Biomechanical pulping of loblolly pine with different strains of the white-rot fungus *Ceriporiopsis subvermispora*

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**ABSTRACT** Loblolly pine chips were treated with five different strains of the white-rot fungus *Ceriporiopsis subvermispora* for four weeks prior to refiner mechanical pulping. Weight loss of the chips during fungal treatment ranged from 4% to 7%. The electricity consumed during fiberizing and refining of the treated chips was 21-37% less than for the untreated control chips. All five fungal strains improved burst (33-46%) and tear (47-60%) indices over the untreated control. Fungal treatment had no effect on tensile properties. Handsheets prepared from treated pulps had lower brightness and light-scattering coefficient. Treatment had no apparent effect on opacity. Based on energy savings and improvement in strength properties, strain FP-90031-sp appeared to be superior to the other strains.

**KEYWORDS**  
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Current mechanical pulping methods are popular because they produce high-yield pulps and because mechanical pulp mills require a much lower capital investment than chemical pulp mills (1-4). Mechanical pulping also enhances the stiffness, bulkiness, and opacity of the pulp fibers, making them particularly desirable for certain products. The main disadvantages of mechanical pulping are the high energy requirements and the fact that paper made from mechanical pulp is not particularly strong and is prone to brightness reversion (5-11).

Chemical pretreatments are currently being used in conjunction with mechanical pulping to mitigate some of these problems (3, 5, 12-15). However, chemical pretreatments reduce pulp yield and generate dilute wastewater streams that require costly treatment. Moreover, the overall
energy requirement for producing chemimechanical pulps is still high (16).

The disadvantages of mechanical pulping processes have provided the incentive for research into the potential of biomechanical pulping, wherein wood chips are subjected to biological treatment prior to mechanical pulping. It is reported that biomechanical pulping saves electrical energy, produces a high-yield pulp, improves paper strength properties, and reduces the environmental impact of pulping (17-23).

Recently, it was reported that biomechanical pulping of loblolly pine chips with white-rot fungi showed promise in reducing energy demand (22). Six fungi were evaluated, and Ceriporiopsis subvermispora appeared to produce the best results. In the report presented here, five strains of C. subvermispora were used to pretreat loblolly pine chips in an effort to determine the best isolate for use in biomechanical pulping. We report here on energy savings, strength properties, and optical properties for biomechanical pulping with the five different strains.

Results and discussion

The objectives of this study were to evaluate biomechanical pulping of loblolly pine as a means of reducing consumption of electrical energy and improving paper strength properties.

Energy savings

Comparison of fungally pretreated chips with untreated chips (control) demonstrated that treating chips with C. subvermispora saved electrical energy during initial fiberization and subsequent refining operations. Figure 1 shows that energy savings ranged from 37% for strain FP-90031-sp to 21% for strain FP-104027. Strains FP-105752, L-14807, and L-15225 gave essentially identical energy savings of 27-31%. These results indicate that biopulping with different strains of the same fungus can give greatly different energy savings.

Strength properties

Physical properties of handsheets prepared with pulps produced from chips treated with different strains of C. subvermispora are presented in Table 1. Fungal pretreatment improved burst and tear indices in all cases. Tensile index, elongation, and tensile energy absorption (TEA) index were not affected by fungal treatment. Densities of the handsheets were slightly lowered by the fungal treatments.

Lower handsheet density from fungal treatments might indicate that less fiber damage occurred during processing, with the result being more intact fibers and less fine material produced during pulp production. In fact, all the fungal treatments increased fiber length (17-28%) and decreased fines (3-15%) compared with the control. Table 1 shows a
maximum of 46% improvement in the burst index and 60% improvement in the tear index following fungal treatment. It appears that there is little variation in strength properties of pulps produced in the presence of the different strains of *C. subvermispora*.

**Optical properties**

Optical properties of handsheets prepared with pulps produced from chips treated with different strains of *C. subvermispora* are presented in Table II. All strains decreased handsheet brightness and light-scattering coefficient but did not affect opacity. Brightness and scattering coefficients of biomechanical pulps were reduced by as much as 21% and 28%, respectively, over that of untreated pulp.

It is not surprising that brightness and light-scattering coefficients were reduced by *C. subvermispora*. A previous study demonstrated that aspen wood chips treated with nine different white-rot fungi under similar experimental conditions had substantially decreased brightnesses and light-scattering coefficients (21). Notably, however, the pulps obtained from the fungus-treated aspen wood chips responded well to peroxide bleaching, readily reaching the same or higher brightness levels than pulp obtained from an unbleached control (20). All of the fungal strains had about the same effect on optical properties.

**Relationship between energy savings, strength properties, and optical properties**

The time and effort required for each biomechanical pulping run did not permit replication and statistical treatment. If it is assumed that the values for energy savings (Fig. 1) and for burst index (Table I) are significantly different for the fungal strains, we can conclude that there is no relationship between energy savings and improvement in burst. This result is in accord with previous results on aspen using various fungi (22). Based on this earlier work, further energy savings and improvements in the strength and other properties can be expected with longer incubation periods and under optimum growth conditions.

**Loss of wood substance during fungal treatment**

Weight losses of the chips during fungal treatments were as follows for the five strains: 5% for FP-90031-sp, 7% for FP-105752, 5% for L-14807, 6% for L-15225, and 4% for FP-104027. These results suggest that biomechanical pulping of loblolly pine with *C. subvermispora* strains is a high-yield process. Our research with a range of white-rot fungi tested under a variety of experimental conditions has shown no definitive correlation between energy savings or enhanced strength and losses of bulk weight or Klason lignin from the wood chips (21, 22). Nevertheless, the possibility still exists that the selective lignin degradation or modification in a specific zone, such as in the secondary cell wall rather than the middle lamella (24), might be important in determining biopulping efficacy.

**Concluding remarks**

Pretreatment of loblolly pine wood chips with different strains of the white-rot fungus *Ceriporiopsis subvermispora* reduced the electrical energy required to prepare refiner mechanical pulp. Biomechanical pulping with all strains improved the burst and tear indices in handsheets of the same fungus can differ in their biopulping efficacy.

**Experimental**

**Fungal strains**

Five different strains of *Ceriporiopsis subvermispora* (Pil.) Gilbn. et Ryv. were selected for this study, based on their greater lignin-degrading ability as compared with those of *Phanerochaete chrysosporium* and *Phlebia tremellosa* strains grown on loblolly pine. Strains were obtained from the Center for Forest Mycology Research of the Forest Products Laboratory (Madison, WI). They were maintained on potato dextrose agar (PDA) (Difco Laboratories, Detroit, MI) slants and kept refrigerated until used. PDA plate cultures were inoculated from these slants and incubated at 27±1°C and 65±5% relative humidity for 10 days.

**Wood chips**

Freshly cut loblolly pine (*Pinus taeda* L.) pulpwod-size logs were obtained from the Bienville National Forest in Mississippi. Logs were debarked and chipped to a nominal size of 6 mm. Chips were placed in plastic bags and frozen to prevent the growth of contaminating microorganisms.

**Seed inoculum preparation**

Frozen chips were thawed and mixed to obtain uniform samples. Initial moisture content of the chips was 49%. A modified, chemically defined medium (21) containing 40 g glucose/kg chips (o.d. weight basis) was used to increase the fungal biomass and suppress cellulose degradation. The medium was added in sufficient quantity to 200 g of chips (o.d. weight basis) to raise the chip moisture content to 60%. These chips were put in 2800-m L Fernbach flasks. The flasks were covered with aluminum foil and autoclave for 45 min at 121°C. After cooling to room temperature, sterilized chips in each flask were inoculated with two 2.5-cm plugs from 10-day-old plate cultures and thoroughly mixed. Flasks were incubated for four weeks at 27±1°C and 65±5% RH. These precolonized chips were used to inoculate the bioreactors.

**Chip preparation and bioreactor inoculation**

Frozen wood chips were thawed and thoroughly mixed to obtain uniform samples. Chip moisture content was increased to 60% using the same glucose-containing medium described in the previous paragraph. For the fungal treatments, 1800 g (o.d. weight basis) of chips were placed in each stationary tray bioreactor, (The bioreactor was constructed from 20.3-cm × 20.3-cm 316 stainless steel wire mesh with dimensions of 53 cm × 41 cm × 8 cm.) For the control, 2000 g (o.d. wood basis) of chips were put in a similar bioreactor. Each stationary tray bioreactor was placed inside a polypropylene containment bag, auto-
claved for 90 min at 121°C, and cooled to room temperature. A 200-g (o.d. weight basis) inoculum, prepared as described previously, was added to the wood chips in the appropriate bioreactors and mixed thoroughly. The polypropylene containment bags were sealed and placed in an incubator maintained at 27±1°C and 65±5% RH. The control bioreactor was treated identically to the inoculated bioreactors, except it was not inoculated.

The complete bioreactor configuration is illustrated in Fig. 2. Filtered and humidified air was supplied to the chips during the four-week fermentation. A simple air pump (1) drove air through a 0.2-μ m-pore-size membrane filter (2) and on through tubing (3) to a humidification vessel (4) filled with sterilized water. The air inlet into the humidification vessel consisted of a glass tube with a fritted glass gas dispenser (5) submerged below the water level. Humidified air was connected by tubing (6) through an inlet plug (7) to the polypropylene containment bag (8), which completely surrounded the tray (9). Tubing (10) extended down the center of the tray under the chips to deliver humidified air to the chips. An exhaust tube (11) extended from the containment bag to the atmosphere, through a tube (12) stuffed with glass wool.

2. Stationary tray bioreactor used for fungal treatments

Chip fiberization, pulp refining, and handsheet production

At harvest, the untreated and the fungus-treated chips were fiberized in a Sprout-Waldron* model D 2202 single rotating 300-mm-diam. disk atmospheric refiner. Energy consumed during fiberization and refining was measured using an Ohio Semitonic* model WH 30-11195 integrating wattmeter attached to the power-supply side of the 44.8-kW electric motor. Energy consumption values for fiberizing and refining are reported as kW-h/kg (o.d. weight basis), with the idling energy subtracted. (Idling energy was measured without a chip or pulp load.) Chips were hand fed into the preheated refiner, and the feed rate was adjusted to keep the load between 6 kW and 15 kW.

The initial plate setting was 0.46 mm, and the refining process was repeated with a decrease in the plate setting after each successive pass until the Canadian Standard Freeness (CSF) of the pulp dropped below 100 mL CSF. Care was taken to prevent fines loss by collecting the pulp slurry in closed plastic containers, transferring the pulp slurry to a canvas bag, and pressing to dewater the pulp. After each refiner pass, the pulp was dewatered to about 25% solids content and fluffed before the next pass.

Details about the weight-loss determination, handsheet preparation, and testing methods have been described previously (21, 22). Paper testing was done by Weyerhaeuser Technology Center (Tacoma, WA). Energy values, strength properties, and optical properties were regressed to 100 mL CSF to facilitate comparison.

*The use of trade and company names is for the benefit of the reader and does not constitute an official endorsement or approval of any service or product by the USDA to the exclusion of others that might be suitable.

**Literature cited**

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