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Biomechanical and Biochemical Pulping of Sugarcane Bagasse with *Ceriporiopsis subvermispora* Fungal and Xylanase Pretreatments

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Sugarcane bagasse was pretreated with both the white-rot fungus, *Ceriporiopsis subvermispora*, and xylanase enzyme for 2 weeks before soda chemithermomechanical (CTMP) and soda chemical (CP) cooking. For fungi−CTMP (BCTMP) and enzyme−fungi−CTMP (EBCTMP), the bagasse, after bio-pretreatment, was cooked with 5% sodium hydroxide, at 130 °C for 20 min. For the chemical pulping (CP), after fungi pretreatment (BCP) or after xylanase and fungal pretreatment (EBCP), the bagasse was cooked with 14.5% sodium hydroxide. With the BCTMP, the Klason lignin was reduced, all of the pulp strength properties were increased, and a 28% savings in refining energy consumption was obtained, but the brightness was reduced 5 points compared to the control. With the EBCTMP, the brightness losses were overcome but with a mild reduction in the pulp strength properties compared to the BCTMP. The energy savings were 5% greater than from BCTMP and 33% over the control. The BCP treatment increases somewhat the pulp strength properties, reduces the energy consumption 23%, and reduces the brightness by 9 points compared to the control; however, the kappa no. was 5.5 points higher than the control. EBCP treatment reduces brightness losses and increases the pulp yield 2% compared to the control, but with some reduction in the strength properties compared to BCP.

Keywords: *Biotechnology; biomechanical pulping; biochemical pulping; mechanical properties; optical properties; Ceriporiopsis subvermispora; sugarcane bagasse; energy consumption; scanning electron microscopy*

INTRODUCTION

The preservation of forests and increasing environmental awareness have focused research on exploration of new renewable fibrous resources and less toxic pulp and bleaching processes. The pulp and paper industry is also working toward technological improvements in the conventional pulping methods. The industry utilizes chemical and mechanical methods to produce pulps with desired characteristics. Chemical delignification is expensive and poses potential pollution problems. Also, chemical treatments are used in current chemimechanical and chemithermomechanical pulping processes to increase sheet strength. These treatments function by removing or modifying lignin or by increasing wood fiber swelling. However, these treatments also have disadvantages. They often increase the energy requirements, decrease the optical properties, and produce diluted waste effluents that require costly treatments (*1*).

The disadvantages of chemical treatments have prompted interest in evaluating the potential of biological treatments, prior to mechanical or chemical pulping (*2*−*4*). Studies so far have been generally based on the concept of application of a lignin-degrading fungi or an isolated enzyme to selectively remove or modify lignin (*5*, *6*). Some studies have used fungi to improve chemical pulping efficiency (*4*) and, for chemical pulp, partial delignification and bleaching (*7*, *8*). Also, some investigators have reported on lignin degradation and pulp bleaching with enzymes (*9*−*12*). Numerous investigations on the use of fungi for pretreatment of wood prior to mechanical refining have been reported, and considerable energy savings and enhancement in strength properties of aspen, pine, and poplar pulps have been realized by the use of white-rot fungi (*13*, *14*).

The use of fungi for nonwoody plants prior to chemical treatment or mechanical refining has also received attention in recent years. There have been some investigations on the biopulping of wheat straw (*15*, *16*), kenaf, jute, and other nonwoody plants (*17*−*19*). In an earlier study we evaluated biomechanical pulping of sugarcane bagasse with the white-rot fungi *Ceriporiopsis subvermispora* and *Pleurotus ostreatus* (*20*). In the present work, we have further evaluated the effects of *C. subvermispora* and a xylanase enzyme pretreatment for the production of biomechanical and biochemical pulps from sugarcane bagasse.

EXPERIMENTAL PROCEDURES

Raw Material. Depithed sugarcane bagasse was obtained from a sugar mill in Jalisco, Mexico. The material was placed in plastic bags and frozen until use to prevent the growth of contaminating microorganisms.

Inoculum Preparation. The white-rot fungus *Ceriporiopsis subvermispora* was selected for this study because it has shown biomechanical pulping performance superior to that of any other fungi until now (*14*). An SS-3 strain of *C. subvermispora* was obtained on potato dextrose agar (PDA) from the Center for Mycology Research of the Forest Products Laboratory, Madison, WI. The inoculum was prepared according to the protocol of Fischer et al. (*21*). PDA plate cultures were inoculated from these slants and then incubated at 27 °C and 70% relative humidity for 10 days. The liquid culture medium

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Table 1. Composition of Corn Steep Liquor[a]

dry substance, %	40.7
proteins, %	28.3
lactic acid, %	13
reducing sugars, %	8.9
pH	4.1

[a] From Akhtar et al. (*22*).

was prepared in a 2800 mL Fernbach flask with 300 mL of water containing potato dextrose broth (PDB) and yeast extract as described in previous work (*20*).

Nutrient Medium. To increase the fungal biomass and suppress cellulose degradation, a glucose-containing medium was used, in this case the corn steep liquor, as it was shown to be very effective during biomechanical pulping of wood chips (*22*). The corn liquor was obtained from Dr. Akhtar from the USDA Forest Products Laboratory, Madison, WI. It had a pH of 4.1 and was analyzed in dry substance by Akhtar et al. (*22*) to contain proteins, lactic acid, and reducing sugars as shown in Table 1. It was added to the bagasse at 1% oven-dry weight basis. A part of the mycelium (equivalent to 5 g of fungus per ton of dry weight of raw material) was added to the nutrient solution and then blended aseptically.

Raw Material Inoculation and Enzyme Treatment. The nutrient solution and some water were added to the bagasse with a known initial moisture content to increase the moisture to 70%. This mixture was autoclaved for 30 min at 121 °C. The bagasse was inoculated prior to incubation. Other samples of bagasse were autoclaved under the same conditions but were impregnated with a xylanase solution at a quantity sufficient to obtain an activity of 15 IU/g of bagasse. The xylanase was obtained from Genencor International as Irgazyme 40-X4 xylanase. An IU (international unit) is that amount of enzyme which catalyzes the formation of 1 μmol of xylose/min from a solution containing xylan (*11*). This solution was filtered through a 0.2 μm filter to avoid contamination. After the enzyme treatment, the bagasse was inoculated as before prior to incubation.

Bioreactor Incubation. Twelve aerated static-bed bioreactors as described by Akhtar et al. (*23*) were used in this work. The bioreactors were sterilized with high-pressure steam prior to incubation. Bagasse (350 g OD) was placed in each bioreactor, and the inoculated material was incubated for 14 days at 27 °C and 70% relative humidity.

Pulping and Refining. For the production of biochemithermomechanical pulps (BCTMP), the bagasse, after the fungal treatment or after the treatment with xylanase enzyme and fungus, was cooked using 5% sodium hydroxide (based on OD bagasse) at 130 °C for 20 min. The liquor-to-bagasse ratio was 3.5:1. The bagasse was cooked and defibrillated under pressure in the same equipment as previously described by Ramos (*24*). The pulp was refined in a 30 cm disk refiner, using 7% consistency until 60 °SR freeness was obtained. The energy consumption during defibrillation and refining was measured on a wattmeter connected to the power supply of the electric motor.

For the production of biochemical pulps (BCP), the bagasse was pretreated with *C. subvermispora* or with xylanase enzyme and the fungus. The pretreated bagasse was then cooked in a Jaime rotating digester with 14.5% sodium hydroxide (based on OD bagasse) at 170 °C for 40 min, which is equivalent to an *H* factor of ~1300. The liquor-to-bagasse ratio was 7:1. The pulp was refined in a Jokro mill at three different levels. These pulps were compared with a sodium hydroxide chemical pulp obtained with 15% sodium hydroxide with the other conditions remaining the same.

Handsheet Preparation and Evaluation. Handsheets of 60 g/m^2 were made according to Tappi Method T-205. The sheets were evaluated for density, burst, tear, and tensile indices, and brightness according to the corresponding Tappi test methods.

Table 2. Comparison of CTMP Bagasse Pulp Characteristics and Relative Energy Consumption

	CTMP[a]	BCTMP[b]	EBCTMP[c]
yield, %	89	85	83
lignin (Klason), %	18.6	15.9	16
burst index, kPa·m^2/g	1.7	1.8	1.75
tear index, mN·m^2/g	4.05	4.3	4.2
tensile index, mN/g	32	38	34.3
brightness, %	37.4	32.5	36.1
relative energy consumption over control, %	100	72	67

[a] Normal sodium hydroxide CTMP. [b] CTMP pretreated with CS fungi. [c] CTMP pretreated with xylanase enzyme and CS fungi.

RESULTS AND DISCUSSION

Biomechanical Pulping. As previously stated, corn steep liquor was used as nutrient source before the fungal treatment of the bagasse. The composition of corn steep liquor, shown in Table 1, varies according to the wet-milling process during which the dry corn is soaked in a warm sulfurous acid solution (*22*). After 2 weeks of treatment of the bagasse with the *C. subvermispora* fungus (CS) or with xylanase enzyme and CS fungus, the bagasse was cooked with 5% sodium hydroxide under the conditions described under Experimental Procedures. The pulp characteristics and energy saving are shown in Table 2. The yield is reduced 4% with fungal pretreatment and is even lower after the treatment with xylanase enzyme and CS fungus, for which the yield losses are ~6% compared with the control CTMP. The lignin content of the bagasse before and after the fungal treatment for 2 weeks was analyzed, and it was reduced from 23.4% in the extractive free bagasse to 18.6% in the sodium hydroxide CTMP. It was further reduced to 15.9 in the bagasse treated for 2 weeks with the CS fungus and to 16% in the xylanase and CS fungal treated bagasse as shown in Table 2. Hatakka et al. (*25*) also found a reduction in the lignin content in reed canary grass after 2 weeks of treatment with the same fungi.

According to Eggert et al. (*26*), CS fungi produce manganese peroxidase (MnP) and laccase (Lac), two phenol oxidases that initiate attack on the lignin polymer by a single electron oxidation step, which explains the yield and lignin content reduction for the BCTMP. In the case of the EBCTMP, the yield is reduced somewhat more, 2% compared with the BCTMP, but the lignin content was not reduced at all. It seems that the xylanase treatment in combination with the CS fungus reduces only the xylan content but not the lignin. There are still questions concerning the mechanisms by which xylanase enhances bleachability. Possible roles of the enzyme included removal of xylan from the fiber surfaces resulting in increased permeability of degraded lignin and cleavage of lignin carbohydrate bonds (*27*−*29*).

Pulp Properties. As can be seen in Table 2 all of the strength properties are comparatively higher when the bagasse was pretreated with CS fungus (BCTMP). There was a 6% improvement in burst and tear indices and a 19% improvement in tensile strength compared with the control. The smaller improvements noted here compared to other studies are due to comparison with CTMP as the control rather than refiner mechanical pulp (RMP) utilized as the control in other investigations of biomechanical pulping of jute (*18*), kenaf (*17*), pine (*14*, *30*), and aspen (*31*, *32*), for example. Sachs et al. (*33*) found that overall tensile indices of the hand-

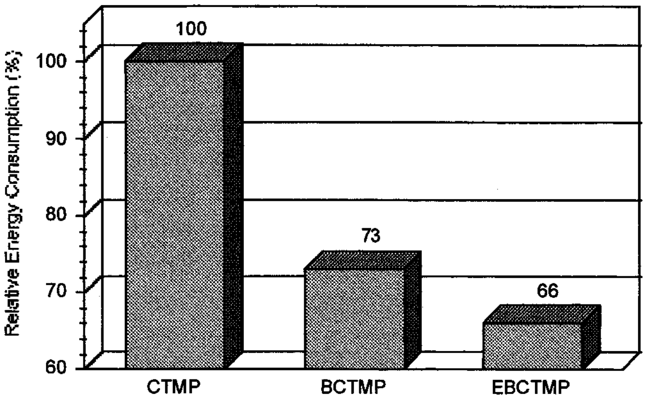

Figure 1. Relative energy consumption during the obtention of CTMP, BCTMP, and EBCTMP from sugarcane bagasse.

sheets produced from the aspen biomechanical pulp (BMP) were much higher than those produced from stone groundwood (SGW), refiner mechanical pulp (RMP), and thermomechanical pulp (TMP) and were within the range of the indices of CTMP handsheets.

When the bagasse is pretreated with xylanase and CS fungus before the soda treatment (pulp EBCTMP), all of the pulp strength properties are also increased in comparison with the control CTMP pulp (Table 2), but these increments are much lower compared with BCTMP. Bhardwaj et al. (*51*) stated that the pulp retained most of the strength properties when it was treated with enzyme during 30 min of residence time, but beyond that time the strength properties deteriorated.

The pulp brightness obtained with the CTMP pretreated with CS fungus was lower compared with control CTMP. The brightness was reduced by 13% (5 points), which is much less a reduction compared with the 21−35% brightness reduction (>11 points) found by other investigators for biomechanical pulping of various lignocellulosic substrates (*18*, *30*, *32*).

In Table 2 it is also shown that when the bagasse was pretreated with xylanase enzyme and the CS fungus (EBCTMP), all of the strength properties were improved compared with the control (CTMP), but smaller strength improvements were noted when compared with BCTMP. On the other hand, the brightness of EBCTMP is very close to the control; in this case only a 1 point brightness loss was noted compared with a loss of nearly 5 points when the bagasse is pretreated only with the fungi. It has been noted by others that there is an insignificant effect of xylanase for direct pulp brightening (*11*, *34*) or direct reduction in the kappa no. of the pulp (*28*, *35*). However, Wong et al. (*36*, *37*) contradicted these conclusions and found that xylanase treatments resulted in enhanced brightening of pulps. In the present work the detrimental effect of the fungal treatment on brightness appears to be counteracted by the addition of xylanase.

Energy Consumption. Comparison of pulps from fungal and enzymatic plus fungal pretreated bagasse with the untreated control bagasse demonstrated that treating bagasse with CS fungus with and without xylanase saved electrical energy during the fibrillation and refining operations (Figure 1). When only CS fungus was used for pretreatment before the chemithermomechanical pulping, a 28% energy savings was obtained, and when the pretreatment was with both xylanase and CS fungi, a 33% energy savings was realized. In the case of CS fungal treatment, the energy savings were similar to the 34% energy savings when a biomechanical pulp is obtained from sugarcane bagasse without any chemical treatment (*20*). Sabharwal et al. (*17*, *18*) found a 27.7% energy savings for biomechanical pulping of kenaf and a 25% savings for biomechanical pulping of jute with pretreatment in both cases with CS fungus. In the case of wood, the energy savings are in the range of 20−37% for different wood species and different fungal treatments (*2*, *30*, *32*).

Table 3. Comparison of CTMP Bagasse Pulp Characteristics and Relative Energy Consumption

	CP[a]	BCP[b]	EBCP[c]
yield, %	50	47	52
kappa no., %	12	17.5	16
burst index, kPa·m^2/g	4.2	4.25	4.3
tear index, mN·m^2/g	5.8	6.1	5.4
tensile index, mN/g	58	65	59
brightness, %	48	39	41
relative energy consumption over control, (%)	100	77	

[a] Chemical pulp using 15% soda. [b] Pretreated with CS fungi and cooked with 14.5% soda. [c] Pretreated with xylanase enzyme and CS fungi and cooked with 14.5% soda.

Biochemical Pulping. *Yield and Kappa Number.* The comparative characteristics of the chemical pulp (CP) obtained with 15% soda, the biochemical pulp (BCP) obtained with pretreatment with CS fungus and then cooked with a 14.5% soda, and the pulp (EBCP) obtained with a pretreatment with xylanase enzyme and CS fungi before cooking with 14.5% soda are shown in Table 3.

The yield of the pulp pretreated with CS fungus before the soda cooking (BCP) was somewhat lower (47%) compared with the soda-cooked chemical control pulp (CP), with a yield of 50%. The manganese peroxidase and laccase enzymes produced by the CS fungus apparently reduced the yield of the pulp by the attack on the lignin polymer (*26*). These two enzymes, together with lipase, have been implicated in lignin biodegradation for white-rot fungi in natural wood-decay processes (*38*). It has been found that manganese peroxidase and laccase treatments are capable of delignifying pulps with the best results obtained when followed by an alkaline extraction stage (*39*).

The pretreatment with xylanase and CS fungus before the soda cooking produced a pulp (EBCP) with a yield slightly higher than the control, 52% compared with 50% of CP (Table 3). It is not apparent why the pretreatment with xylanase and fungi produced a greater yield. Oriaran et al. (*40*) also found that pulp yields increased with increasing incubation time with *P. chrysosporium* fungal regardless of the following kraft cooking time.

The lignin content of the BCP was higher (17.5%) compared with 12% lignin for the control pulp (Table 3). The use of xylanase and CS fungus as a pretreatment before the soda cooking produces a pulp with a lignin content slightly lower than the one for BCP, 16% compared with 17.5%, but the lignin content is still higher compared with the control pulp at 12% (Table 3). Normally the fungi or xylanase/fungal pretreated pulp would be expected to have a lower lignin content compared to the control. The manganese peroxidase and laccase enzymes, produced by the *C. subvermispora* fungi, are capable of delignifying pulps, and the best delignification is obtained when followed by an alkaline extraction (*26*, *39*). Also, as already noted, kraft pulp can be partially delignified by *P. chrysosporium* when the fungal treatment is followed by alkaline extraction. Furthermore, a reduction in lignin content of hardwood unbleached kraft pulp has been observed without extraction, because xylanase can aid delignification, presumably by liberating lignin from a complex with hemicelluloses (*35*).

However, de Jong et al. (*41*) found no significant reduction of kappa no. after xylanase treatment. Also, Paice et al. (*7*) found that extraction of the pulps with 2% NaOH following fungal treatment gave no kappa no. decrease for *C. versicolor* treated pulp relative to control. They even found that some strains of *Coriolus versicolor* increased the kappa no. and the Klason lignin content with the treatment before and after 2% soda extraction. It should be noted, however, that both kappa no. and Klason values should be interpreted with caution, because fungal biomass may interfere with the assays and the lignin contents are at the limits of detection by the kappa no. technique (*7, 42*); the permanganate can react with degradation products from carbohydrates and has stained holocellulose in other studies (*42*). Also, the measure of acid insoluble lignin requires careful consideration because adsorbed proteins may register (*36, 37*). Recent work has led to the hypothesis that xylan contributes to the kappa no. of pulp because its methylglucuronic acid substituents on xylan are converted to hexenuronic acid under alkaline pulping, a modified component that is thought to contribute to kappa no. and brightness reversion (*43, 44*). Also, xylose and xylan macromolecules are known to be modified during alkaline cooking to produce colored and partly aromatic structures (*45, 46*).

Energy Consumption. With pretreatment of bagasse with CS fungus before soda cooking, the material refines more easily and the relative energy consumption is reduced 23% compared to the control pulp (Table 3). Unfortunately, we did not measure the relative energy consumption for the enzyme and fungi pretreated pulp, but it is possible that further reductions might be possible than with only fungal pretreatment. Oriaran et al. (*40*) also showed that as incubation time increases with *P. chrysosporium*, the time required to beat the pulp to a given freeness decreases. Wong et al. (*36, 37*) found that less beating was required for xylanase-treated pulp to reach a given freeness. Giovannozzi-Sermanni et al. (*15*) also found that enzymatic treatments of wheat straw before soda cooking resulted in shorter beating times than for untreated straw.

Pulp Properties. The burst index as a function of freeness for the pulp obtained with 15% soda (CP), the pulp from 2 weeks of pretreatment with CS fungus before the cooking with a 14.5% soda (BCP), and the pulp obtained with a pretreatment with xylanase enzyme and CS fungus before the cooking with a 14.5% soda (EBCP) are shown in Figure 2. Normally the burst index increases with an increase in freeness. The burst index is somewhat higher from the fungus-pretreated pulp over the control in the range of 17–26 °SR freeness. The EBCP has the highest value of burst index in this freeness range, the range in which the most chemical pulps are used. Also, Oriaran et al. (*40*) found that burst properties increased with the pretreatment of aspen chips with *P. chrysosporium*. In their work with unbleached hardwood kraft pulps, Paice et al. (*7*) incubated the wood with *C. versicolor* for 5 days and the burst properties were increased. Paice et al. (*35*) also used pure enzymes for lignin removal from pulp, and the pulp fully retained viscosity and strength properties.

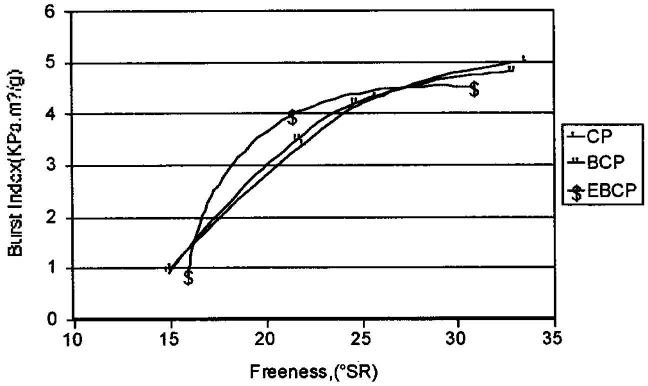

Figure 2. Burst index of CP, BCP, and EBCP from sugarcane bagasse.

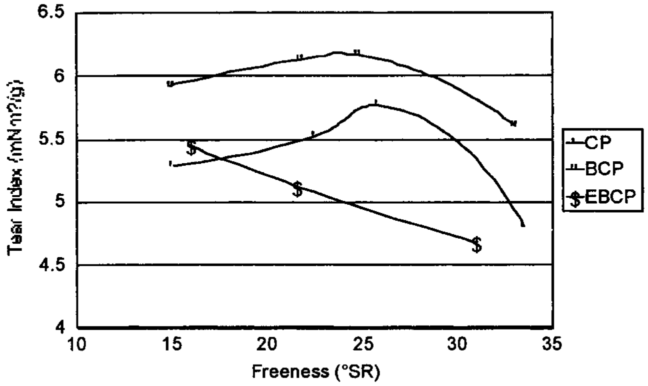

Figure 3. Tear index of CP, BCP, and EBCP from sugarcane bagasse.

The tear index of the three pulps, CP, BCP, and EBCP, as a function of freeness is shown in Figure 3. Normally the tear increases when the pulp is refined, reaching a maximum value and then declining. The freeness at maximum strength for CP and BCP was at 24–25 °SR, and BCP has a higher tear at all values of freeness compared with the control pulp (CP). Above 25 °SR freeness, the tear index of both pulps is reduced with further refining. Hunt et al. (*39*) found that the treatments of pulp with manganese peroxidase and laccase enzymes before an alkaline extraction did not produce strength loss as judged from tear–tensile plots, although pulp viscosity was lowered slightly by either enzyme treatment. However, treatment of unbleached hardwood kraft pulp with *C. versicolor* increased the tear strength (*7*).

The tear index of the pulp pretreated with xylanase enzyme and CS fungus (EBCP) showed a distinctly different behavior. In this case the tear index steadily declined with continued refining (increased freeness) (Figure 3). The tear index of this pulp was also lower than that of the control pulp. Other investigators (*47, 48*) have had difficulty evaluating the effects of xylanase on pulps because of the possible presence of contaminating cellulolytic activity in the enzyme preparations, which can have detrimental effects on pulp strength.

The behavior of the tensile index of pulps CP, BCP, and EBCP with the variation of freeness is shown in Figure 4. Normally the tensile index increases with the increase in freeness and then levels off. This was also found to be the case for the pulps evaluated in this investigation. The tensile index of BCP was generally

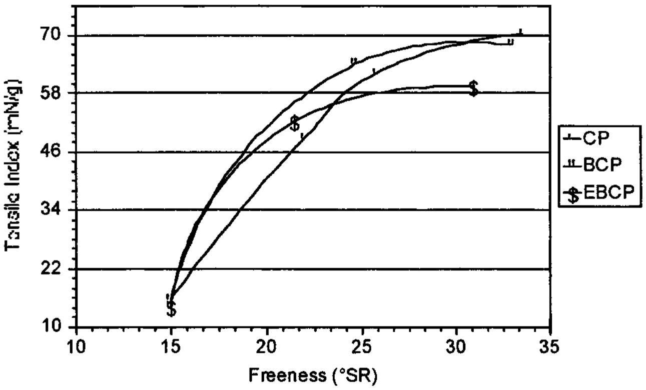

Figure 4. Tensile index of CP, BCP, and EBCP from sugarcane bagasse.

higher than that of CP up to the maximum freeness. The tensile index of EBCP increased in a similar way as BCP, but only until 22 °SR freeness was reached, at which point it leveled off. Above 25 °SR freeness, the tensile index value of EBCP is lower than that of the control. In other work with unbleached hardwood kraft pulp pretreated during 5 days with *C. versicolor,* Paice et al. (*7*) reported increases in all of the paper properties, including breaking length (*11*). Oriaran et al. (*40*) found that under typical kraft cooking conditions, 30-day pretreatment of aspen chips with *P. chrysosporium* showed increased tensile strength by ∼21%. Pretreatment of pine with *Fomes pini* before kraft cooking caused the breaking length increase at all beating levels as the decay advanced (*49*). A pretreatment with an exoenzyme mixture, obtained from solid-state fermentation of straw by *Lentinus edodes*, was used before soda cooking of straw, and the breaking length was generally affected negatively by the biotreatments (*16*).

The brightness of pulps pretreated with fungus (BCP) and with xylanase enzyme and fungus (EBCP) was lower than that of the control. The brightness of CP, the control pulp, was 48% compared with 39% for the pulp pretreated with CS fungus (BCP) and 41% brightness for EBCP pulp (Table 3). The pretreatment with only CS fungus caused a brightness drop of 9 points, and when xylanase was included in the pretreatment with the fungi, it only compensated 2 points in brightness. Oriaran et al. (*40*) also found that brightness of unbleached kraft pulp pretreated with *P. chrysosporium* decreased with increasing fungal incubation time. The pulp brightness was reduced by 35, 54, and 62% after 10, 20, and 30 days of fungal pretreatment, respectively. Paice et al. (*7*), however, obtained an increase in brightness of 5% ISO points by direct biological bleaching of a hardwood kraft pulp with the fungus *C. versicolor,* although a softwood pulp treated in the same way showed no brightness enhancement.

Hemicelluloses have been used for bleaching of chemical pulps, and the most viable enzyme is xylanase. An apparent concensus has been that xylanase makes kraft pulp more amenable to chemical bleaching, without brightening the pulp during the xylanase prebleaching stage (*36*, *37*). Bleach boosting has been advocated as the main mechanism of xylanase action on kraft pulp, primarily because direct brightening (*27*, *34*) or direct decreases in the kappa no. of pulp with xylanase treatment (*28*, *35*) have been found to be insignificant. However, there have been no previous studies on the use of xylanase and white-rot fungi together as a pretreatment before the chemical cooking.

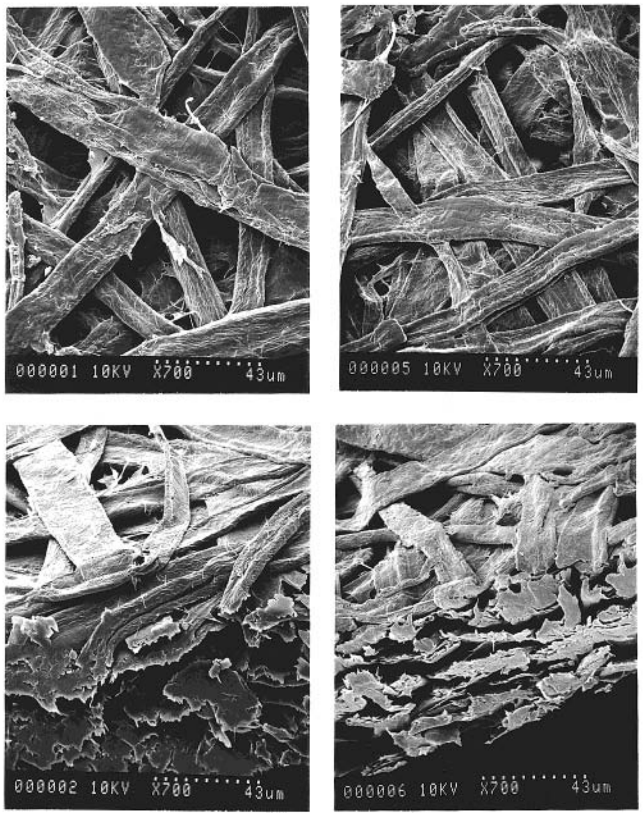

Figure 5. Scanning electron micrographs: (top) cross sections and (bottom) view of paper sheets made from bagasse chemical pulp (left side) and from CS fungi pretreated chemical pulp (right side).

Scanning electron micrographs (SEMs) from the pulps are shown in Figure 5. Comparing the handsheets made from CP and BCP, the fibers from the BCP (pretreated with CS fungus) exhibit a cleaner surface and an apparent higher flexibility and conformability, which would contribute to good bonding (top right, Figure 5) compared with the chemical pulp (top left). In a cross-sectional view of the paper sheets, the fibers from BCP (bottom right) show better apparent compressibility and bonding compared with CP fibers (bottom left). In a previous investigation of wood chips treated with *P. chrysosporium* for 4 weeks, SEMs showed cell wall swelling, softening, and collapse of the cell structure (*50*). The biotreated pulp fibers resembled those from kraft pulp because of the uniform length and collapse of the lumen of the fibers, which promotes excellent bonding (*33*).

SUMMARY AND CONCLUSIONS

Sugarcane bagasse, a fibrous raw material widely available in Mexico, the United States and many other countries, has been shown to be a viable fibrous source for different cooking processes. The chemithermomechanical process (CTMP) is a good alternative for production of mechanical pulp from bagasse. Pretreatment of bagasse with *C. subvermispora* fungi before the CTMP process decreases the Klason lignin content in the pulp, with a mild decrease in yield. Comparison of biochemithermomechanical pulp (BCTMP) with the normal CTMP demonstrated that the biological treatment improved the strength properties of the pulp, with a 6% increase in burst and tear indices and a 19% increase in tensile strength, but reduced the brightness by 5 points.

Treatment with *C. subvermispora* saved considerable electrical energy during the fibrillation and refining operations. The biological treatment of bagasse decreased the energy consumption by 28% compared with the normal CTMP. When xylanase enzyme was used with the *C. subvermispora* for pretreatment, the energy savings were 5% over the BCTMP and 33% over the CTMP, the control pulp.

Compared to the soda chemical bagasse pulp (CP), a pretreatment with *C. subvermispora* fungi (BCP) increased somewhat the pulp strength properties, especially the tear index and tensile strength, and reduced the electrical energy consumption by 23% during refining. However, the pretreatment also reduced somewhat the pulp yield and considerably reduced the unbleached brightness by 9 points, whereas the kappa no. was 5.5 points higher than that of the control.

When xylanase enzyme was used with the *C. subvermispora* fungal pretreatment prior to soda pulping (EBCP), the pulp brightness losses were reduced 2 points compared to the BCP and the pulp yield increased 2% over the control. However, there was some reduction in the strength properties compard to the BCP, especially the tear index, which was reduced to the level of the control. A savings of 0.5% of chemicals for cooking was realized by use of the pretreatments.

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