Enhanced the enzymatic hydrolysis efficiency of wheat straw after combined steam explosion and laccase pretreatment

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HIGHLIGHTS

- An alkali-stable laccase, MSLac, was used for the selective degradation of lignin in lignocellulose.
- Steam explosion combined with laccase was used for improving the enzymatic hydrolysis of wheat straw.
- The mechanism of the synergistic effect between laccase and steam explosion on enzymatic hydrolysis was investigated.

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ABSTRACT

Laccase, capable of selectively degrading lignin while keeping cellulose intact, has been widely applied for the modification and bio-bleaching of pulp. In this study, Sclerotium sp. laccase (MSLac) was employed in combination with steam explosion to evaluate the effect of this treatment on cellulose hydrolysis. Combined steam explosion with laccase pretreatment enhanced the cellulose conversion rate of wheat straw no matter in the case of successive (MSLac-Cel) and simultaneous (MSLac+Cel) MSLac and cellulase hydrolysis. The highest cellulose conversion rate of 84.23% was obtained when steam-exploded wheat straw (SEWS) (1.3 MPa, 5 min) was treated by MSLac+Cel at a laccase loading of 0.55 U g⁻¹ substrate. FT-IR and SEM analyses indicated that MSLac oxidized the phenol and changed electron configuration of the ring, which contributed to loosening the compact wrap of lignin-carbohydrate complex and consequently enhancing the enzymatic hydrolysis efficiency of cellulose. This article provided a promising method for lignocellulose bio-pretreatment.

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1. Introduction

Enzymatic hydrolysis of lignocellulose is relatively slow since that substrate is generally complex, insoluble, and semi-crystalline. Fan et al. (1982) considered that the specific surface area was the leading factor affecting cellulose hydrolysis, followed by the lignin content, and the degree of crystallinity of cellulose. Fan et al. (1982) considered that the specific surface area was the leading factor affecting cellulose hydrolysis, followed by the lignin content, and the degree of crystallinity of cellulose. Chen and Li (2000) proposed that hemicellulose, lignin and crystallinity restricted the diffusion of cellulase to cellulose and that the enzyme could bind non-specifically absorption to hemicellulose and lignin. Therefore, pretreatments are carried out to destroy the shielding effect of lignin and break the crystal structure of cellulose.

Steam explosion is one of the most extensively studied pretreatment methods. It breaks the crystalline structure of lignocellulose through chemical effects and mechanical forces (Chen and Liu, 2007), and is especially effective for hardwoods and agricultural crops. During steam explosion, more than 80% of hemicelluloses can be auto-hydrolyzed by the acetic and other acids released at high temperatures (Chen and Qiu, 2007). The removal of hemicellulose and lignin contributes to exposing the cellulose surface and increasing enzyme accessibility to the cellulose microfibrils (Alvira et al., 2010; Chen and Li, 2002).

However, steam explosion does not disrupt the lignin–carbohydrate matrix completely, removes only some of the lignin and generates inhibitors at high pretreatment severity, and redistributes lignin onto cellulose surfaces (Chen and Wang, 2008). Therefore, it is necessary to combine other methods with steam explosion to obtain a maximum pretreatment effect (Chen and Qiu, 2010). Biodegradation methods are attractive as can selectively provide complete degradation of lignocellulose. Many lignin-modifying enzymes, such as lignin peroxidase, manganese peroxidase, soybean peroxidase, horseradish peroxidase, and laccases, have extensively been used to increase the degradation rate of lignin-rich waste materials (Aracri and Vidal, 2011; Ibrahim et al., 2011). Among them, laccases are the most easily accessible group of enzymes to lignin.

Laccase (EC 1.10.3.2; benzenediol: oxygen oxidoreductase) is an extracellular multicopper oxidase which catalyzes the oxidation of