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Properties and chemical modifications of lignin: Towards lignin-based nanomaterials for biomedical applications

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ABSTRACT

Biorenewable polymers have emerged as an attractive alternative to conventional metallic and organic materials for a variety of different applications. This is mainly because of their biocompatibility, biodegradability and low cost of production. Lignocellulosic biomass is the most promising renewable carbon-containing source on Earth. Depending on the origin and species of the biomass, lignin consists of 20–35% of the lignocellulosic biomass. After it has been extracted, lignin can be modified through diverse chemical reactions. There are different categories of chemical modifications, such as lignin depolymerization or fragmentation, modification by synthesizing new chemically active sites, chemical modification of the hydroxyl groups, and the production of lignin graft copolymers. Lignin can be used for different industrial and biomedical applications, including biofuels, chemicals and polymers, and the development of nanomaterials for drug delivery but these uses depend on the source, chemical modifications and physicochemical properties. We provide an overview on the composition and properties, extraction methods and chemical modifications of lignin in this review. Furthermore, we describe different preparation methods for lignin-based nanomaterials with antioxidant UV-absorbing and antimicrobial properties that can be used as reinforcing agents in nanocomposites, in drug delivery and gene delivery vehicles for biomedical applications.

Contents

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1. Introduction

Biopolymers have shown great potential as alternatives to classic metallic and organic materials for a variety of applications, because of their biocompatibility, biodegradability and low production cost [1–3]. The biorenewable polymers *inter alia* that have been extracted from different sources are attracting increasing attention of the research community because of their key advantages, which include: biodegradability, low density and minimization of the environmental effects related with their production and usage [3–5]. One example of biorenewable polymers is the lignocellulosic biomass, which are derived from wood and plant sources and is the most promising renewable carbon-containing resource on Earth [6,7]. Lignocellulosic materials are mainly constituted by 30–50% cellulose, a polymer of glucose, 20–35% hemicellulose, a heteropolymer containing xylose, as well as 15–30% lignin, and their compositions are dependent on their origin and species (hardwood, softwood or grass) [3,8,9]. Thus, lignin is one of the main bio-resource raw materials that can be used for the synthesis of environmentally friendly polymers, and its high content of aromatic structures offers the possibility to replace industrially relevant aromatic polymers and fine chemicals [10]. However, only approximately 2% of the annually extracted lignin by the paper and pulp industry from woody biomass has been mainly used for low-value applications as dispersants, adhesives and fillers [11]. This is mainly due to the complex and variable lignin structure, high polydispersity and immiscibility of lignin with host polymer matrices [6,11,12]. The procedures that are applied to separate, to isolate and to chemically transform these three components can lead to a multifunctional array of bio-derived value-added fuels, chemicals and other materials [13,14]. Another way to overcome these limitations is to prepare lignin nanoparticles, which improves the blending properties with host matrix, and offers a morphological and structural control of the lignin [15–17]. In addition, the preparation of nanostructured lignin also opens the possibility to use lignin-based materials for high-value applications, such as drug/gene delivery and tissue engineering [17].

In this review, we provide an overview of the composition and properties of lignin, the processing methods for lignin extraction, chemical modifications of lignin, and the industrial applications of lignin derivatives. Finally, we discuss the preparation of lignin-based nanomaterials for different applications, highlighting the potential of these nanomaterials for biomedical applications.