Bioplastics Are Revolutionizing the Packaging Industry

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The production of bioplastics is a growing trend. The utilization of renewable sources, in some cases currently wasted, to replace petroleum derivatives, is providing opportunities to achieve more environmentally friendly product life cycles. The possibility of producing biodegradable products under normal environmental conditions is another goal of recent studies. This editorial summarizes current aspects in the production of bioplastics. We highlight new studies that make it possible to obtain biodegradable composites using a natural, renewable, high availability, and low-cost material, such as cellulose.

Keywords: Biodegradable bioplastics; 3D printed structures; Cellulose composites; Nanocellulose

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Plastic products are the third most widely used application of petroleum. Currently, 4 to 10% of available oil is used for the manufacture of plastics. The use of these materials has generated new environmental and economic challenges for governments and industries in recent years (Hogan *et al.* 2015). Both world production and consumption of bioplastics are expected to grow, mainly in food packaging applications. Unlike traditional plastics, bioplastics are obtained from renewable sources. First-generation bioplastics are obtained from starches or sugars, such as corn, sugarcane, wheat, or soy. Second-generation bioplastics use cellulose from crops or industrial processes, such as sugarcane bagasse or sawdust, and other industrial residues, such as whey, as raw materials. Bioplastics can be either biodegradable or not, which is important since some of the uses require durability.

Types and Uses of Bioplastics

In recent years, interest in the production of bioplastics from second-generation raw materials has increased to avoid competition with food. The use of lignocellulosic waste to obtain these materials is a plausible strategy, not only because it avoids this problem, but also because it also takes advantage of a waste (which today is accumulated or burned in the open air), of low cost and high availability.

Lignocellulosic biomass can be processed in various ways to obtain bioplastics such as polyhydroxyalkanoates (PHA), polylactic acid (PLA), and biopolyethylene (BioPE). Besides, the polysaccharides of this raw material can be chemically modified to obtain cellulose acetate. Nevertheless, the processes for obtaining bioplastics derived from biomass are still very expensive, which is why numerous research groups are working on process optimization to improve viability. Table 1 shows a list of bioplastics, their raw materials, approximate biodegradation time, and applications (Ashter 2016; Kyulavska *et al.* 2017; Ross *et al.* 2017; Rydz *et al.* 2019; Folino *et al.* 2020.). Social concern about the biodegradability of plastics has prompted the study of new materials that present relatively short periods of degradation. Among these biobased and biodegradable plastics, we can mention PLA and PHA, two plastics that have taken center stage in recent years.

Table 1. Description of the Bioplastics Most Used Today

Designation		Raw material	Biodegradation time	Applications
BioPP	Bio polypropylene / Bio-based polypropylene	Sugarcane	Non-biodegradable	Packaging, textile industry
BioPE	Biopolyethylene / Bio-based polyethylene	Wheat grains Sugarcane Sugar beet	Non-biodegradable	Packaging for all kinds of products, bottles, pipes, bazaar pieces
BioPET	Bio polyethylene terephthalate	Sugarcane	Non-biodegradable	In packaging, textile industry, thin films for capacitors
PA	Bio-polyamide / Bio-based polyamide	Mainly Castor oil	Non-biodegradable. Except for low molar mass polyamides	Textile industry, 3D printing
PLA	Polylactic acid	Sugarcane Corn	Up to 180 days (in compost)	Films food packaging, bottles, foamed trays, 3D printing, electronics
PHA	Polyhydroxyalkanoates	Sugarcane, microorganisms	60-365 days (in soil) 14-90 days (seawater)	3D printing for medical devices, films food packaging
Based on Starches		Potato, corn, wheat, rice	14-110 days (in soil)	Food films packaging, medical products
Cellulose-Based		Sugarcane Wood	Up to 154 days (in soil and compost)	Food films packaging, textile fibers, filters, etc.

Currently, PLA is the most widely used bioplastic for 3D printing. It is obtained through the polymerization of lactic acid, which, in turn, is obtained from the fermentation of sugars (Sousa *et al.* 2019). PLA is not 100% biodegradable, but it is compostable under controlled conditions of temperature, pH, humidity, oxygen, and quality of the compost (ash content, C / N ratio, the number of microorganisms, *etc*.). Under these conditions, it can degrade in 180 days (according to ASTM D6400, ISO 17088, and EN 13432).

PHAs are biodegradable polyesters synthesized by microorganisms from renewable raw materials. The most common is poly(3-hydroxybutyrate) (PHB). The fermentative production of PHA uses agricultural products that have sugars and fatty acids as sources of carbon and energy under moderate process conditions, with minimal environmental impact. Furthermore, PHB can be degraded in aerobic and anaerobic environments (in the presence or absence of oxygen) by different species such as *Bacillus, Pseudomonas*, and *Streptomyces* (Raza *et al.* 2018), without forming toxic products.

The most popular bioplastic is PLA, which is commonly found in bags, food containers, and bottles. Its newest application is for 3D printing. The 3D structures can be created even at home. The most common printers use fused deposition methods (FDM), and most use PLA filaments to manufacture parts. Another widely used bioplastic is thermoplastic starch (TPS), which is sensitive to humidity. In many applications it must be mixed with synthetic plastics, such as polyethylene (PE), polystyrene (PS), or degradable polyesters (PEsB). Applications include bags, containers, and packaging foams.

Advances in Bioplastics

Advances in bioplastics include the use of new raw materials, optimized production processes, and the development of new products that can degrade in a relatively short period. Besides, the addition of biodegradable additives accelerates biodegradability and improves the mechanical properties of the bioplastic.

Due to its many benefits, bioplastics appear poised to revolutionize the industry as soon as the cost of obtaining them becomes competitive compared to plastics derived from petroleum. Because of the complexity of the raw material, their technical and economic feasibility must be continuously evaluated. The subject is being intensively studied around the world. Thus, commercially competitive technologies are expected in the short term. According to the European Bioplastic Institute, production is expected to increase to about 2.44 million tons by the year 2022, considering consumer markets such as packaging (containers rigid and flexible) and different printing systems (European Bioplastic 2017).

Composite or biocomposite materials have been widely studied for applications in which plastics are usually used. Biocomposites typically are mixtures of a plastic matrix with a reinforcing agent, which can be a natural fiber such as wood or other plant fibers, microfibrillated cellulose, cellulose nanofibers, lignin, or a combination of them.

The Pulp and Paper Program (PROCYP) of the Institute of Materials of Misiones (IMAM), Argentina, with the RISE-PFI, Norway, has been working on the elaboration of composite materials using bioplastics and cellulosic fibers for 3D printing (Ehman *et al.* 2021). Until now, 3D structures have been printed with optimized mixtures that include BioPE, PLA, and PHA with fibers, using FDM and injection techniques. Characteristics of the printed structures, such as mechanical properties and water absorption, were evaluated. The presence of lignocellulosic fibers makes it possible to improve the strength and biodegradability of the printed structures. Figure 1 shows a typical scheme to produce pieces using composites of PHA and lignocellulosic fibers. A possible use of these composite materials is in the manufacture of orthosis parts.

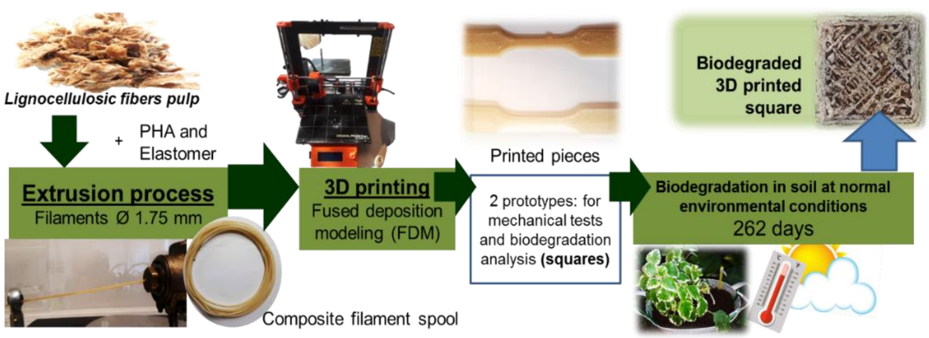

Fig. 1. Production scheme of 3D printed structures from PHA/cellulose fibers

Nanocellulose is another promising material that could partially (or totally) replace plastics for some uses. It has a nanometric size (one-millionth of a millimeter) and improves the mechanical strength of certain materials when included in their composition. The addition of nanocellulose to bioplastics matrixes at low reinforcement levels leads to an increase in thermal, mechanical, and barrier properties, as well as low weight, and an increase in biodegradation rate (Siró and Plackett 2010).

Recent studies have shown the possible total replacement of bioplastics by nanofibrillated cellulose (NFC, also called CNF) in 3D printing (Chinga-Carrasco *et al.* 2019; Espinosa *et al.* 2019; Kangas *et al.* 2019). NFC from different raw materials, such as sugarcane bagasse or pine sawdust, can be used to produce 3D structures by inkjet printing. These inks make it possible to obtain pieces with good mechanical properties, low cytotoxicity, and high biodegradability. This combination of properties makes it suitable for biomedical devices, such as wound dressings, using it at 100% or with bioplastics.

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