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Bioplastics and their role in achieving global sustainability

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ABSTRACT

In recent years, bioplastics are becoming increasingly prominent owing mainly to scarcity of oil, increase in the cost of petroleum-based commodities, and growing environmental concerns with the dumping of non-biodegradable plastics in landfills. In the present paper, we first discuss the definition and basic facts as well as the major advantages of bioplastics, then the main differences between plastics and bioplastics in packaging are briefly reviewed. Finally, possible future developments of bioplastics are prospected.

Key words: bioplastics, petroplastics, packaging, environmental, sustainability

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INTRODUCTION

In view of dwindling reserves of fossil resources， industry is showing growing interest in bioplastics. About 4% of the world's oil production is converted into plastics for use in products as varied as shopping bags and the external panels of cars. Another few percent is used in processing industries because oil-based plastics require substantial amounts of energy to manufacture.

As oil runs out，and the use of fossil fuels becomes increasingly expensive，the need for replacement sources of raw material for the manufacture of vital plastics becomes increasingly urgent. In addition， the use of carbon-based sources of energy for use in plastics manufacturing adds greenhouse gases to the atmosphere， impeding the world's attempts to cut CO_2 emissions[1-2].

An environmental dilemma with more far-reaching implications is climate change. The need for rapid and deep greenhouse gas（GHG）emissions cuts is one of the drivers for the resurgence of industrial biotechnology generally，and the search for bio-based plastics more specifically. Bio-based has come to mean plastics based on renewable resources， but this need not necessarily imply biodegradability. If the primary purpose is GHG emissions savings, then once again plastics durability can be a virtue， if the end-of-life solution can be energy recovery during incineration or recycling. The pattern of production is shifting from the true biodegradable plastics to the bio-based plastics， and that trend is likely to persist into the future.

Another environmental aspect of plastics manufacture is green house gas generation. The Intergovernmental Panel on Climate Change（IPCC）trajectory to 2050 for stabilization of atmospheric GHG concentrations at 450 ppm CO_2 requires emissions reduction of 80% compared to the 1990 level [1]. This will be perhaps the biggest human challenge of the next generation. Several countries have adopted targets for such deep reductions in GHG emissions [2]， and part of the strategy for many is the development of a biobased economy. The biobased economy first emerged as a policy concept within the OECD at the start of this century，linking renewable biological resources and bioprocesses through industrial scale biotechnologies to produce sustainable products， jobs and income [3].

These problems can be overcome. All the major oil-based plastics have substitutes made from biological materials. The polyethylene in a shopping bag can be made from sugar cane and the polypropylene of food packaging can be derived from potato starch. Plastics are irreplaceable and will all eventually be made from agricultural materials.

DEFINITION AND BASIC FACTS OF BIOPLASTICS

A bioplastic is a plastic that is made partly or wholly from polymers derived from biological sources such as sugar cane，potato starch or the cellulose from trees，straw and cotton. Bioplastics are not just one single substance，they comprise of a whole family of materials with differing properties and applications. According to European Bioplastics [4] a plastic material is defined as a bioplastic if it is either biobased，biodegradable，or features both properties.

However，in spite of the effort spent by the associations，the term bioplastics is still prone to misunderstandings. Basically，the problem arises because traditional petrochemical plastics（such as polyethylene（PE）and polyethylene terephthalate（PET））can now also be produced starting from renewable raw materials. The reader can easily understand that to define an item made with traditional plastics like PE as bioplastics is quite strange. Innovation in this case lies in *the production process* rather than in *the product*. Therefore，the term，biobased plastics，seems more suitable to describe traditional plastics that are made from vegetable resources. On the other hand，the term，bioplastics，seems more suitable to describe those innovative materials that are biobased and biodegradable.

Biobased：The term "biobased" means that the material or product is（partly）derived from biomass（plants）. Biomass used for bioplastics stems from e.g. corn，sugarcane，or cellulose.

Biodegradable：Biodegradation is a chemical process during which micro-organisms that are available in the environment convert materials into natural substances such as water，carbon dioxide，and compost（artificial additives are not needed）. The process of biodegradation depends on the surrounding environmental conditions（e.g. location or temperature），on the material and on the application.

The property of biodegradation does not depend on the resource basis of a material，but is rather linked to its chemical structure. In other words，100％ biobased plastics may be non-biodegradable，and 100％ fossil based plastics can biodegrade.

In short，contrary to conventional fossil-based plastics，bioplastics are（partly）biobased，biodegradable，or both. Generally，the family of bioplastics is roughly divided into three main groups[5-6]：

(1) Biobased or partly biobased non-biodegradable plastics such as biobased PE，PET and biobased technical performance polymers such as PTT.
(2) Plastics that are both biobased and biodegradable，such as PLA and PHA.
(3) Plastics that are based on fossil resources and are biodegradable，such as PBAT.

THE MAJOR ADVANTAGES OF BIOPLASTICS

In this section we outline the major advantages of bioplastics as follows[5-6]：

• ***Potentially a much lower carbon footprint.*** It should be pointed out that the carbon footprint of a bioplastic is crucially dependent on whether the plastic permanently stores the carbon extracted from the air by the growing plant. A plastic made from a biological source sequesters the CO_2 captured by the plant in the photosynthesis process. If the resulting bioplastic degrades back into CO_2 and water，this sequestration is reversed. But a permanent bioplastic，made to be similar to polyethylene or other conventional plastics，stores the CO_2 forever. Even if the plastic is recycled many times，the CO_2 initially taken from the atmosphere remains sequestered.

• ***Lower energy costs in manufacturing***. On the other hand，plastics are made from ~4% of the oil that the world uses every year. With oil scarcity the manufacture of plastics becomes increasingly exposed to fluctuating prices.

• ***Do not use scarce crude oil.*** In contrast，each kilogram of plastic typically requires 20 kilowatt hours of energy to manufacture，more than the amount needed to make the same weight of steel. Almost all this comes from fossil sources.

• ***Reduction in litter and improved compostability from using biodegradable bioplastics***. The best understood advantage of biodegradable bioplastics lies in the reduction of permanent litter. Plastic single use shopping bags are the most obvious example of how plastics can pollute the environment with huge and unsightly persistence. A large fraction of the litter in our oceans is of disposable plastic bags. Cities and countries around the world are taking action against the litter, sometimes by banning non-degradable plastic bags entirely.

There are also some significant technical advantages to bioplastics，these depend on the precise plastic used and how it is made. Products characteristics of value can include[5-6]：

• Improved printability， the ability to print a highly legible text or image on the plastic.

• A less oily feel. Bioplastics can be engineered to offer a much more acceptable surface feel than conventional plastics.

• Less likelihood of imparting a different taste to the product contained in a plastic container. Milk， for example， will acquire a new taste in a styrene cup but the bioplastic alternative has no such effect.

• A bioplastic may have much greater water vapour permeability than a standard plastic. In some circumstances， such as sandwich packaging，this can be a disadvantage，but in the case of newly baked bread a bioplastic container will offer a significant advantage in letting out excess vapour or steam.

• A bioplastic can feel softer and more tactile. For applications such as cosmetics packaging， this can be a major perceived consumer benefit.

• Bioplastics can be made clearer and more transparent.

• Plastics made from biological sources still need to contain additives such as plasticisers that give the product its required characteristics.

In search of new material solutions and keeping an eye on the goal of sustainable production and consumption， bioplastics have several potential advantages. The use of renewable resources to produce bioplastics is the key for：

• increasing resource efficiency：① the resources can be cultivated on an annual basis，② the principle of cascade use， as biomass can first be used for materials and then for energy generation；

• a reduction of the carbon footprint and GHG emissions of some materials and products；

• saving fossil resources and for substituting them step by step.

It is noteworthy that bioplastics are manufactured using biopolymers which offer a renewable and sustainable alternative to *oil-based plastics*（*petroplastics*）. Other advantages of bioplastics include novel functional properties and relatively low GHG emissions during manufacture（see Table 1）.

Bioplastics can be produced from plant starch， cellulose， lignin（wood）， oils and proteins. Like petroplastics， bioplastics are compounds constructed of linked molecules that form long polymer chains（biopolymers）

Most bioplastics can be broken down in the environment by micro-organisms in a process called biodegradation. This process produces CO_2 and water under aerobic conditions or CH_4 under anaerobic conditions（in the absence of air）such as in landfill.

Mixed bioplastics are usually biodegradable， but some are not and can be either recycled or processed for energy recovery. Note that items labelled as biodegradable should not be confused with those marked as degradable. The latter materials break down in the environment by chemical rather than biological means.

Table 1: Comparing Bioplastics with Petroplastics

	Bioplastics	Petroplastics
Renewable	Yes or partially	No
Sustainable	Yes	No
Break down in the environment	Biodegradable and/or compostable	Some degradable by polymer oxidation
Polymer range	Limited but growing	Extensive
GHG emissions	Usually low	Relatively high
Fossil fuel usage	Usually low	Relatively high
Arable land use	Currently low	None

PLASTICS AND BIOPLASTICS IN PACKAGING

Currently，the majority of bioplastics are used in packaging applications such as bottles，film， clamshell cartons and loose-fill. Bioplastics are also used in waste collection bags，carrier bags， mulch-film and food service-ware such as cutlery.

In general，the selection of the most adequate preservation technology is a major consideration when designing food products， particularly if these are going to be packaged and distributed. Thus， by means of a correct selection of materials and packaging technologies， it is possible to keep the product quality and freshness during the needed period for its commercialization and consumption.

Plastic packaging offers excellent advantages，multi-functionality and versatility for this purpose. Nowadays，plastic packaging is the largest application for plastics（37% in Europe），and within the packaging niche，food packaging stands out as the largest plastic-demanding application. Plastics bring in enormous advantages， such as thermo-weldability， flexibility in thermal and mechanical properties， lightness， integrated projects（integrating forming， filling， and sealing）， and low price [6-7].

Nevertheless，plastics also have some limitations when compared with more traditional materials like metals，alloys or ceramics：

• One of the major disadvantages of plastics is the possibility of transport of low molecular weight components by means of permeation，migration（of polymer residues and/or additives），or scalping（sorption of aroma compounds）. Transport or barrier properties are determined by permeability， diffusion， solubility and partition coefficients.

• Other limitations of plastics are a comparatively low thermal resistance and a strong interdependence among thermal， mechanical and barrier properties.

On the other hand， there is a current trend to substitute petroleum-based materials by renewable bio-based derived plastics， which will reduce the oil dependence， facilitate the after-life of the packaging， and reduce the carbon footprint of the food-packaging industry. Regarding biodegradable（renewable and nonrenewable）materials，three families are usually considered[6-7].

• The first one includes polymers directly extracted from biomass， such as the polysaccharides chitosan， starch and cellulose， and proteins， such as gluten and zein.

• A second family makes use of either oil-based or biomass-derived monomers and applies classical chemical synthetic routes to obtain the final biodegradable polymer； this is the case， for instance， of polycaprolactones （PCL），polyvinyl-alcohol（PVOH），ethylene-vinyl alcohol copolymers（EVOH），and sustainable monomers of polylactic acid（PLA）.

• The third family consists of polymers produced by natural or genetically modified microorganisms such as polyhydroxyalcanoates（PHA）and polypeptides.

The most commercially viable materials at the moment are some biodegradable polyesters， which can be processed by conventional equipment. In fact， these materials are already used in a number of monolayer and also multilayer applications， particularly in the food-packaging and biomedical fields.

There are also other materials extracted from biomass resources，such as proteins （e.g.，zein）， polysaccharides （e.g.，chitosan），and lipids（e.g.，waxes），with excellent potential as gas and aroma barriers，and as carriers of active and bioactive compounds. The main drawbacks of these families of materials are their inherently high rigidity, difficulty of processing in conventional equipment, and, for proteins and polysaccharides, the very strong water sensitivity arising from their hydrophilic character, which leads to a strong plasticization, deteriorating the excellent oxygen barrier characteristic (in dry state) as relative humidity and water sorption in the material increase.

The current tendencies include the development of packaging materials that interact with the environment and with the food, playing an active role in its preservation. Moreover, the packaging can also be designed to impact the consumer health by integrating functional ingredients in the packaging structure.

The new food-packaging systems have been developed as a response to trends in consumer preferences toward mildly preserved, fresh, tasty, healthier and convenient food products with prolonged shelf life. The novel packaging technologies can also be used to compensate for shortcomings in the packaging design, for instance, in order to control the oxygen, water, or CO_2 levels in the package headspace.

In addition, changes in retail practices, such as a globalization of markets resulting in longer distribution distances, present major challenges to the food-packaging industry, which finally act as driving forces for the development of new and improved packaging concepts that extend shelf life while maintaining the safety, quality, and health aspects of the packaged foods. Novel active and bioactive packaging technologies, combined with biopackaging and nanotechnology can best help to do so. Therefore, proper combination of these three technological cornerstones will provide innovation in the food-packaging sector over the next few years.

The use of polymeric packages for food applications has increased considerably over the last decades. Apart from the intrinsic benefits associated with polymers, significant improvements in their physicochemical characteristics, specifically regarding barrier, mechanical, and thermal properties, have been attained as a consequence of extensive research work. Furthermore, due to the shortage of oil resources and waste-management issues, research focus is shifting from synthetic oil-based plastics to biomass-derived biodegradable and environmentally friendly polymers. The drawbacks initially showed by these biopolymers in terms of poor barrier properties and high instability have, in turn, resulted in novel applications, making polymers an ideal partner for active and bioactive packaging, in which the package is not a passive barrier anymore, but actively contributes to the preservation of food. Biopolymers are, thus, the ideal matrix for the incorporation and controlled release of a number of substances to be added to foods [7-8].

CONCLUSION

Bioplastics are growing rapidly because of the clear advantages they have in many applications. As oil supply tightens, these advantages will grow. Their carbon footprint can be much lower than oil-based equivalents. Bioplastics can provide excellent biodegradability, helping the world deal with the increasing problems of litter, particularly in the world's rivers and seas. Durable plant-based bioplastics can also be recycled as well as their conventional equivalents, assisting the growth of a more sustainable world economy[6-8].

• Bioplastics are renewable and sustainable alternatives to oil-based plastics.
• Currently, the main opportunities for bioplastics are in packaging materials, but in future bioplastics may be used more in higher value applications (electronics and vehicle parts).
• Bioplastics have a 0.1% share of the current global plastics market.
• Land usage for the production of bioplastics is currently small (e.g. 0.1% of US maize area for PLA production).
• The world bioplastics market has potential to grow six-fold by 2011.
• Implementation of the correct disposal methods and corresponding infrastructure are vital if the bioplastics industry is to flourish and deliver environmental benefits.

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