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Variable optimization for biopulping of agricultural residues by *Ceriporiopsis subvermispora*

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Abstract

Ceriporiopsis subvermispora was used for biochemical pulping of agricultural residues and the results were compared with chemical pulping. Independent variables were screened by Plackett–Burman and optimized by full factorial experimental designs. Biological treatment of rice, wheat and barley straw samples resulted in decrease of the kappa number of these straws by 34%, 21% and 19%, respectively, as compared with controlled samples. The tensile strength and burst factor of hand sheets produced from rice straw were increased by 51% and 33% as compared with the control straws. The tensile strength and burst factor of hand sheets produced from wheat straws were improved by 67% and 36%, these variables for barely straws were 36.7% and 45%, respectively. Although the delignification of wheat and barley straws are not as efficient as chemical process, but the quality of papers produced by biochemical pulping of straws were excellent.

Keywords: Agricultural residues; Biopulping; *Ceriporiopsis subvermispora*; Full factorial experimental design; Plackett–Burman experimental design

1. Introduction

Increase of demand for paper production and limited wood resources have directed researchers to look for appropriate additional resources of non-wood materials for pulp and paper manufacturing. Several kinds of non-wood lignocellulosic by-products of agricultural cultivation have been investigated in which wheat straw is the most prominent (Giovannozzi-Sermanni et al., 1994; Martinez et al., 1994).

Apart from searching for new resources, biological degradation of lignocellulosics has been increasingly emphasized (Akhtar et al., 1998) and much attention has currently been drawn toward development of new environmentally friendly technologies for pulp and paper manufacture (Mesner and Srebotnik, 1994; Reid, 1998). Refining of straw lignocellulose has been recommended by low-energy reactions (Dorado et al., 1999; Gualidex et al., 1996). *Ceriporiopsis subvermispora,* a white rot basidiomycetous fungus, has gained importance in causing selective specific changes in lignin content and structure, which leads into fiber individualization and decolorization of substrate and produces manganese-dependent peroxidase enzyme (Hatakka et al., 1996; Saxena et al., 2001; Souza-Cruz et al., 2004).

This research, studies the effects of different independent variables for *C. subvermispora* growth as well as those for chemical cooking, using Plackett–Burman and full factorial experimental designs. The effect of the above variables on kappa number and pulp properties, as well as paper properties (tensile index, burst factor and folding endurance), was also studied. Rice straw is used as our main candidate for biochemical pulping treatment, since it is abundantly available in northern part of Iran, where this work has been carried out. After optimization of variables for biological and chemical treatment, the same strategies were

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applied for wheat and barley straws, and their pulp and paper properties were then compared together.

2. Methods

2.1. Organism and cultivation

Ceriporipsis subvermispora IROST 8052 was obtained from Department of Biotechnology, Iranian Research Organization for Science and Technology (IROST). The fungus was maintained on PDA medium (Merck, Germany). Two hundred and fifty milliliter of potato dextrose broth was inoculated by 15 discs (each 9 mm in diameter) of *C. subvermispora*-precultured solid medium. This liquid culture was left at 27 °C for 10 days. The grown mycelium mat was filtered aseptically (Wattmann No. 41) and homogenized by blender and resuspended in 300 ml sterile deionized water. The concentration of cell mass was measured by drying a known volume of suspension in aluminum foils at 105 °C to a constant weight overnight. The prepared fungus suspension was kept in refrigerator at 0–4 °C and was used to inoculate the straws.

2.2. Nutrient preparation

Basal medium, vitamin solution and trace elements solution were prepared separately. Composition and concentration of each is given in Table 1. Nutrient solution for biological delignification was prepared by mixing of 10 ml of basal medium solution, 1 ml of the vitamins solution and 1 ml of the trace elements solution and made up to 1 l using distilled water.

2.3. Substrate preparation

Straws of rice, wheat, and barley were obtained from Talesh region of Gilan Province, Iran and transferred to the Chuka Wood and Paper Industries, Gilan, Iran. The straws were dried and manually chopped to pieces of 0.5–2.0 cm. The moisture, organic and inorganic material contents of the straws were determined in percent of dry weight basis. The results obtained were as follows: Rice, 7.70, 86.86 and 13.14; wheat, 15.00, 92.71 and 7.29 and barley, 22.20, 92.71 and 7.29, respectively.

Table 2
Experimental field definition for the Plackett–Burman and factorial designs

Variable	Key	Plackett–Burman		Factorial	
		Low (−)	High (+)	Low (−)	High (+)
Fungus/substrate[a](g/kg)	A	5:1000	5:100	*	*
Liquid volume (ml)	B	120	200	80	120
pH	C	3.5	6.0	*	*
Incubation time (day)	D	12	18	*	*
Incubation temperature (°C)	E	25	30	30	38
Nutrients (ml)	F	0.2	1.5	*	*
CSL[b](g)	G	0.4	4.0	*	*
Cooking time (min)	H	20	30	15	20
Chemicals/substrate (%)	I	5	8	1	4

Normal units of variables are presented in brackets.
* The values are determined by the effect of each variable in the Plackett–Burman design and are set to be: A, 6:100; C, 5.0; D, 18; F, 1.0; CSL, 3.5.
[a] Weight of dry substrate used in this design is 40 g.
[b] CSL, corn steep liquor.

2.4. Biological treatment of substrates

Solid-state fermentation is used for biological treatment of substrate in flask. The chopped substrates were heated for sterilization in oven at 150 °C for 1 h. After cooling it was mixed with a suspension of fungus, solution of nutrients, and corn steep liquor based on the experimental design for biological delignification (see Tables 2 and 3).

2.5. Chemical cooking

Straws (biologically treated and untreated by Kraft liquor) were cooked by Kraft liquor solution (A solution of NaOH, and Na_2S with active alkaline equal to 100 g/l and sulfidity percentage equal to 20) at atmospheric pressure for a definite time according to the experimental design reported in Tables 2 and 3.

2.6. Substrate pulping

Cooked substrates were washed by tap water to remove Kraft solution. The clear color of the effluent was an indication of the total chemicals removal. The process was carried out in two steps. In the first step, the fibers separated

Table 1
Composition of basal medium, vitamin solution, and trace element solution

Basal medium		Vitamin solution		Trace element solution	
Composition	Concentration (g/l)	Composition	Concentration (mg/l)	Composition	Concentration (g/l)
Glucose	25.0	i-inositol	500	$Fe(NH_4)(SO_4)_2 \cdot 6H_2O$	14.1
l-glutamic acid	0.25	Thiamine–HCl	500	$CuSO_4 \cdot 6H_2O$	0.784
KH_2PO_4	2.0	Pyridoxine–HCl	50	$CoCl_2 \cdot 6H_2O$	0.081
$MgSO_4 \cdot 7H_2O$	2.0	Nicotinic acid	50	$Na_2MoO_4 \cdot 2H_2O$	0.051
–	–	–	–	$NiCl_2 \cdot H_2O$	0.081
–	–	–	–	$SnCl_2 \cdot 2H_2O$	0.038
–	–	–	–	Con. HCl	2 ml