

Chapter 2

General Considerations on the Use of Lignocellulosic Residues

Abstract Single-cell protein from lignocellulose biomass presents forthcoming technology aimed at providing protein supplement for both animal feed and human food. Lignocellulosic biomass does not compete with feedstocks used for human food and presents a readily available feedstock for microbial bioconversion. General considerations on the use of lignocellulosic residues are presented in this chapter.

Keywords Single-cell protein • Human food • Animal feed • Lignocellulosic biomass • Microbial bioconversion

SCP from lignocellulose biomass present forthcoming technology aimed at providing protein supplement for both animal feed and human food (Gabriel et al. 2014). Lignocellulosic biomass does not compete with feedstocks used for human food and presents a readily available feedstock for microbial bioconversion. Lignocellulose represents a major source of renewable organic matter and is the major structural component of woody plants and non-woody plants such as grasses. Lignocellulosic biomass is rich in fermentable sugars, high in fibre but low in protein content. Microorganisms such as yeast, fungi, bacteria and algae are involved in bioconversion of low-cost carbon feedstocks such as lignocellulose to produce biomass rich in proteins and amino acids.

Lignocelluloses serve as the major structural component of all plant biomass and represent the major source of renewable organic matter, making it a substrate of enormous biotechnological importance (Malherbe and Cloete 2002). Lignocelluloses are either derived as a by-product from agricultural products or can be derived from plant biomass grown on non-agricultural or marginal lands, ultimately for conversion to fuels, feeds and chemicals (Howard et al. 2003). The nature and availability of lignocellulosic feedstocks in different parts of the world depends on agricultural practice, climate and other environmental factors and technological development. Lignocelluloses are composed of various biopolymers, sugars and chemicals which could be of commercial value. Unfortunately, most lignocelluloses are disposed of as waste. Lignocellulosic feedstocks that have attracted attention for research on SCP

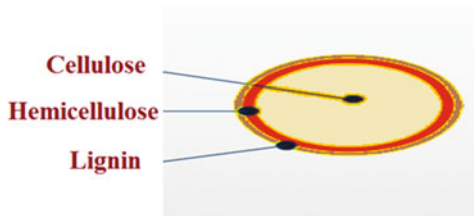
production include corn stover, apple pomace, sugarcane bagasse, rice polishings, rice husks, maize cobs, maize fibre and citrus waste (Bhalla and Joshi 1994; Pandey et al. 2000; Rajoka et al. 2006; Robinson and Nigam 2003; Singh et al. 1988; Villa Bôas et al. 2002; Yakoub Khan et al. 1992; Zhang et al. 2006). Production of SCP from lignocelluloses is gaining much attention, with the recovery of valuable by-products and simultaneous reduction of the organic load as the chief economic advantages of such processes.

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Lignocellulosic biomass consists of an intermeshed and chemically bonded complex of three main polymers, namely cellulose, hemicelluloses and lignin (Hendricks and Zeeman 2009; Howard et al. 2003) (Fig. 2.1). The composition and proportions of these compounds vary between plants (Howard et al. 2003; Prasad et al. 2007; McKendry 2002; Malherbe and Cloete 2002; John et al. 2006; Stewart et al. 1997; Reguant and Rinaudo 2000) (Table 2.1). Cellulose is the major constituent of lignocelluloses. When existing as unbranched homopolymer, cellulose is a polymer of β -D-glucopyranose moieties linked via β -(1,4) glycosidic bonds with well-documented polymorphs. In plants, the cellulose structure consists of a crystalline (organized) structure and a not well-organized, amorphous structure which are bundled together to form cellulose fibrils or cellulose bundles (Hendricks and Zeeman 2009). Each independent cellulose bundle is weakly bound together through hydrogen bonding. The structural conformation of cellulose and its close association with lignin, hemicellulose, starch, protein and minerals render cellulose highly resistant to hydrolysis (Aristidou and Penttilä 2000; van Maris et al. 2006). The degree of polymerization of cellulose chains in nature ranges from 10,000

Fig. 2.1 Lignocellulosic material

Lignocellulose = Lignin+ Cellulose + Hemicellulose



glucopyranose units in wood to 15,000 in native cotton. The repeating unit of the cellulose chain is the disaccharide cellobiose as opposed to glucose in other glucan polymers (Desvaux 2005; Fengel and Wegener 1984). The cellulose chains (20–300) are grouped together to form microfibrils, which are bundled together to form cellulose fibres. The long-chain cellulose polymers are linked together by hydrogen and van der Waals bonds, which cause the cellulose to be packed into microfibrils. Lignin and hemicelluloses cover the microfibrils. Fermentable D-glucose can be produced from cellulose by the action of either acid or enzymes breaking the beta-(1,4)-glycosidic linkages. Cellulose is present in both crystalline and amorphous forms in biomass. Crystalline cellulose contains the major proportion of cellulose, and a small percentage of unorganized cellulose chains form amorphous cellulose. Cellulose is more susceptible to enzymatic degradation in its amorphous form. The cellulose microfibrils are generally independent but the ultrastructure of cellulose is largely due to the presence of covalent bonds, hydrogen bonding and Van der Waals forces. Hydrogen bonding within a cellulose microfibril determines ‘straightness’ of the chain but interchain hydrogen bonds might introduce order (crystalline) or disorder (amorphous) into the structure of the cellulose (Laureano-Perez et al. 2005).

Hemicellulose, the second major constituent of lignocelluloses, is a highly branched and complex heteropolymer that contains hexoses (D-glucose, D-galactose, D-mannose, L-rhamnose, L-fucose), pentoses (D-xylose and L-arabinose) and uronic acids (D-glucuronic acid and D-galacturonic acid). The hemicellulose composition is strongly dependent on the plant source, with xylan as the dominant component in hardwoods, whereas glucomannan is the major hemicellulose component in softwoods (Hendricks and Zeeman 2009). However, in contrast to cellulose, hemicellulose branches into short lateral chains that consist of different sugars that are easily hydrolyzed to their constituent. Hemicellulose serves as a connection between the lignin and the cellulose fibres and imparts the whole cellulose–hemicellulose lignin network more rigidity.

Lignin is one of the most abundant polymers in nature and is present in the cellular wall of plants, giving the plant structural support and resistance to microbial attack. Lignin is an aromatic polymer containing three different phenylpropane units such as trans-coumaryl alcohol, trans-coniferyl alcohol and trans-sinapyl alcohol (Hahn-Hägerdal et al. 1991; Hendricks and Zeeman 2009; van Maris et al. 2006). While the lignin fraction does not contribute fermentable carbon sources, it is relevant as a potential source of microbial inhibitors. Generally, in lignocellulosic biomass, pectin is less prominent than cellulose and hemicelluloses. But, some agricultural wastes such as citrus peels and sugar beet pulp are very rich in pectin (van Maris et al. 2006). Pectins are complex and heterogeneous polymers which basically act as hydrating and cementing agents for the cellulosic matrix of plant cell walls. The principal unit in pectin chains is α -(1-4) linked galacturonic acid. The galacturonic acid residues can be esterified with methyl and acetyl groups. Furthermore, pectin contains the branched polysaccharides rhamnogalacturonan I, rhamnogalacturonan II and xylogalacturonan (Blanco et al. 1999; van Maris et al. 2006).

Table 2.1 Composition of some lignocellulosic materials

Lignocellulosic residues	Lignin (%)	Hemicellulose (%)	Cellulose (%)	Ash (%)
Hardwood stems	18–25	24–40	40–55	NA
Softwood stems	25–35	25–35	45–50	NA
Nut shells	30–40	25–30	25–30	NA
Corn cobs	15	35	45	1.36
Paper	0–15	0	85–99	1.1–3.9
Rice straw	18	24	32.1	NA
Sorted refuse	20	20	60	NA
Leaves	0	80–85	15–20	NA
Cotton seeds hairs	0	5–20	80–95	NA
Newspaper	18–30	25–40	40–55	8.8–1.8
Waste paper from chemical pulps	5–10	10–20	60–70	NA
Primary wastewater solids	24–29	NA	8–15	NA
Swine waste	NA	28	6	NA
Solid cattle manure	2.7–5.7	1.4–3.3	1.6–4.7	NA
Coastal Bermuda grass	6.4	35.7	25	NA
Switch grass	12.0	31.4	45	NA
S32 rye grass (early leaf)	2.7	15.8	21.3	NA
S32 rye grass (seed setting)	7.3	25.7	26.7	NA
Orchard grass (medium maturity)	4.7	40	32	NA
Grasses (average values for grasses)	10–30	25–50	25–40	1.5
Sugar cane bagasse	19–24	27–32	32–44	4.5–9
Wheat straw	16–21	26–32	29–35	NA
Barley straw	14–15	24–29	31–34	5–7
Oat straw	16–19	27–38	31–37	6–8
Rye straw	16–19	27–30	33–35	2–5
Bamboo	21–31	15–26	26–43	1.7–5
Grass Esparto	17–19	27–32	33–38	6–8
Grass Sabai	22.0	23.9	NA	6.0
Grass Elephant	23.9	24	22	6
Bast fibre Seed flax	23	25	47	5
Bast fibre Kenaf	15–19	22–23	31–39	2–5
Bast fibre Jute	21–26	18–21	45–53	0.5–2
Leaf Fibre Abaca (Manila)	8.8	17.3	60.8	1.1
Leaf Fibre Sisal (agave)	7–9	21–24	43–56	0.6–1.1
Leaf Fibre Henequen	13.1	4–8	77.6	0.6–1
Coffee pulp	18.8	46.3	35	8.2
Banana waste	14	14.8	13.2	11.4
Yuca waste	NA	NA	NA	4.2

Based on Howard et al. (2003), Prassad et al. (2007), McKendry (2002), Malherbe and Cloete (2002), John et al. (2006), Stewart et al. (1997), Reguant and Rinaudo (2000)

Lignocellulose constitutes a major part of plant biomass. This vast resource has diverse biotechnological potential in the production of value added products (Tengerdy and Szakacs 2003). To fully utilize the potential of lignocellulosic biomass, hydrolysis of lignocellulose into fermentable sugars by physical, chemical, physico-chemical and biological pretreatment methods is the primary requirement in all applications. During pretreatment, lignin is removed and the porosity of the lignocellulosic materials increases to release the cellulose and hemicellulose sugars. Inhibitors are also produced in the hydrolysates. Complete substrate utilization by the microorganism and inhibitor tolerance are the prerequisites to render lignocellulosic microbial bioconversion processes economically competitive (Hahn-Hägerdal et al. 2007). However, owing to the chemical and structural complexity of lignocellulosic biomass, the sustainable utilization of lignocelluloses is limited until it undergoes pretreatment. This is usually followed by enzymatic hydrolysis, during which oligomeric sugars such as cellulose are broken down to monomeric sugars. A pretreatment method is regarded as an effective method based on a number of features such as a high recovery of all carbohydrates, the production of limited amounts of by-products that are inhibitory to the subsequent hydrolysis and bioconversion processes, minimum energy consumption and cost-effectiveness (Kumar et al. 2009). ARBIOM has licensed the COSLIF lignocellulosic biomass pretreatment technology from Virginia Polytechnic Institute and State University (e.g., Virginia Tech) and has innovated further to develop the overall technology into a commercially feasible technology ARBIOSE (Gilles 2015, Personal communication). The process has been proven on a variety of species and worked similarly on different types of feedstocks.

To summarize, in order to convert a lignocellulosic material for obtaining a more nutritive product, it is important to select a microorganism or a microbial complex capable of synthesizing proteins with high nutritional value and, in the case of use of a substrate that has not been subjected to a previous hydrolysis step, able to degrade selectively the lignin present in the substrate (Zadrazil and Reiniger 1988).

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