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Agro-industrial lignocellulosic biomass a key to unlock the future bio-energy: A brief review

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ABSTRACT

From the last several years, in serious consideration of the worldwide economic and environmental pollution issues there has been increasing research interest in the value of bio-sourced lignocellulosic biomass. Agro-industrial biomass comprised on lignocellulosic waste is an inexpensive, renewable, abundant and provides a unique natural resource for large-scale and cost-effective bio-energy collection. To expand the range of natural bio-resources the rapidly evolving tools of biotechnology can lower the conversion costs and also enhance target yield of the product of interest. In this background green biotechnology presents a promising approach to convert most of the solid agricultural wastes particularly lignocellulosic materials into liquid bio based energy-fuels. In fact, major advances have already been achieved to competitively position cellulosic ethanol with corn ethanol. The present summarized review work begins with an overview on the physico-chemical features and composition of agro-industrial biomass. The information is also given on the multi-step processing technologies of agro-industrial biomass to fuel ethanol followed by a brief summary of future considerations.

1. Introduction

Lignocellulosic materials are the most promising feedstock as natural and renewable resource essential to the functioning of modern industrial societies. A considerable amount of such materials as waste byproducts are being generated through agricultural practices mainly from various agro based industries (Pérez, Muñoz-Dorado de la Rubia, & Martínez, 2002). Sadly, much of the lignocellulosic biomass is often disposed of by burning, which is not restricted to developing countries alone. Recently lignocellulosic biomasses have gained increasing research interests and special importance because of their renewable nature (Asgher, Ahmad, & Iqbal, 2013;

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Ofori-Boateng & Lee, 2013). Therefore, the huge amounts of lignocellulosic biomass can potentially be converted into different high value products including bio-fuels, value added fine chemicals, and cheap energy sources for microbial fermentation and enzyme production (Asgher et al., 2013; Iqbal, Kyazze, & Keshavarz, 2013; Irshad et al., 2013; Isroi et al., 2011).

2. Physico-chemical characteristics of lignocellulosic biomass

All plant materials are mostly composed of three major units *i.e.*, cellulose, hemicellulose and lignin. Lignocellulosic materials including agricultural wastes, forestry residues, grasses and woody materials have great potential for bio-fuel production. Typically, most of the agricultural lignocellulosic biomass is comprised of about 10–25% lignin, 20–30% hemicellulose, and 40–50% cellulose (Iqbal, Ahmed, Zia, & Irfan, 2011; Kumar, Barrett, Delwiche, & Stroeve, 2009; Malherbe & Cloete, 2002). Cellulose is a major structural component of plant cell walls, which is responsible for mechanical strength while, hemicellulose macromolecules are often repeated polymers of pentoses and hexoses. Lignin contains three aromatic alcohols (coniferyl alcohol, sinapyl alcohol and *p*-coumaryl alcohol) produced through a biosynthetic process and forms a protective seal around the other two components *i.e.*, cellulose and hemicelluloses (Fig. 1) (Calvo-Flores & Dobado, 2010; Jiang, Nowakowski, & Bridgwater, 2010; Menon & Rao, 2012). In general the composition of lignocellulose highly depends on its source whether it is derived from the hardwood, softwood, or grasses. Table 1 shows the typical chemical compositions of all these three components in various lignocellulosic materials that vary in composition due to the genetic variability among different sources (Bertero, de la Puente, & Sedran, 2012; Iqbal et al., 2013; John, Monsalve, Medina, & Ruiz, 2006; Kumar et al., 2009; Malherbe & Cloete, 2002; Prassad, Singh, & Joshi, 2007). To obtain a clear picture of the material, an analysis of the structure of each main component is made in the following section.

2.1. Physical and structural properties of cellulose

Cellulose is a highly stable polymer consisting of glucose and attached with linear chains up to 12,000 residues. It is majorly composed of (1,4)-D-glucopyranose units, which are attached by β-1,4 linkages with an average molecular weight of around 100,000 (Himmel et al., 2007). Plant biomass contain 40–50% of cellulose molecules which are held together by intermolecular hydrogen bonds in native state, but they have a strong tendency to form intra-molecular and intermolecular hydrogen bonds and this tendency increases the rigidity of cellulose and make highly insoluble and highly resistant to most organic solvents. Naturally cellulose molecules are exists as bundles which aggregated together in the form of micro-fibrils order *i.e.*, crystalline and amorphous regions (Iqbal et al., 2011; Taherzadeh & Karimi, 2008). The chemical formula of cellulose is $(C_6H_{10}O_5)_n$ and the structure of one chain of the polymer is presented in Fig. 1.

2.2. Physical and structural properties of hemicelluloses

Hemicellulose is the second most abundant heterogeneous polymers that mainly consist of glucuronoxylan, glucomannan and trace amounts of other polysaccharides. Grasses and straws contain arabinan, galactan and xylan, while mannan is a component of hardwood and softwood hemicellulose (Brigham, Adney, & Himmel, 1996). They are catalogued with sugar as a backbone, *i.e.*, xylans, mannans and glucans, with xylans and mannans being the most common (Wyman et al., 2005). Galactans, arabinans and arabinogalactans are included in the hemicellulose group; however, they do not

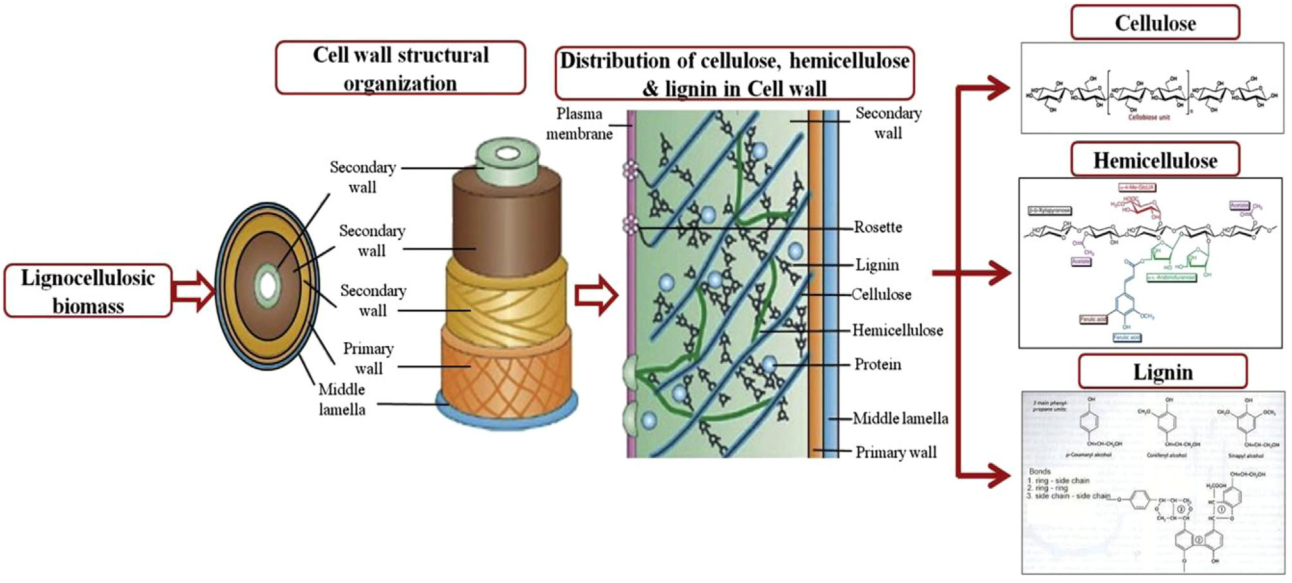

Fig. 1 – Diagrammatic illustration of the framework of lignocellulose; cellulose; hemicellulose and lignin. Adapted with permission from, Menon & Rao, 2012.