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Application of enzymes in producing bleached pulp from wheat straw

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Abstract

Crude enzymes produced by different strains were used in the production of bleached wheat straw pulp. Pre-treatment with enzymes from *Penicillium* A10 and *Aspergillus* L22 at a xylanase dosage of 4 IU/g prior to pulping decreased pulp kappa number by 6.29% and 12.07% respectively as compared to the control. High cellulase activity in crude enzymes has a negative influence on pulping. Xylanase pre-bleaching reduced chlorine charge by 20–30%, or increased final brightness by approximately 4–5% ISO, and improved the pulp strength properties. Xylanase could substitute for alkali extraction in CEH sequence, and be used for treating chemical-bleached pulp, which resulted in higher strength properties for bleached pulp. Modification of bleached pulp with enzymes of 3 IU/g (on xylanase) increased pulp brightness and breaking length by 3–6% ISO and 160–790 m respectively, and decreased post color number and beating degree of pulp by 29–36% and 2.5–5.5 °SR respectively, as compared to the original pulp.

Keywords: Pulping; Bleaching; Modification; Enzyme treatment; Wheat straw

1. Introduction

Wheat straw is an important source of raw material for pulp and paper manufacture because of the shortage of forest resources and the extensive supply of wheat straw in China. The most common pulping and bleaching technologies used for bleached straw pulp production are soda or neutral/alkaline sulfite cooking and CEH or HH bleaching processes (C, E and H stand for chlorination, alkaline extraction and hypochlorite stage respectively). However, this conventional cooking and bleaching processes have caused serious water pollution problems (Yu, 2004; Lin, 2005; Zhong, 2000; Xie and Long, 2000).

In recent years, there has been increasing interest in applying green biotechnology to pulping and bleaching processes to reduce pollution as well as improve the quality of pulp produced. Biopulping and biobleaching processes have been investigated frequently over the past 15 years (Akhtar et al., 1993; Bhandari and Srivastava, 1992; Yashimori et al., 1993; Patel et al., 1994; Zhao et al., 2002, 2004; Sabharwal et al., 1994, 1995; Camarero et al., 1998; Valchev et al., 1998; Jacobs-Young et al., 1998a,b, 2000). It has been proven from numerous published studies that enzyme (mainly xylanase) pre-bleaching is a clear environmentally friendly, economically attractive technology, and can decrease the amount of bleaching chemicals required to attain a given brightness in subsequent chemical bleaching stage. In general, biopulping is the pre-treatment of wood or non-wood by lignin degrading fungi (i.e. white-rot fungi) prior to conventional mechanical or chemical pulping. Fungal pre-treatment might reduce the costs of pulping processes (in terms of refining energy or cooking chemicals) or improve pulp properties, and reduce the environmental impact of pulping. However,

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the drawbacks of fungal pre-treatment are the length of pre-treatment time (about 2–4 weeks) and yield loss because the fungi would simultaneously attack both the polysaccharides and the lignin.

To overcome these problems, it is of interest to use isolated enzymes. It was shown in the work of Jacobs-Young et al. (1998a,b, 2000) that enzyme (mixture of cellulase and hemicellulase) pre-treatment increased the diffusion of sodium hydroxide in both hardwoods and softwoods, and enhances conventional kraft pulping of wood chips and pulp uniformity (Jacobs-Young et al., 1998a,b, 2000). Some additional advantages, such as more uniform pulp, fewer rejects, lower residual lignin content in pulp, shorter cooking time and higher brightness of pulp, can be achieved by enzymatic pre-treatment. Our previous work also shown that pre-treating wheat straw with a crude enzyme containing mainly xylanase from the culture filtrate of *Aspergillus niger* An-76 prior to soda pulping improved pulpability of straw and produced straw pulps with lower kappa number, lower rejects and similar yields of screened pulps under identical pulping conditions as compared to the control (Zhao et al., 2002). The enzyme pre-treatment can also improve bleachability of pulp, and the brightness of bleached pulps from the xylanase-treated straw was approximately 3% (ISO) higher than that of the control under identical bleaching conditions. Further studies were conducted and the effect of pre-treatment using crude enzymes (containing xylanase and cellulase) from the culture filtrate of *Penicillium decumbens* A10 and *Aspergillus aculeatus* L22 on soda pulping of wheat straw, and crude xylanase from *A. niger* An76 pre-treatment on bleaching of unbleached wheat straw pulp are evaluated and presented in this paper.

Compared with pulp from wood, the main problems of wheat straw pulp are poor drainage, pasting of the nets and rolls of the paper machine, and resultant paper products with low opacity, high fragility and low strength. As a result, straw pulps can only be used to produce low-grade paper. Wood pulp must be added in order to produce paper of higher grade. The problems are probably related to the high hemicellulose content and short fiber length in the wheat straw pulp. Therefore, the properties of wheat straw pulp may be improved when the hemicellulose on the surface of the fibers and short fibers are partially removed by xylanase and cellulase. A crude xylanase preparation from *Pseudomonas* sp. G6-2 was fractionated and purified xylanase and cellulase components were used for modification of straw pulp (Liu et al., 1998). The preliminary results showed that the physical properties and drainage of the pulp could be modified by enzymatic treatment using the purified single enzyme components. The ratio of cellulase/xylanase has an influence on the improvement of straw pulp properties. In this paper, crude enzymes from different fungi were used for modification of bleached wheat straw pulp in order to produce the high-grade paper from wheat straw instead of wood.

2. Methods

2.1. Materials

Wheat straw was collected in Dingtao County, Shandong Province, China, and chopped to 3–5 cm in length. The supernatant of cultured broth from *A. niger* An76, *P. decumbens* A10, *A. aculeatus* L22 and *Trichoderma pseudokoningii* S28 were used as crude enzymes. All of the strains were from the stock cultures maintained in our laboratory. Media and culture conditions were prepared according to the literature (Qu et al., 1991, 1996; Liu et al., 2001).

2.2. Assays of enzymes

Xylanase activity was determined by incubating 0.5 ml suitably diluted enzyme with 1 ml of 1% xylan (oat spelts xylan, Sigma Chemical Company, St. Louis, MO, USA) in a 0.2 M, pH 4.8 acetate buffer for 30 min at 50 °C. The activity was expressed as equivalent of reducing sugar produced, which was assayed by DNS (3,5-dinitrosalicylic acid) reagent (Gao, 1994). Cellulase activity was measured in a similar manner as above using carboxymethyl cellulose as the substrate. One unit (IU) was defined as the amount (1 μmol) of xylose or glucose produced by enzymes per minute under the given conditions. The activities of the crude enzymes used in the experiments were shown in Table 1.

Table 1
The activities of the crude enzymes from various fungal strains

Strains	Xylanase (IU/ml)	Cellulase (IU/ml)	Xylanase/cellulase*
Aspergillus niger An76	357.5 ± 5.52	2.04 ± 0.03	175.2
Aspergillus aculeatus L22	54.0 ± 0.74	1.56 ± 0.05	34.6
Penicillium decumbens A10	82.3 ± 1.25	8.42 ± 0.24	9.8
Trichoderma pseudokoningii S28	260 ± 7.79	33.7 ± 0.79	7.7

* Based on mean value of enzyme activities.
** The mean values and standard deviation were calculated from an average of three replicates.