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# Bioengineering for utilisation and bioconversion of straw biomass into bio-products

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ABSTRACT

This paper focuses on straw biomass and its main composition with the emphasis on the concept of bioengineering where agricultural biotechnology is discussed with references to success and limitations for the bioconversion of straw biomass to value added bio-products, mainly bio-energy and bio-composite. Biological pre-treatments on straw biomass have been reviewed where the function of biological enzymes and fungi have been discussed in details. Biological pre-treatments have been linked with fungi capable of generating enzymes that biodegrade lignin, hemicellulose and polyphenols. Lignocellulolytic enzymes are considered as prospective biomass degraders for industrial applications, although lignin which is the most recalcitrant constituent of straw biomass, links to hemicellulos and cellulose, thus turns into a barrier for enzymes and stops the infiltration of enzymes to biomass structure. White-rot fungi are identified to be responsible for effective lignin biodegradation in straw biomass decay procedures. It was found that biological pre-treatment in combination with mild chemical and or physical pre-treatments are the most critical process for the success of bioengineering. Bioconversion of biomass to bio-products e.g. bioethanol, biogas and bio-composites has achieved some success, however, several limitations such as long incubation times remain to be solved. The summarised information presented in this paper shall serve as scientific insights and directive fundamentals for researchers and industries for further developments and investments in biotechnology of straw biomass.



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## 1. Introduction

Rising global energy demands have significantly increased the cost of fossil-fuel-based energy sources and petrochemical products. It is clear to many industry sectors that there is an enormous need to promote the use of biotechnology for biomass pre-treatment and optimisation, many researchers have been working on these concepts e.g. (Agbor et al., 2011; Arora et al., 2002; Arora, 1995; Chang et al., 2012; Chen et al., 2013; Lopez-Abelairas et al., 2013; Maehara et al., 2013; Matsumoto and Taguchi, 2013; Petrik et al., 2013; Schilling et al., 2012; Shi et al., 2008; Singh et al., 2011; Taniguchi et al., 2005; Van Dyk and Pletschke, 2012; Zhang et al., 2007). Lignocellulosic residues e.g. from straw, are predominantly ample in nature which have a great prospective for bioconversion. However, very minor volume of the lignin, cellulose and hemicellulose produced as derivatives in biomass are utilised. It was calculated that 73.9 teragram (Tg) of dry wasted crops (e.g. agricultural residues) could possibly yield 49.1 gigaliter (GL) of bioethanol in the world (Kim and Dale, 2004). Asia could be the major potential producer of bioethanol from straw biomass, estimated to be up to 291 GL/year of bioethanol. Europe is second largest producer with a potential of 69.2 GL/year of bioethanol, mostly from wheat straw. In North America core feedstock is corn stover; that has a potential of producing 38.4 GL/year of bioethanol (Kim and Dale, 2004). Straw biomass is recognised as major origin of biofuels and bio-products. The use of such carbon sources that are accessible in big quantities and could be utilised in a carbon dioxide neutral way is a sensible solution to major sustainability problems of the society.

The exciting combination of biology and engineering called biotechnology is becoming more real every day and is an emerging solution for sustainability issues faced by industries. Biotechnology offers state of art chances for sustainable emergence of new products.

Biological microorganisms degrade and use cellulose and carbohydrates as sources of energy and carbon; other collections of filamentous fungi possess the capability of breaking lignin, the most recalcitrant constituent of biomass cell walls. Microorganisms which are able to completely and efficiently biodegrading lignin to $CO_2$ and breakdown the lignin/carbohydrate complex are categorised as white-rot fungi. Further categories of fungi are brown-rot fungi that depolymerise and modify the lignin in biomass (Sánchez, 2009). The capability of fungi to biodegrade straw biomass efficiently and selectively is because of their effective enzymatic system and the mycelial growth routine that permits the fungus to carry nutrients, for instance nitrogen and iron into the less nutrient lignocellulose substrate that creates its carbon source. A variety of enzymes that have different functions are vital in biodegradation of constituents of lignocellulose (Banerjee et al., 2010; Saha, 2003a,b; Zhang and Lynd, 2004). Table 1 gives a summary of categories of enzymes which are essential to biodegrade compound lignocellulose constituents (Van Dyk and Pletschke, 2012).

Bioengineering of straw biomass to bio-products requires accurate and efficient processes; the pre-treatment of straw biomass is one key step (mechanical, chemical, biological or combinational). The term bioengineering suggests the adoption of biological treatment or combination of mild chemical and physical treatments with biological treatments. Maximising the synergistic effect of each pre-treatment or technologies whilst controlling the detailed parameters, therefore the disadvantages of each pre-treatment type or processing technology will be reduced to minimum. Several uses have been suggested for bioengineering of straw biomass; among them the production of bioethanol (Alvira et al., 2010; Binod et al., 2010; Kim and Dale, 2004; Maehara et al., 2013; Talebnia et al., 2010), biogas (Cheng et al., 2011; Kaparaju et al., 2009; Sapci, 2013; Zhong et al., 2011b) and bio-products (Ribbons, 1987) (e.g. organic acids, amino acids and vitamins (Sánchez, 2009)) has received much attention with sufficient success in the process. The exploration which is required for future agricultural biomass technology is of a comprehensive nature linking contributions from biochemistry, microbiology, biotechnology and biochemistry. The evidence for the success of bioengineering of straw biomass is discussed in more details along with further debate about the advantages and disadvantages later in the paper.

This review delivers an overview of recent scientific reports on biotechnology concept and investigates its possible use for straw biomass bioconversion into bio-products, with main emphasis on biological pre-treatments and the use of various enzymes for lignin biodegradation, hence optimisation of straw biomass. Scientific insights and novel concept of biotechnology are identified and discussed. Clear and feasible strategies to solve the problems associated with the bioconversion of straw biomass and directions for further research in industrial application are proposed.

## 2. Main constituents of straw biomass for bioengineering

The main component of straw biomass is cellulose, hemicellulose and lignin. Cellulose is a long chain of glucose molecules, connected to each other primarily by β (1 → 4) glycosidic bonds; the non complicated structure of cellulose indicates that it could be biodegraded. Main difficulty in the bioconversion procedure is the crystalline nature of cellulose, therefore it must be pre-treated to expose the cellulose structure and change it to be more vulnerable to cellulase action (van Wyk, 2001). Hemicellulose just like cellulose is a macromolecule from different sugars but alters from cellulose in that it is not chemically homogeneous, is a polysaccharide which has lower molecular weight compared to cellulose. Key alteration among cellulose and hemicellulose is that the latter possesses branches with short lateral chains containing various sugars and cellulose contains easily hydrolysable oligomers. Hemicelluloses in straw biomass are made mainly of xylan, whereas softwood hemicelluloses have glucomannan. Lignin is connected to both hemicellulose and cellulose, founding a physical cover that is an impermeable wall in the plant cell wall. The existence of lignin in the cellular wall offers rigidity, impermeability and a confrontation to microbial attack. Lignin is a complex three-dimensional polymer formed by radical coupling polymerisation of *p*-hydroxycinnamyl, coniferyl and sinapyl alcohols; these three lignin precursors' monolignols induce the *p*-hydroxyphenyl (H), guaiacyl (G) and syringyl (S) phenylpropanoid units (Ghaffar and Fan, 2013). Lignin is biodegradable in nature unlike other synthetic polymers and is known to be one of the most durable biopolymers available. Huge quantities of lignin result as a by-product of

**Table 1**
The key enzymes essential for biodegradation of lignocellulose to monomers (Van Dyk and Pletschke, 2012).

| Component | Type of enzyme |
|---|---|
| Lignin | Laccase, manganese peroxidase, lignin peroxidase |
| Pectin | Pectin methyl esterase, pectate lyase, polygalacturonase, rhamnogalacturonan lyase |
| Hemicellulose | Endo-xylanase, acetyl xylan esterase, β-xylosidase, endomannanase, β-mannosidase, α-L-arabinofuranosidase, α-glucuronidase, ferulic acid esterase, α-galactosidase, *p*-coumaric acid esterase |
| Cellulose | Cellobiohydrolase, endoglucanase, β-glucosidase |