BIOPULPING SMALL-DIAMETER TREES

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ABSTRACT

Biopulping, as developed at Forest Products Laboratory (FPL), involves treating wood chips from a common pulpwood species with a white-rot fungus prior to pulping. The fungal treatment decreases mechanical pulping energy, significantly increases paper strength properties, and lowers brightness, but has minimal effect on other optical properties. Fifty-ton chip pile trials have shown biopulping to be commercially feasible. Current technology is based on using specialized equipment to steam chips for surface sterilization, inoculating with a lignin-degrading (white-rot) fungus, and aerating the chips during a two-week incubation prior to pulping.

In separate studies at FPL and the University of Washington, small-diameter softwood trees from the Colville National Forest, Washington, were found suitable for chemical and mechanical pulping. The small-diameter tree species are an alternative to the commonly used pulpwood species. Biopulping was not included in that investigation.

We biopulped small-diameter softwood and aspen, for comparative purposes, using wild-type isolates of *Ceriporiopsis subvermispora* and *Phanerochaete chrysosporium* and a genetically altered strain of *Phanerochaete chrysosporium.* Results showed that refiner mechanical pulping of lodgepole pine and aspen chips treated with wild-type or genetically modified strains generally saved electrical energy, improved pulp properties, and improved paper strength properties. Genetic manipulation of *P. chrysosporium* substantially enhanced biopulping performance relative to the parental wild-type strain.

INTRODUCTION

The focus of forest management on public lands has taken on a more ecological orientation during the past decade (1,2,3). Some common ecological concerns in the western United States are lack of diversity at the landscape level, potential for large-scale disturbances such as insect infestations and fire, and development of functional late-successional stand structures within watersheds where they are currently in deficit. In some cases, active management will be required to change the development trajectory of stands or landscapes to either hasten the development of desired conditions or reach conditions that might never be achieved without intervention. Landscape-level manipulations can be expensive, and funding for these activities must compete with other federal and state budget priorities that may have nothing to do with forest management. Accordingly, whenever possible, government land managers will attempt to use timber sale programs to fund management activities that have more to do with meeting ecological objectives than with providing economic benefits from timber management. In practice, this means that state and federal land managers will offer a different type of resource for sale than they would have under a program oriented more toward timber production. This resource will often be smaller in diameter than the traditional resource (4). Previous studies on utilization of small-diameter trees found that mechanical and chemical pulping were suitable uses for small-diameter material (5,6), but biopulping was not included in those investigations.

Biopulping, which involves fungal treatment of wood chips prior to mechanical pulping, has been a major success for Forest Service research. A biopulping program began in April 1987 with the formation of a consortium that included the Forest Products Laboratory (FPL), the Universities of Wisconsin and Minnesota, and up to 22 pulp and paper and related companies. During the initial five years of the consortium, more than 200 bench-scale biopulping

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runs were completed, which screened several hundred fungi (7). *Phanerochaete chrysosporium,* the most studied lignin-degrading fungus, worked very well with hardwood but poorly with softwood (7). *Ceriporiopsis subvermispora* was found to be the best fungus for saving mechanical pulping energy and improving paper strength properties, for both hardwood and softwood. The biopulping process decreases energy consumption and significantly increases paper strength properties. Furthermore, large-scale trials using 50-ton chips piles conducted since the initial five-year consortium have shown the commercial feasibility of biopulping (8). Current biopulping technology tends to use specialized equipment within or near a mechanical pulping mill to steam, inoculate, and aerate chips from a common pulpwood species.

Comparative analyses of fungal strains have revealed substantial physiological adaptations to changes in wood species. The objective of this study was to evaluate the effectiveness of a genetically manipulated *P. chrysosporium* against the parental wild-type strain and another successful biopulping fungus, using a hardwood and small-diameter softwood resources.

EXPERIMENTAL

Raw Materials

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) submerchantable logs (SMLs), which had less than an 89-mm end diameter and primarily represented treetops, were obtained from Vaagen Bros. Lumber (Colville, Washington). Aspen (*Populus tremuloides*) logs were obtained from a Wisconsin source. All logs were shipped to FPL, where they were hand peeled to remove all bark and chipped to a 19-mm length in a four-knife chipper. Chips were screened to remove all particles greater than 38 mm long and less than 6 mm long. Screened chips were thoroughly mixed, placed in polyethylene bags and frozen until needed for experimentation. Bags of frozen chips were thoroughly mixed again after thawing, and weighed into individual samples for fungal treatment and mechanical pulping trials.

Fungus Selection

P. chrysosporium strain BKM-F-1767 was selected because it is the most widely studied lignin-degrading fungus. This fungus was heavily used during the initial portion of the Biopulping Consortium until the lignin-degrading *C. subvermispora* (SS-3) was evaluated and found to be effective on both hardwoods and softwoods. A homokaryon derivative of BKM-F-1767, RP-78, was isolated for evaluation as a biopulping fungus (9).

Surface Sterilization, Nutrient Addition, Inoculation, and Incubation

Chip surfaces were decontaminated by atmospheric steaming for 10 min, followed by cooling under aseptic conditions. Inoculum for SS-3 consisted of fragmented fungus mycelium of SS-3 (application rate of 5 g/ton of dry weight wood) mixed with unsterilized corn steep liquor (application rate of 0.5% of dry weight wood). Inoculum for BKM-F-I767 and RP-78 consisted of spore suspensions of BKM-F-1767 and RP-78 (application rate of 5 g/ton of dry weight wood) mixed with water. Inoculum was poured on the decontaminated wood chips, placed in 1.5-L solid-substrate bioreactors, and thoroughly mixed (1 0). Each bioreactor had a perforated bottom plate, and humidified air was constantly passed thorough the bioreactor during incubation. SS-3 was incubated at 27ºC and BKM-F-1767 and RP-78 were incubated at 39ºC for two weeks.

Refiner Mechanical Pulp (RMP) Preparation

A Sprout-Waldron Model 105-A 300-mm-diameter atmospheric refiner (Andritz, Inc., Muncy, Pennsylvania), fitted with plate pattern C2976, was used for fiberization and refining. Raw materials were hand fed to the refiner inlet while maintaining a constant drive motor load. Dilution water was added to the refiner inlet to maintain approximately 20% refiner consistency. Multiple passes were required to achieve Canadian Standard Freeness (CSF) values above and below 100 mL. Multiple replicates were prepared for each raw material evaluated. Energy consumed during fiberization and refining was measured using an Ohio Semitronics model WH30-11195 integrating watt-hour meter (Ohio Semitronics, Inc., Hilliard, Ohio) attached to the power-supply of the 44.8-kW electric motor, measuring amperes, volts, and power factor. Energy consumption values for fiberizing and refining were reported as watt-hours per kilogram (ovendry weight basis), with the idling energy subtracted. Latency was removed from the

pulp after fiberization and each refining step by soaking the pulp in 90ºC water for a minimum of 30 min, with occasional stirring. Pulps were vacuum and/or press dewatered between refining stages,

Pulp Testing, Handsheet Formation, and Paper Testing

Canadian Standard Freeness (CSF) was measured according to TAPPI Test Method T227. Average fiber length, fines content, and coarseness were determined with a Kajaani FS-100 analyzer (Kajaani Automation, Norcross, Georgia). Handsheets weighing 60 g/m^2 were made according to TAPPI Test Method T205. Burst and tear indexes and tensile breaking properties were measured according to TAPPI Test Methods T403, T414, and T494, respectively. Brightness and printing opacity were measured with a Technidyne Corp. Technibrite Model TB-1 diffuse brightness apparatus (Technidyne Corp., New Albany, Indiana) according to TAPPI Test Method T525.

RESULTS AN DISCUSSION

Presentation of Results

Instead of presenting data for all RMP evaluations, the estimated values for 100-mL CSF are presented in Table I for the different raw materials. Results for raw materials were compared by computing a percentage change from their respective controls and presenting these in figures for lodgepole pine SML (Figures 1 and 2) and aspen (Figures 3 and 4). Weighted average fiber length distributions for lodgepole pine SML are presented in Figure 5 and for aspen in Figure 6. No statistical analysis was conducted on these initial results.

Pulp Preparation and Pulp Properties

Energy consumption is high in preparing mechanical pulp, and biopulping has consistently saved electrical energy (8). Pretreatment using each of the three fungi saved electrical energy, 15% to 27% for lodgepole pine and 16% to 29% for aspen. RP-78 treatment gave results in the middle, saving 20% and 21% energy for the softwood and hardwood, respectively. BKM-F-1767 treatment saved the least and SS-3 the most electrical energy for both lodgepole pine and aspen.

Significant energy savings can also be achieved by using high temperatures to soften and separate the fibers in the middle lamella, but this practice yields poor quality fiber for papermaking. Fiber quality is very important for paper strength properties. Shive content, average fiber length, fines content, and fiber coarseness are all measures of fiber quality. Shive content, which usually indicates incomplete fiber separation, increased for all treatments except lodgepole pine treated with RP-78 (Figures 1 and 3). BKM-F-1767 treatment generally resulted in the lowest and SS-3 the highest shive contents. The shive content value with RP-78 treatment was between those with the other two fungi on aspen. Fiber length decreased when lodgepole pine was treated with BKM-F-1767. The other two fungal treatments resulted in fiber length increases with lodgepole pine, and all fungal treatments resulted in increased fiber length for aspen. The fiber lengths reported in Table I are still less than the actual fiber lengths of lodgepole pine (3.1 mm) and aspen (1.1 mm). Fiber lengths (Table I, Figures 1 and 3) illustrate that by using fungal pretreatment, more of the original fiber length had been retained during fiberization and refining. Fines content decreased for all but one fungal pretreatment (SS-3 on lodgepole pine) (Table I, Figures 1 and 3). Less fines content in the pulp implies less fiber breakage and less material removed from the fiber surface during fiberization and refining. Fiber coarseness, an indicator of fiber diameter (Figure l), was reduced in all fungal treatments of lodgepole pine, which is desirable because lodgepole pine has coarse fibers. RP-78 was the only fungus to reduce aspen coarseness (Figure 3), but aspen, which has very fine fibers, needs no additional reduction of coarseness. Materials stripped from the fiber surface, which a coarseness reduction indicates, become fines material in fiber analysis. Fiber quality was apparently improved as a result of all three fungal pretreatments.

Plotting percentage distribution against weighted average fiber length illustrates very little difference among the three fungal pretreatments and the untreated control within a wood species (Figures 5 and 6). However, large differences are evident between lodgepole pine and aspen, which is also indicated in the previously described fiber length and fines content results.

Strength Properties

Burst index increased with all three fungal pretreatments for both wood species (Figures 2 and 4). Burst index increase was the least with RP-78 treatment and greatest with SS-3.

Tear index decreased with all three fungal pretreatments when applied to lodgepole pine (Figure 2) but increased when all three treatments were applied to aspen (Figure 4). Previous experiments have found that tear index increases as a result of fungal pretreatment, with both softwoods and aspen (10). Tear index is a strength property that is primarily dependent upon fiber length and secondarily on fiber-to-fiber bonding. Less of the original fiber length was retained by lodgepole pine, which may have contributed to the loss of tear index.

Tensile index increased with all three fungal pretreatments applied to lodgepole pine (Figure 2). For aspen, tensile index increased with RP-78 and SS-3 treatment but decreased substantially with BKM-F-1767 treatment. Tensile and burst indexes are usually very similar, but in aspen pretreated with BKM-F-1767, the two indexes differ.

Optical Properties

Fungal pretreatments darken the wood chips and generally lower the optical properties resulting from both softwood and hardwood pulps (10). RP-78 pretreatment raised brightness slightly for lodgepole pine (Figure 2), and the BKM-F-1767 pretreatment produced a minute brightness increase in aspen (Figure 4). Pretreatment with SS-3 resulted in a large brightness loss with lodgepole pine and slightly less loss with aspen. Opacity changes were less than 2% plus or minus (Figures 2 and 4). All three fungal pretreatments caused a minute opacity increase in lodgepole pine and a slight decrease in aspen. Opacity itself is extremely high for all fungal pretreatments of lodgepole pine and aspen (Table I).

CONCLUSIONS

Three fungal pretreatments evaluated in this study successfully

- saved electrical energy in mechanical pulping,
- maintained fiber quality, and
- improved paper strength properties.

The three fungal pretreatments lowered paper brightness but had minor impacts on opacity.

Homokaryotic fungus (RP-78) performed better than the parent *P. chrsosporium* (BKM-F-1767) on lodgepole pine and aspen.

C. subvermispora (SS-3) performed better than the homokaryon fungus (RP-78) on lodgepole pine and aspen.

A more comprehensive biopulping research program is needed for the homokaryotic fungus (RP-78).

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Table I. Biopulping of small-diameter softwood and aspen

		Kajaani analysis								
Fungus treatment	Energy con-sumption (Wh/kg)	Pulmac shive (%)	Length (mm)	Fines (%)	Coarse-ness (mg/mm)	Burst index (Nm/g)	Tear index (mNm^2/g)	Tensile index (Nm/g)	ISO bright-ness (%)	Printing opacity (%)
Lodgepole pine										
None, control	3,277	5.7	1.13	8.8	0.293	0.85	4.5	19.9	46.4	96.2
BKM-F-1767	2,792	7.2	1.11	8.6	0.271	0.98	4.0	22.8	44.2	96.7
RP 78	2,615	3.9	1.15	8.3	0.243	0.96	3.6	21.6	47.1	96.9
SS-3	2,391	9.3	1.14	8.9	0.256	1.30	3.9	24.3	39.4	97.0
Aspen										
None, control	3,303	5.0	0.69	10.6	0.293	0.53	2.2	14.0	52.8	97.0
BKM-F-1767	2,790	6.7	0.74	8.7	0.305	0.63	2.5	8.1	52.9	96.8
RP 78	2,607	7.8	0.78	8.8	0.276	0.57	2.7	14.7	51.3	95.5
SS-3	2.333	8.2	0.79	8.4	0.304	0.83	3.3	20.3	46.5	96.7

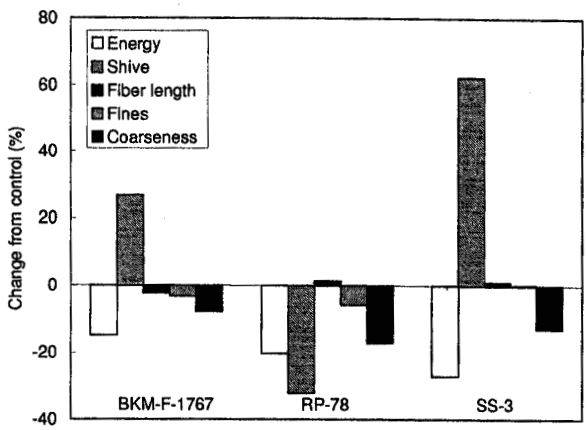

Figure 1. Energy and pulp properties for lodgepole pine SML.

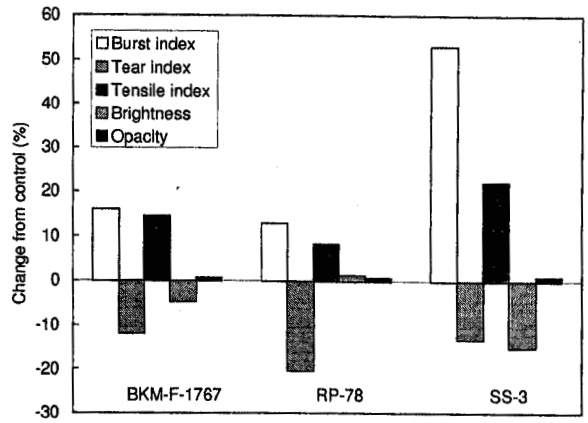

Figure 2. Strength and optical properties for lodgepole pine SML.

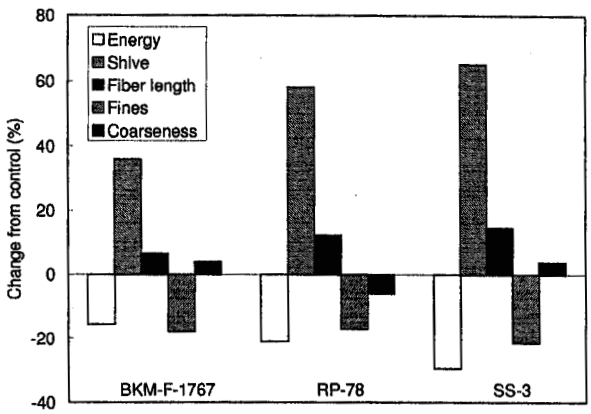

Figure 3. Energy and pulp properties for aspen.

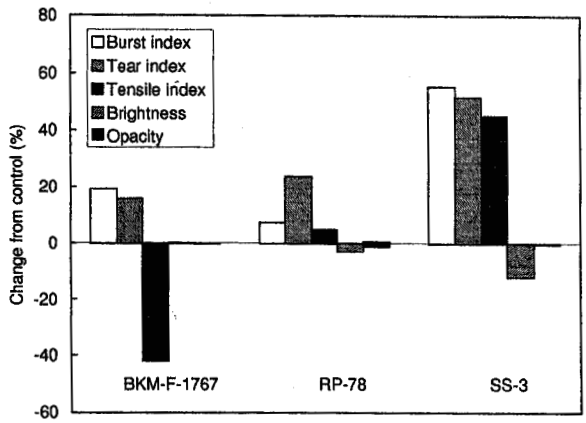

Figure 4. Strength and optical properties for aspen.

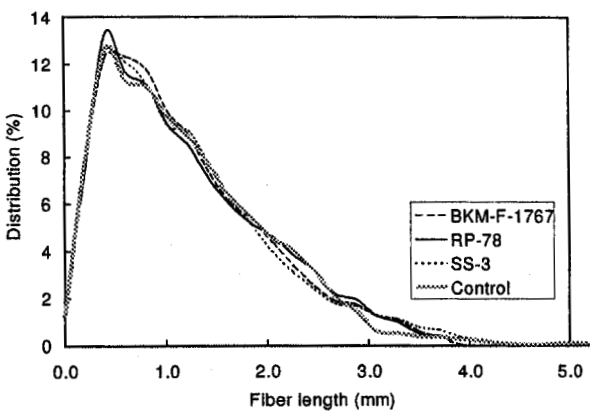

Figure 5. Kajaani FS100 analysis of weighted length for biopulped lodgepole pine SML.

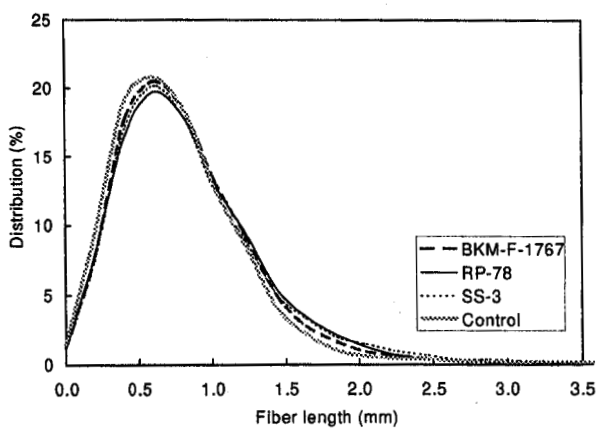

Figure 6. Kajaani FS100 analysis of weighted length for biopulped aspen SML.

Problem 1 **Develop technologies to better utilize a wide range of fiber**

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Publications

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