetyl coenzyme A which is converted to PHB by three biosynthetic enzymes like 3-ketothiolase (*pha* A), aceto acetyl-coA reductase (*pha* B), PHB synthase (*pha* C). some of the important bacterial species used for the production of PHA's are *Bacillus megaterium* which has PHA content of 20%*w/v* (*Mirtha et al., 1995*), *Klebsiella aerogenes* recombinants which has PHA content of 65%w/v (Zhang et al., 1994), *Pseudomonas aeroginosa* which has PHA content of 20–30% w/v (Egg ink et al., 1995). The production of bioplastics from bacteria has certain limitations such as requirement of specific conditions for their cultivation, contamination, special apparatus and infrastructure. To overcome these limitations from the above mentioned sources, algae may provide a better potential for bioplastic production.

Algal sources:

Algae are the autotrophic organisms ranging from unicellular to multicellular forms (Zabochnicka-Swiatek, 2010). Microalgae such as *Spirulina dregs* are used in the production of bioplastics, but cannot be easily harvested (Thurmund, 2010). Whereas macro algae like seaweeds have more potential than above mentioned sources because of its high biomass, ability to grow in wide range of environments, cost effective, easily cultivated in natural environment and can be harvested round the year.

Seaweeds are best known for the natural polysaccharides that can be extracted from them which are widely used particularly in the fields of food technology, biotechnology, microbiology and even medicine but not yet in the plastic industry. Since they are renewable biomass resources and are polymers made from sugars which contain carbon, they could be used to create biodegradable and high quality bioplastics. It aims to make a good, environment friendly, inexpensive and toxic free bioplastics that will match the quality in terms of tensile strength and chemical resistance of many conventional plastics being used today. Owing to its unique properties seaweeds can be served as a new and alternative source for bioplastics.

Seaweeds

Seaweeds are photosynthetic algae that lives in the bottom of the sea which are classified into three major groups based on their pigments and colouration.

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

Bioplastic making from seaweeds

The component of seaweeds used in the making of bioplastics is polysaccharides. Some of the polysaccharides of seaweeds are carrageenan, agar, floridean starch and alginate. Quality control of polysaccharides extract begins at the harvest. The seaweed is systematically gathered, quickly dried and then baled to maintain its quality and freshness. At the manufacturing site, the dried seaweed is mechanically ground and sieved to eliminate impurities such as sand and salt which is followed by extensive washing to ensure additional quality. Seaweeds undergo a hot extraction process to separate the polysaccharides which is a two-step clarification process. First the dissolved polysaccharide mixture is centrifuged to eliminate the dense cellulosic particles, filtered to remove the smaller particles and then, the solution is concentrated by evaporation for the removal of water. The polysaccharides are then recovered by one of the two processing methods. In one method, potassium chloride solution is added to the concentrated solution of polysaccharides to increase the gelling temperature so that the filtrate will gel immediately. The gel is then frozen and compressed to remove excess water. In another method, the concentrated solution is precipitated in isopropyl alcohol and as the polysaccharides are insoluble in alcohol, the filtrate turns into a coagulum of polysaccharides, alcohol and water. The coagulum is compressed to remove excess of liquids and vacuum dried to completely remove the alcohol. Drying is completed on a belt drier and is blended to meet the finished product of exact specification (Fig. 4).

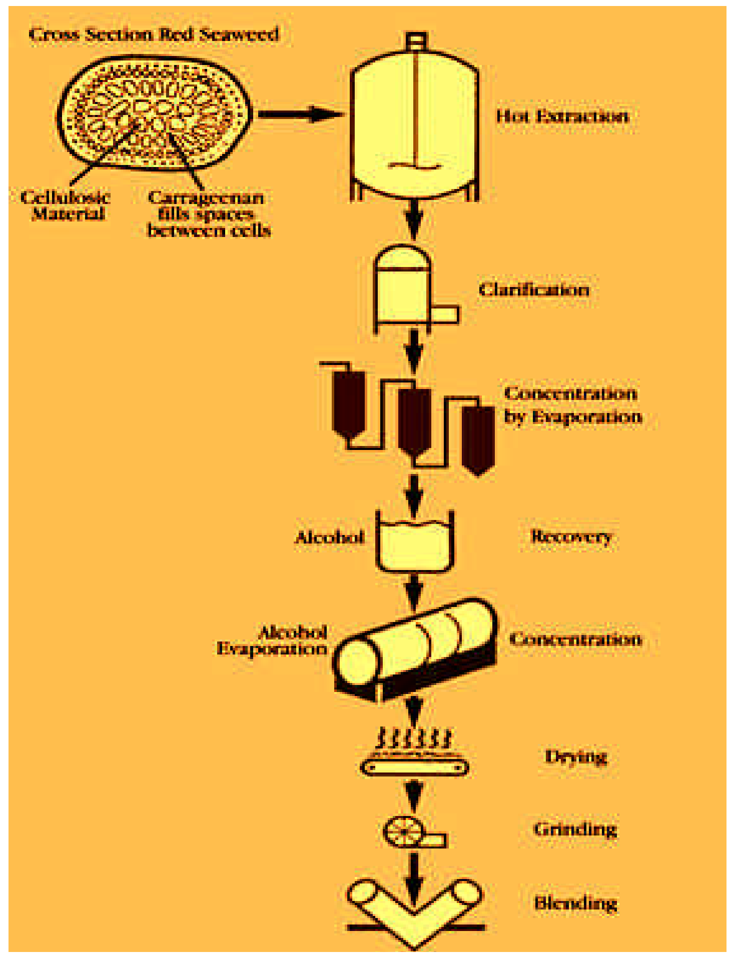

Fig. 4. Manufacturing process of bioplastic from seaweeds
(*Source*: http://www.fmcbiopolymer.com/Food/Ingredients/Carrageenan/Manufacturing.aspx).

Cultivation of seaweeds

Seaweeds can be cultivated through open farming or in a closed system using photo bioreactors (*Chopin and Sawhney, 2009*). Among many culture techniques, single rope floating raft technique developed by Central salt and marine and chemical research institute (CSMCRI) is suitable for culturing seaweeds in wide area and greater depth. Greater biomass can be obtained through open farming. The locations for growing seaweeds is dependent on species being cultivated and should include a strong substrate where stakes can be installed. The viable seed plants are transplanted onto the stakes for further growth. The first large scale commercial cultivation of seaweeds in India has been embarked upon by Pepsi food limited. The company has planned to expand culture operation to over 5000–10,000 hectares in the near future.

Seaweeds in India

Seaweeds grow abundantly along Tamilnadu and Gujarat coast and along Lakshadweep and Andaman and Nicobar islands. Out of approximately 700 species of marine algae found in both intertidal and deep water regions of Indian coast, nearly 60 species are important. The service carried out by CMSCRI and central marine fisheries research institute (CMFRI) have revealed vast seaweed resources along the coast belts of south India which offer great potential for the development of seaweed based industries for India. The production of total seaweeds in India in 2000 was approximately 600,000 tons(Kaliaperumal et al., 2004; Jha et al., 2009).

Applications of bioplastics

- **Packaging industry**
  Because of their biodegradable property, the use of bioplastics is popular in packaging sector.
- **Catering products**
  It has application in disposable crockery, bowls and spoons.
- **Gardening**
  In the agricultural economy and the gardening sector mulch foils and flower pots made of biodegradable bioplastics are used due to their adjustable lifespan and the advantage that they do not leave residues in the soil.
- **Medical products**
  Bioplastics made of thermoplastic starch (polystarch) absorbs humidity which is applied in the production of drug capsules.
- **Automobiles**
  It has been reported that Toyota Company is working on eco car made from seaweed biomass which is officially marked as the pioneer of Green automotive movement. The company hopes to replace the oil-based carbon fibre now used in many modules with a seaweed based bioplastic. The bioplastics from seaweeds used in vehicle's body by Toyota Company is likely to be released in to the market by 2015.

CONCLUSION

Currently application of bioplastics is in its infancy stage but holds significant promise in developing sustainable plastics for the future. The price of fermentative PHA production per unit polymer is estimated to be $2/kg prices which are twice the price of polyethylene. Even though bioplastics are expensive they are still considered as a viable option to improve environmental sustainability

Bioplastics from seaweed may also be expensive but they have gained utmost importance in the recent times because of their advantages over other biological sources which have already mentioned above. Seaweed based bioplastics play a vital role as an environment friendly and biodegradable alternative compared to conventional plastics. Exploring the production of bioplastics could play a major role in shaping the economics and viability of seaweed based products. The technology routes for the production of seaweed based bioplastics are still under research and the use of biotechnological and genetic engineering techniques play a key role in conducting the feasibility and sustainability studies in seaweed based bioplastics. It is hoped that significant advances made in the bioplastics industry in general will benefit seaweed based bioplastics industry as well and will make seaweed based bioplastics a reality in the distant future.

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