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## Review Article

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### A Review on Biodegradable Plastic and Non Polluting Plastic

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#### ABSTRACT

Currently, about 80 % of all polymeric materials are produced by the petrochemical industry, i.e. they are produced from fossil (non-renewable) resources. The present review will detail the efforts to produce biodegradable plastics in plants and will be extended to include the broader topics of biodegradable polymers derived from plant materials, including starch and cellulose.

Along with the increased use of plastics the burden on the environment is also increasing. In addition to the environmental impacts caused by the mere production of polymers and plastics, there is a growing burden of waste, generated when users discard products that are no longer needed. Waste has been a pressing problem for many years; with the increasing mass consumption of products with a short life span, the amount of waste is also increasing rapidly.

**Keywords:** petrochemical industry, biodegradable plastics, environmental impacts, life span

#### ARTICLE INFO

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### 1. Introduction

**Bio -Plastics:** According to Merriam–Webster Dictionary, The term ‘plastic’ is defined as any of numerous organic synthetic or processed materials that are mostly thermoplastic or thermosetting polymers of high molecular World Journal of Pharmacy and Biotechnology

mass and that can be made into objects, films or filaments. The majority of plastics are synthetic, using petroleum both as feedstock and as energy during manufacture. With the price of oil rising and easily accessible reserves dwindling,

alternative sources of fuel and of oil-based commodities such as plastics are being explored across the world. The environmental concerns of the oil-based economy are also being widely voiced as companies and individuals attempt to reduce their carbon footprints. A bioplastic is a substance made from organic biomass sources, unlike conventional plastics, which are made from petroleum. Bioplastics are made through a number of different processes. Some use a microorganism to process base materials, such as vegetable oils, cellulose, starches, acids and alcohols.

Plastics are truly a huge industry. The simple 'paper or plastic' decision one makes in the supermarket eventually has consequences for the environment. These consequences have been recognized in the form of bans on plastic bags in many of the EU (European Union) countries, China, Australia, the City of San Francisco and an attempted ban in the State of California.

Plastics have become a large environmental problem. In fact, "Americans go through 25 billion plastic bottles each year". Unfortunately, these plastic bottles along with other forms of plastic account for "25 per cent" of the total volume of landfills. The plastics that do residue in landfills degrade very slowly, which can cause the original products to remain in our landfills for hundreds or even thousands of years. Biodegradable plastics are becoming a new trend because they are believed to be friendlier to our environment. Biodegradable plastics are plastics that will decompose in both aerobic and anaerobic environments. Unlike conventional plastics, "a genuine biodegradable plastic will be converted to carbon dioxide, water and compost, without any persistence or toxic residue". Biodegradable plastics have the ability to significantly decrease the quantity of plastics within our landfills, and also eliminate toxins within our air from the burning of quantity of plastics within our landfills, and also eliminate toxins within our air from burning of conventional plastics. Biodegradable plastics are made from renewable raw materials, and presently found in various forms with different degree of biodegradability. One of the most frequent used forms of biodegradable plastic is term as hydro-biodegradable plastic. Unlike conventional plastics, which are comprised primarily of starches that are found in plants or food although some contain a small percentage of synthetic polymers. When hydro-biodegradable compounds are degraded, the original product reduces to water, carbon dioxide, methane, and biomass. The search for alternatives to traditional petroleum-based plastics is progressing to the point that not just the source, but also the downstream consequences, are being addressed in the form of biodegradable plastics. Although photodegradable plastics continue to be explored, these alternatives must be constantly exposed to sunlight and so are not suitable for landfill disposal. Biodegradability in composters or municipal landfills is the goal. Even large chemical companies, like BASF with its Ecoflex® product, are touting their biodegradable-plastics efforts to address the downstream consequences on the environment of conventional plastics.

In this context, production of biodegradable plastics in plants is an enviable goal. Plants naturally produce many polymers, such as starch or cellulose, and these have been exploited for plastics production. Additionally, novel plastics, like the PHAs (polyhydroxyalkanoates), are also being synthesized in plants. Plants can be considered as solar-driven bio-factories with the potential for being renewable, sustainable, scaleable and relatively environmentally benign sources of edible vaccines or 'plantibodies', novel oils and fatty acids and biodegradable plastic. The present review will detail the efforts to produce biodegradable plastics in plants and will be extended to include the broader topics of biodegradable polymers derived from plant materials, including starch and cellulose.

## 2. Types of Degradation

Degradation has been reflected in changes of material properties such as mechanical, optical or electrical characteristics viz. crazing, cracking, erosion, discoloration, phase separation or delamination. The changes include bond scission, chemical transformation and formation of new functional groups. The degradation will either be photo, thermal or biological.

### Photodegradation:

Sensitivity of polymers to photodegradation is related to the ability to absorb the harmful part of the tropospheric solar radiation. This includes the UV-B terrestrial radiation (~295 – 315nm) and UV-A radiation (~315 – 400nm) which are responsible for the direct photodegradation (photolysis, initiated photooxidation). Visible part of sunlight (400 – 760nm) accelerates polymeric degradation by heating. Infrared radiation (760 – 2500nm) accelerates thermal oxidation. Most plastics tend to absorb high energy radiation in the ultraviolet portion of the spectrum, which activates their electrons to higher reactivity and causes oxidation, cleavage, and other degradation.

### Thermal degradation:

As a result of overheating, molecular deterioration of polymers takes place. At high temperatures the components of the long chain backbone of the polymer can begin to separate (molecular scission) and react with one another to change the properties of the polymer. The chemical reactions involved in thermal degradation lead to physical and optical property changes relative to the initially specified properties. Thermal degradation generally involves changes to the MW (and MW distribution) of the polymer and typical property changes include: reduced ductility and embrittlement, chalking, color changes, cracking and general reduction in most other desirable physical properties.

### Biodegradation:

In this process organic substances are broken down by living organisms. The term is often used in relation to ecology, waste management, bioremediation and to plastic materials, due to their long life span. Organic material can be degraded aerobically, with oxygen, or anaerobically, without oxygen. A term related to biodegradation is biomineralization, in which organic matter is converted into minerals. In contrast to photo degradation which leads to

breakdown of the polymers into non-degradable smaller fragment leading to loss of structural integrity of material, biodegradation leads to complete decomposition of polymers. Plastics are biodegraded aerobically in wild nature, anaerobically in sediments and landfills and partly aerobically and partly anaerobically in composts and soil. The main advantage is that, the biodegradable polymers are completely degraded to water, carbon dioxide and methane by anaerobic microorganisms in various environments such as soil, sea, lake water and sewage and hence, is easily disposable without harming environment while carbon dioxide and water are produced during aerobic biodegradation. Generally, the breakdown of large polymers to carbon dioxide (mineralization) requires several different organisms, with one breaking down the polymer into its constituent monomers, one able to use monomers and excreting single waste compounds as byproducts.

### Plant Based Bio Degradable Plastics

Although plant-based biodegradable plastics are not new, the current interest in green technologies has led to a renewed interest in using plants for a number of applications. Many of these applications are traditionally based on crop plants, be it for ethanol production, biomass production for power generation and sources of novel compounds such as pharmaceuticals. Additionally, with pressures on land use for farming, the concomitant use of fertilizers and pesticides, and various threats of genetically modified organisms to the human food chain, non-food crops are also being explored as biofactories.

### 3. Natural Plant Polymers

Plants naturally produce a number of structural and carbon-reserve polymers. Polysaccharides are estimated to make up approx. 70% of all organic matter. Cellulose accounts for about 40% of total organic matter and is the most abundant macromolecule on earth. Lignin comprises 15–25% of a typical woody plant. Starch is also a major component of global biomass, and the ability to digest starchy foods is thought to have played a role in human evolution and its success over other species. A number of natural polymers have been exploited for commodity manufacturing, and most of these products retain the inherent biodegradability of their carbohydrate building blocks.

#### Rubber

Rubber, a polymer of isoprene *cis*-1,4-polyisoprene; is the most widely used natural plant polymer. All commercial production of rubber comes from the Brazilian rubber tree (*Hevea brasiliensis*). Despite the plant's common name, more than 90% of the world's natural rubber supply now actually comes from South-East Asia. Although natural rubber production only accounts for 40% of demand (the remainder is synthetic), natural rubber is superior to synthetic, owing to its. Although synthetic-rubber production has reached a plateau, natural-rubber production continues to increase, particularly in China and Vietnam. The main reason production has switched to Asia from South America is the South American leaf blight fungal infection caused by *Microcyclus ulei*, which originates in the Amazon region. All attempts at commercial-scale World Journal of Pharmacy and Biotechnology

rubber cultivation in South and Central America have been thwarted by this, as yet, uncontrolled fungus. More recently, molecular-breeding approaches have been explored to attempt to confer resistance traits, and, with strict quarantine, plantations in Asia have been unaffected by the blight. Rubber plantations are composed of clonal trees; in fact, the commercial rubber tree is one of the most genetically restricted crops grown, making the *Hevea* rubber tree particularly susceptible to pathogen attack. Natural rubber's isoprene monomers are derived almost exclusively from IPP (isopentenyl diphosphate). IPP is derived from cytosolic acetyl-CoA through the mevalonate pathway. Polymerization of the isoprenyl units is catalysed by 'rubber elongation factor' or 'particle-bound rubber transferase'. This enzyme is a *cis*-prenyltransferase, which adds isoprenyl units from IPP to form the polymer. Two transferase cDNAs were cloned from *H. brasiliensis*, then expressed in, and purified from, *Escherichia coli*. Although low-molecular-mass rubber (<10 kDa) was made *in vitro* using the purified enzymes, the addition of a fraction from latex containing washed rubber particles permitted the formation of a high-molecular-mass product. Clearly, then, other factors present in the natural-rubber particles are required for high-molecular-mass polymer production, but these components are ill-defined, although magnesium cations seem to regulate the activity of the prenyltransferase. Other natural sources of rubber are being explored owing to *H. brasiliensis*' disease susceptibility and also because of the prevalence of allergy to latex. Type I latex allergy is based on the reaction to natural-rubber latex proteins, and type IV is based on chemical additives, in gloves, for example. Latex allergies occur at a rate of about 1% of the general population, but at a 10–20-fold higher rate in healthcare workers. Although a number of plant species (about 2500) synthesize rubber, many of these are not suitable for commercialization because they do not produce the high-molecular-mass form of the polymer with its concomitant useful properties. Two promising alternatives to *Hevea* that do produce high-molecular-mass rubber are guayule (*Parthenium argentatum* Gray) and Russian dandelion (*Taraxacum kok-saghyz*). Guayule is a non-tropical shrub native to Mexico and parts of the U.S. South-West. Guayule rubber is considered hypoallergenic compared with that from *Hevea* because it is less proteinaceous and the proteins that are present do not cross-react with *Hevea* immunoglobulins. However, unlike *Hevea*, the guayule shrub cannot be 'tapped' for latex extraction, and the kilogram yield per acre of rubber is about one- to two-thirds that of *Hevea*. This obviously increases the cost of production, and without significant improvements in cultivation, harvesting and processing, guayule rubber will likely remain as a specialized-use product. Russian dandelion produces a higher-molecular-mass polymer than either *Hevea* or guayule (about 2 MDa), which accumulates in lactifers in the roots. It was discovered in Kazakhstan in the 1930s and was used as a source of motor-tyre rubber during World War II by a number of countries, including the United States and the U.K. Although production yields are poor and large-scale cultivation is hampered by cross-

breeding with weedy species and labour-intensive crop maintenance, it can be useful as a model species for rubber biosynthesis because, in part, of its relatively short life cycle (altered rubber phenotypes can be screened within 6 months) compared with guayule and *Hevea*. A further advantage is the 'double-cropping' potential of Russian dandelion, both as a source of rubber and its fructose-based storage sugar, inulin, which accumulates at 25–40% of root dry weight and could be used in bioethanol production.

### Proteins

Proteins can be considered polymers of amino acids that are combined in various combinations that confer function on the basis of their side-chain structure and on the arrangement of the amino acid monomers within a protein for tertiary/quaternary structure. Although plants are being used to synthesize novel proteins (see the subsequent section), a number of naturally occurring proteins have been exploited as plastics. For example, proteins from wheat (*Triticum aestivum*), maize (*Zea mays*) and soybean (*Glycine max*), particularly zeins and glutens, have been used as the basis for biodegradable polymers.

Gluten is a composite of the proteins glutenin and gliadin (with other globulin and albumin components). Two-dimensional gel-electrophoretic analysis shows multiple spots corresponding to multiple isoforms of glutenin. The gluten fraction comprises about 80% (w/w) of the wheat seed protein and about 8–15% of seed dry weight. Gluten is easily harvested from seed by washing away soluble components (mainly starch) to produce an essentially pure protein isolate. Gluten is used as a protein source in a number of food products, for example in preparing fibrous meat analogues composed of gluten, soy protein and starch. Gluten confers elastic properties on dough, owing to the presence of disulfide-linked glutenin chains gliadin intercalating with the glutenin chains.

This property has led to research in using gluten and zein/gluten composites as plastics. Gluten coated with zein has been used to produce a plastic that is biodegradable and yet has a compressive strength similar to that of polypropylene. Production of this polymer is very simple; gluten and zein are mixed in ethanol and then formed in moulds. Essentially the zein forms a 'glue', which binds the matrix (gluten) and causes aggregation; pressure moulding then removes the ethanol and allows to form polymer. Maize gluten has been used in the manufacture of wood composites. In this process, wood fibres are mixed with maize gluten, plasticized using glycerol, water and ethanol, and then extrusion-moulded into pots that are reasonably water-resistant and biodegradable. An early use of plasticized soy protein was by the Ford Motor Company. In 1940, Henry Ford applied for patent protection on his invention for automobile body construction, which stated that "the object of my invention is to provide a body construction in which plastic panels are employed, not only for the doors and side panels, but also for the roof, hood and all other exposed panels on the body." The panels were made from soy meal (about 50% protein) that was cross-linked with formaldehyde with the addition of phenol or

urea to increase strength and resistance to moisture. The panels were layered over a unique (at the time) tubular steel cage that provided the structural rigidity for the car, which was actually the focus of the patent application.

The patent was issued on 13 January 1942 (Automobile body construction, U.S. Patent 2269451). Henry Ford was photographed demonstrating the strength of the panels by swinging an axe at the car (although the photograph fails to show the impact or any damage associated with it). The prototype was never put into production, partly because the plastic was susceptible to microbial degradation (it was biodegradable!) and was not adequately moisture resistant, and apparently the car smelled strongly of formaldehyde. SPI (soy protein isolate) is a minimum of 90% protein (by dry weight) and is purified from defatted soy flour. The glycinin and conglycinin seed storage proteins are the bulk of the protein content. Although SPI has been widely used as a food ingredient, it also has been used as a basis for plastic production. Heat-induced cross-linking of the proteins creates a thermoplastic polymer based on three-dimensional networks of disulfide bonds, as well as hydrophobic interactions and hydrogen bonding. Addition of plasticizers, such as glycerol, improves the structural properties of the film. Combining 5% (w/v) SPI and 3% (w/v) glycerol in water and then adjusting the pH outside the pI of the major storage proteins to prevent aggregation/coagulation (<pH 3 or >pH 6), followed by heating to 80 °C, allowed casting of films on a levelling table. Alkaline-cast films are more flexible than acid-cast ones. Although these films are poor moisture barriers, they are good oxygen barriers and so can be used as a layer in a multilayer sheet to prevent oxidation of packaged food.

Using  $\gamma$ -irradiation for protein cross-linking in film production has the added benefit of being a common sterilization technique.  $\gamma$ -Irradiation causes the production of free radicals in the protein solution, and cross-linking through biphenolic compounds is achieved. These films have superior puncture strength and deformation properties than have the thermoplastic SPI films, and this could be further improved by the inclusion of carboxymethylcellulose or poly (vinyl alcohol). More recently, composites of SPI and chitin or cellulose microfibrils ('whiskers') have been produced that have superior properties compared with pure SPI-based plastics. Cellulose whiskers with average dimensions of 1.2  $\mu\text{m}$  long  $\times$  90 nm diameter were prepared from cotton by hydrolysis in sulfuric acid. Mixing SPI, whiskers and glycerol in water was followed by heating and pressure moulding to produce the polymer. The SPI-cellulose composites have a superior moisture resistance, tensile strength, thermal stability and flexibility to SPI-based polymers, but retain biodegradability. Similar improvements in the quality of SPI-based plastics have been achieved by using polylactide in the composite.

### Cellulose

Although much research using starch and cellulose reserves is based on their use for biofuels, they have also been used for plastic production through derivatization. Cellulose is a

linear polymer of  $\beta$ -1,4-linked D-glucose. Although cellulose cannot be thermally processed into plastics, owing to decomposition of its hydrogen-bonded structure, derivatized cellulose has been employed for plastics production. Parkesine was an early pressure-mouldable form of nitrocellulose. The cellulose was derived from cotton fibres solubilized with nitric acid and ethanol. This solution, called 'collodion', could be cast in sheets or pressure-moulded. Parkesine was eventually updated and replaced by celluloid, which used camphor, a tough gummy volatile aromatic crystalline compound ( $C_{10}H_{16}O$ ), as a plasticizer. The addition of the camphor plasticizer made celluloid more flexible and mouldable and less likely to fracture compared with Parkesine. Celluloid was also used as a substitute for ivory, specifically for billiard balls and, towards the end of the 19th Century, was used as a photographic film for still photographs and movie films and even as windshields. Cellulose acetate is another derivative of cellulose, is prepared by dissolving cellulose in acetic acid and acetic anhydride in the presence of sulfuric acid. Sheets are then cast, or fibres spun, typically from an acetone solution. Cellulose acetate was widely used as film stock in the early 20th Century.

#### 4. Bioplastic and Social Benefits

What makes bioplastic especially important is that petroleum oil price is increasing tremendously and its stock will end in the near future. It is important for the global community to have an alternative for the product derived from petroleum oil such as plastics. PHAs at least will be a solution for the most of the industries and society, which largely depend on materials made from plastic. No new inventions can escape from the limitations and drawbacks and bioplastics too have some drawbacks. The most important drawback for PHA production is its production cost, but the good news is that the price of PHA production is decreasing, whereas, petroleum oil price is increasing constantly. As a result, the gap between the petroleum oil and PHA are becoming very narrow. The first potential application of PHA polymers was recognized in the 1960s. PHA patents cover a wide range of PHAs products such as coating and packaging, bottles, cosmetic containers, golf tees, and pens. PHAs have also been processed into fibers, for a non woven fabrics material, PHAs can be used for all sorts of biodegradable packaging materials, including composting bags, food packaging, sanitary articles like diapers and fishing nets, biodegradable rubbers. PHAs are also used to develop scaffold for tissue engineering, and also possess numerous applications in pharmacy and medical science.

#### 5. Conclusion

This review sums up, the production of plant-based polymers can be approached in a number of ways; Some progress has been made in commercialization of plant-based materials, However, commercialization of transgenic plants specifically designed to synthesize polymers has not been achieved. Parameters affecting commercialization of transgenic plants for bioplastics include the time and costs associated with their development (often 10–12 years and World Journal of Pharmacy and Biotechnology

tens of millions of U.S. dollars in total), the typically poor accumulation levels of novel polymers (compared with bacterial systems), the lack of proven processing and extraction methods, the price per unit of polymer from plants, and the stigma associated with GMOs in many parts of the world.

Researchers started to look if plastics could be designed to become susceptible to microbial attack, making them degradable in a microbial active environment. Biodegradable plastics opened the way for new considerations of waste management strategies since these materials are designed to degrade under environmental conditions or in municipal and industrial waste treatment facilities. The synthesis of PHA in crop plants can be regarded as a promising alternative for the large scale and low cost production of this polymer. Changing the carbon source and bacterial strains for biopolymer production with properties ranging from stiff and brittle plastics to rubbery polymers is one way of cost reduction. However, bioplastics can have its own environmental impacts, depending on the way it is produced. Hence there is an urgent need to develop efficient microorganisms and their products to solve this global problem with plastics.

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