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Original article

Pulp and Papermaking Properties of *Baccaurea ramiflora* Lour.

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ABSTRACT

The potential of *Baccaurea ramiflora* Lour., an indigenous hardwood species, for use as an alternative raw material in the pulp and paper production was evaluated. The basic density and chemical composition of *B. ramiflora* wood were analyzed. Then, wood chip was pulped by kraft process, and subsequently bleached using elemental chlorine-free bleaching. Fiber characteristics, chemical and physical properties of the obtained pulps were throughout investigated. The result shows that the basic density of *B. ramiflora* wood was between 541–623 kg/m^3, which could be classified in medium-density wood. The wood contained high content of acid-insoluble lignin (30.9%), whereas low pentosan (9.6%). The unbleached kraft pulp yield ranged from 40.1–48.5% with high kappa number (39.0–86.5) and low hexenuronic acid (15.4–81.2 µmol/g). The fiber length, fiber width, and fiber coarseness of unbleached pulp was 2.075 mm, 32.2 µm, and 0.182 mg/m, respectively. These values were higher than a range of tropical hardwoods. Moreover, the unbleached pulp contained a high content of primary fines (22.4%). After fines removal, the fiber fraction had higher holocellulose and cellulose content, whereas lower lignin, kappa number, acetone extractives, and ash content. Due to low lignin content, the fiber fraction was easier to bleached than the whole pulp and could be achieved an ISO brightness of 88% without oxygen delignification. Both bleached pulp and bleached fiber fraction contained low viscosity (450–470 mL/g) and low hexenuronic acid (0.1–0.3 µmol/g). The *B. ramiflora* pulp had a faster response on beating, compared to the fiber fraction. However, the strength of handsheets could be improved by the removal of fines fraction and the bleaching. The maximum tensile, burst and tear indices were of 56.0 Nm/g, 3.5 kPa*m^2/g and 17.8 mN*m^2/g, respectively, while the maximum folding endurance was 180 double folds.

Keywords: *Baccaurea ramiflora*, Elemental chlorine-free (ECF) bleaching, Fiber fraction, Fines fraction, Kraft pulping, Papermaking properties

INTRODUCTION

Lignocellulosic materials are the most abundant renewable resource in the world. They can be separated into individual fibers by either chemical or mechanical treatment. These materials can be classified into softwood, hardwood, and non-wood, each having substantially different chemical properties, fiber characteristics, and strength properties. Thailand, with its diverse geographical characteristics, supports a variety of tropical ecosystems that include approximately 15,000 plant species, accounting an estimated 56% of the plant species found globally (Royal Forest Department, 2009). Thailand produces over 1.2 million tons of pulp annually from seven pulp mills; with all the pulp being short-fibered and derived from eucalyptus trees, sugar cane bagasse and palm solid residue (Thai Pulp and Paper Industries Association, 2019). However, long fibers are still necessary to reinforce the pulp used in paper production to improve strength properties. Most domestic softwood in Thailand is grown in conservation areas in the north, which have restrictions on tree cutting. As a result, more than 0.35 million tons in 2017 of long-fibered softwood pulp has to be imported from other regions. (Thai Pulp and Paper Industries Association, 2019). It could be of great benefit to identify an indigenous long-fibered hardwood species for use as an alternative source in the pulp and paper industry.

The current study investigated the potential of *Baccaurea ramiflora* Lour. (Common name : Burmese grape; Thai name: Mafai), an indigenous hardwood species in South and Southeast Asia, as a source of long-fibered pulp to be used in pulp and paper production. At present, there is no published research characterizing the potential of this species for pulp and paper production. The chemical characterization and optimization of pulp production from *B. ramiflora* was investigated using kraft pulping, elemental chlorine-tree bleaching, and physical properties testing from laboratory handsheets.

MATERIALS AND METHODS

Raw material and wood basic density

Ten *B. ramiflora* log samples were obtained from the Trat Agroforestry Research and Training Station, Trat province, Thailand. The average diameter and average growth ring were 15.7 cm and 27, respectively. Each wood discs from DBH positions were cut into four pieces for determination of wood basic density according to the Technical Association of the Pulp and Paper Industry 2012 standards (TAPPI T 258)

Chemical composition

The rest of wood logs were debarked and then chipped, air-dried, screened to a size with thichness between 2.5 and 3.5 mm, and the knots were removed. The wood chip obtained was then stored in polyethylene bags at room temperature. The randomly selected wood chips were ground using a Willy mill and then further separated the finer material by sifting on a 40-mesh screen prior to determining the chemical composition. The wood particles were determined according to the Technical Association of the Pulp and Paper Industry 2012 standards by preparing the wood sample for chemical analysis (TAPPI T 264), ash (TAPPI T 264), acetone solubility (TAPPI T 204), and water solubility (TAPPI T 207). Extractive-free samples were subsequently used for the determination of pentosan (TAPPI T 223), acid-insoluble lignin (TAPPI T 222), holocellulose (Wise *et al.*, 1946), and cellulose (Updegraff, 1969).

Kraft pulping

Kraft pulping experiments were carried out in a 5 L vertical rotating digester using the following pulping conditions: 500 g oven-dried wood chips, 16–24% active alkali as Na_2O, liquor-to-wood ratio 4:1, 25% sulfidity, 60 min heating from ambient temperature to 165°C and 1,500 H-factor. After terminating the cooks, the black liquor was drained from the chips and thoroughly washed until it was free from residual chemicals. The fiber separation occurred in a 2 L disintegrator (Regmed; Brazil) and the pulp was then screened using a 0.2 mm slot laboratory screener. The gravimetrical method was used to determine the pulp yield and rejects. The kappa number and pulp viscosity were determined according to the International Organization for Standardization 2011 standards : ISO 302 and ISO 5351, respectively. The amount of hexenuronic acid was analyzed according to TAPPI T 282. The unbleached pulp from optimum pulping condition was then selected for the further study on fiber characteristics, effect of fines and elemental chlorine-free bleaching.

Fiber characteristics

The fiber characteristics of the unbleached pulp samples was analyzed according to the International Organization for Standardization 2011 standards using a fiber quality analyzer (FQA-360; OpTest Equipment; Canada) to determine the fiber length, fiber width, fines content (ISO 16065-1), and fiber coarseness (ISO 23713).

Fines removal

To study the effect of fines content on the bleaching and papermaking properties, the unbleached pulp was subjected to fines removal by washing through a 200-mesh screen at a 0.3% consistency. The chemical composition of unbleached pulp, unbleached fiber fraction and fines fraction was then analyzed.

Elemental chlorine-free bleaching

The unbleached pulp was subjected to a multistage bleaching treatment using the O-D_0-E_P-D_1-E_2-D_2 sequence, while the unbleached fiber fraction were bleached using the D_0-E_P-D_1-E_2-D_2 sequence. The bleaching condition has been shown in Table 1. In these sequences, D was chlorine dioxide stage, E_P was alkaline extraction stage with hydrogen peroxide, and O was oxygen delignification stage. Chlorine dioxide charge was calculated from the kappa factor (KF) using the formula chlorine dioxide (%) = kappa number × KF. The bleaching chemical was divided into three portions, namely 60% for D_0, 30% for D_1, and 10% for D_2.

Table 1 Bleaching condition.

Parameter	Bleaching stage					
	O	**D_0**	**E_P**	**D_1**	**E_2**	**D_2**
Consistency (%)	12	10	10	10	10	10
Temperature (°C)	90	70	70	75	70	75
Time (min)	60	60	60	120	60	180
ClO_2 (% on total ClO_2 (KF = 0.2)	-	60	-	30	-	10
H_2O_2 (%)	-	-	1.0	-	-	-
NaOH (%)	3	-	1.5	-	0.5	-
$MgSO_4$ (%)	0.5	-	0.3	-	-	-
O_2 pressure (bar)	6	-	-	-	-	-
pH	11.0–12.0	2.0–3.0	11.0–12.0	3.0–4.0	11.0–12.0	3.5–4.5

Remark: - = not applicable

Preparation and evaluation of laboratory handsheets

The pulp samples (unbleached pulp, unbleached fiber fraction pulp, bleached pulp, and bleached fiber fraction pulp) were beaten using a PFI mill according to ISO 5267. The papermaking properties of the pulps were determined as follows: pulp freeness (ISO 5267-2) using a freeness tester (Lorentzen & Wettre; Sweden), laboratory sheets (ISO 5270), apparent density (ISO 534), tensile index (ISO 1924-2) using a tensile tester (Thwing-Albert; USA), folding endurance (ISO 5626) using a folding tester (Kumagairiki; Japan), tear index (ISO 1974) using a tear tester (Lorentzen & Wettre; Sweden), and burst index (ISO 2758) using a burst tester (Lorentzen & Wettre; Sweden).

RESULTS AND DISCUSSION

Wood density and chemical composition

The wood density of *B. ramiflora* was between 541–623 kg/m^3, indicating that it had a medium density. The density was different from that reported by Sosef *et al.* (1998), who reported that *B. ramiflora* was a medium-to-heavy hardwood with a density of 630–950 kg/m^3. The lignin content in *B. ramiflora* wood was 30.07%, which was at the high end of the normal range of hardwood (20-30%) (Dutt and Tyagi, 2011; Neiva *et al.*, 2015; Rowell *et al*, 2013; Sharma *et al.*, 2011). Consequently, this species should require a higher consumption of cooking liquor, resulting in a higher kappa number. The pentosan content of *B. ramiflora* was lower than that of most eucalyptus species. The solubility in acetone and in water were used to determine the extractive components, which in the wood were 0.86% and 6.57%, respectively (Table 2).

Table 2 Chemical composition of *B. ramiflora* wood.

Property	Composition
Acetone solubility (%)	0.86
Water solubility (%)	6.57
Acid-insoluble lignin (%)	30.07
Holocellulose (%)	69.99
Pentosan (%)	9.56
Cellulose (%)	41.12
Ash (%)	2.24

Kraft pulping

The pulp yield, rejects, pulp viscosity, kappa number, and hexenuronic acid decreased with an increase in pulping chemicals. Unbleached pulp had a higher kappa number (39.0–86.5) and a lower hexenuronic acid (15.4–81.2 µmol/g) than the hardwood pulp due to a high lignin and low pentosan in the former (Table 3). The optimum pulping conditions were chosen based on the pulp yield, kappa number, and pulp viscosity. The rate of delignification decreased more slowly when using an active alkali content of more than 22%, while the pulp viscosity dropped continuously. As a result, an active alkali content of 22% was selected as an optimal pulping condition. However, the screened pulp yield (40.1–48.5%) and pulp viscosity (520–600 mL/g) were lower, when compared with the eucalyptus pulp (Neiva *et al.*, 2015).

Table 3 Kraft pulp properties of *B. ramiflora* wood chip.

Parameter	Active alkali (% as Na_2O)				
	16	18	20	22	24
Pulp yield (%)	48.5	46.1	43.0	40.8	40.1
Rejects (%)	0.60	0.21	0.07	0.02	0.01
Pulp viscosity (mL/g)	*n.a.*	*n.a.*	600	560	520
Kappa number	86.5	66.6	51.8	41.6	39.0
Hexenuronic acid (µmol/g)	81.2	61.2	37.5	23.1	15.4

Remark: *n.a.*=not analyzed

Effect of fines removal

The unbleached fiber fraction had a lower acetone solubility, lignin, and ash content, while the holocellulose and cellulose were higher than those of the fines fraction (Table 4). The fines fraction was composed of ray and parenchyma cells which are well known sources of extractives and lignin, resulting in this fraction having a higher content of hemicellulose, lignin, and extractives (Asikainen *et al.*, 2010; Seth, 2003).

The fiber length, fiber width, and fiber coarseness of *B. ramiflora* pulp was 2.075 mm, 32.2 µm, and 0.182 mg/m, respectively.

The fiber length was higher than that obtained from a range of tropical hardwoods (0.7–1.5 mm), which considered to be long fibered. The fines content (22.4%) was noticeably high which meant that the kappa number and lignin content was higher than for the fiber fraction. The kappa number had decreased significantly after the fines fraction was separated from the *B. ramiflora* pulp.

Table 4 Properties of unbleached *B. ramiflora* pulp separated into fiber traction and fines fraction.

Property	Unbleached *B. ramiflora* pulp (active alkali 22%)		
	Unbleached pulp	Fiber fraction	Fines fraction
Chemical property			
Acetone solubility (%)	0.24	0.11	0.62
Water solubility (%)	0.21	0.24	0.89
Acid-insoluble lignin (%)	5.12	3.49	13.79
Holocellulose (%)	91.46	96.77	82.59
Cellulose (%)	74.98	77.79	58.89
Ash (%)	3.34	1.91	7.05
Kappa number	37.5	28.2	81.2
Fiber dimension			
Length-weighted fiber length (mm)	2.075	2.161	0.407
Length-weighted fines (%)	22.4	0.5	88.2
Fiber width (μm)	32.2	31.9	-
Fiber coarseness (mg/m)	0.182	0.182	-

Elemental chlorine-free bleaching

The fiber fraction had a lower kappa number (28.2) than that of the unbleached pulp (37.5) as shown in Table 5, due to a lower amount of oxidized compounds such as lignin, extractives, and hexenuronic acid. The oxygen delignification process was required for the *B. ramiflora* pulp bleaching experiment to reduce the kappa number before bleaching with chlorine dioxide. The fiber fraction had a lower chlorine dioxide consumption per weight (ClO_2/BDT) and the chlorine dioxide consumption per △brightness than the *B. ramiflora* pulp, while the chlorine dioxide consumption per △kappa number was similar. The pulp viscosity of the fiber fraction (470 mL/g) was slightly higher than that of the bleached pulp (450 mL/g). However, the total pulp yield (34.98%) was higher than that of the fiber fraction (29.10%). Although the fiber fraction had good properties for bleaching, the pulp yield was considered as an important parameter in determining the pulp mill productivity.

Table 5 Properties of bleached *B. ramifora* pulp under optimum pulping conditions.

Parameter	Bleached pulp	Bleached fiber fraction
Initial kappa number	37.5	28.2
Kappa number after oxygen delignification	29.5	-
Initial brightness (%ISO)	16.12	17.45
Final brightness (%ISO)	88.20	89.32
Chlorine dioxide consumption (kg/BDT)	61.6	58.8
Bleaching yield (%)	84.69	93.44
Pulp viscosity (mL/g)	450	470
Hexenuronic acid (µmol/g)	0.3	0.1
Total pulp yield (% of original wood)	34.98	29.10

Papermaking properties

The faster response on beating of the unbleached pulp, compared to the fiber fraction, could be explained by the higher content of parenchyma cells (Figure 1). The bleached pulp had a higher density than the unbleached pulp due to an increased bonding in the pulp after the removal of lignin (Figure 2).

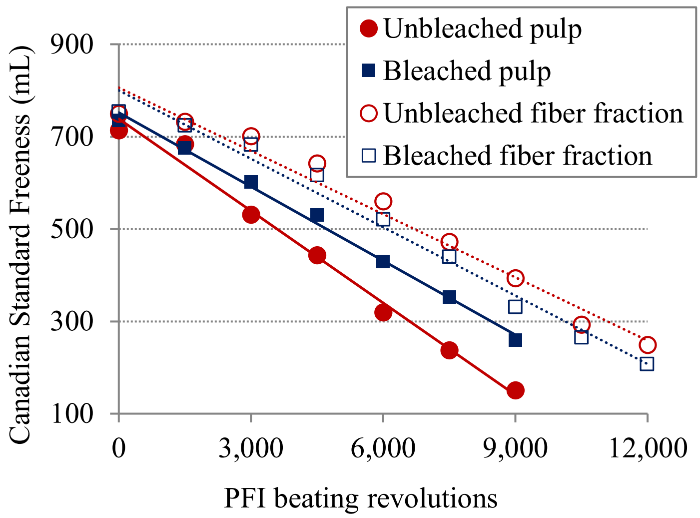

Figure 1 Pulp freeness versus PFI beating revolutions of *B. ramiflora* pulp and fiber fraction.

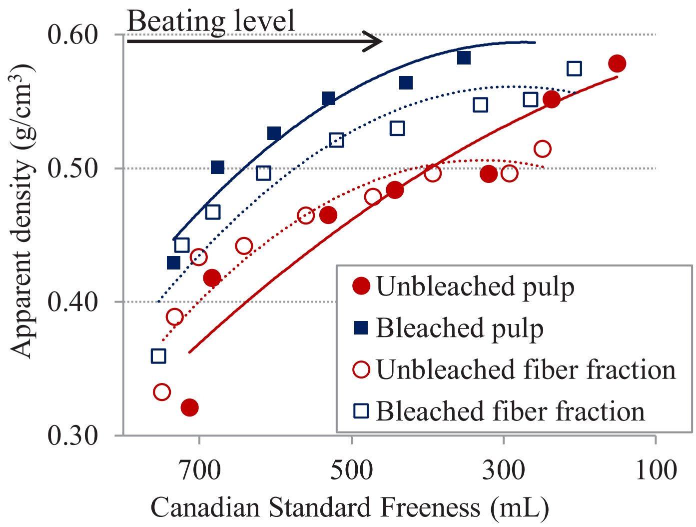

Figure 2 Apparent density versus pulp freeness of *B. ramiflora* pulp and fiber fraction pulp.

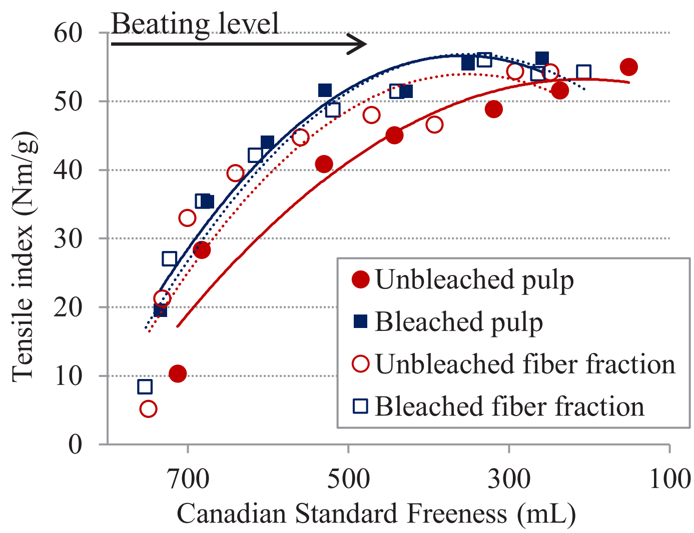

Figure 3 Tensile index versus pulp freeness of *B. ramiflora* pulp and fiber fraction.

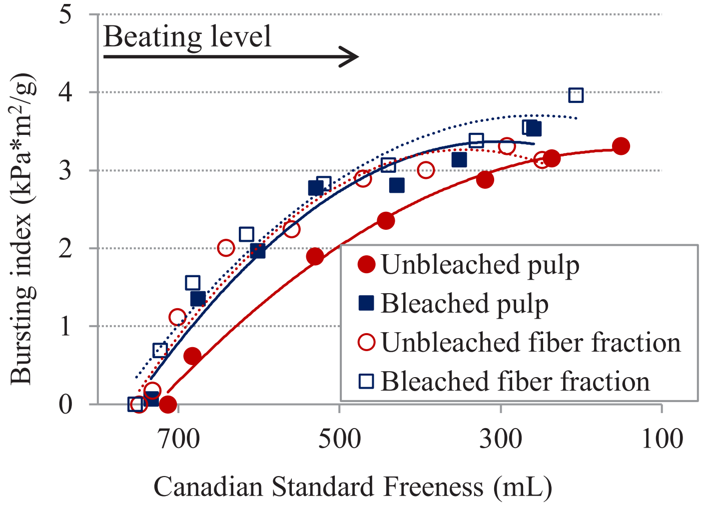

Figure 4 Bursting index versus pulp freeness of *B. ramiflora* pulp and fiber fraction.

At a given freeness, the tensile and bursting indices of the unbleached fiber fraction were similar to those of the bleached pulps and the bleached fiber fraction while the unbleached pulp had the lowest strength (Figure 3-4). These results indicated that the fines component, with a high lignin content, blocked the interfiber bonding resulted in a lower tensile index at a given freeness after bleaching, indicating a better bonding of fibers in the bleached paper sheet (Shaikh, 1990). It was observed that the strength of *B. ramiflora* laboratory handsheets could be improved by removing the fines fraction before PFI milling, as the high fines content with beating resulted in a slower dewatering of pulps (Shatalov and Pereira, 2002); however, the fibrillation in the pulp was low. The maximum tensile and burst indices were 56 Nm/g and 3.6 kPa*m^2/g, respectively.

The tear index of fiber fraction was higher than that of the *B. ramiflora* pulps (Figure 5). It increased rapidly with a small amount of beating and soon reached a maximum, with further beating causing a decrease in the tear index, because of the shortening of fibers and a decreased stretching ability (Libby, 1962). The maximum tear index was 17.8 mNa*m^2/g. The folding endurance increased with increasing beating level. The maximum folding endurance was 180 double folds (Figure 6). The fiber fraction had a higher folding endurance than the *B. ramiflora* pulp.

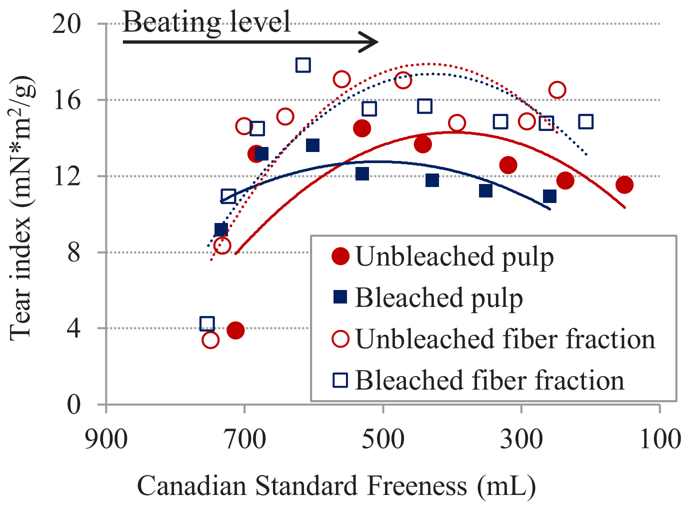

Figure 5 Tear index versus pulp freeness of *B. ramiflora* pulp and fiber fraction.

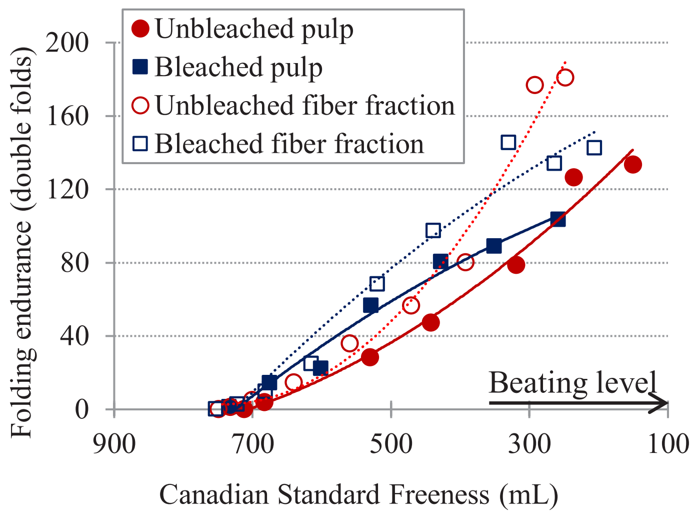

Figure 6 Folding endurance versus pulp freeness of *B. ramiflora* pulp and fiber fraction.

CONCLUSION

The *B. ramiflora* wood was a medium-density wood with a high content of acid-insoluble lignin, whereas low pentosan. In kraft pulping, *B. ramiflora* wood chip gave a low pulp yield with high kappa number and low hexenuronic acid.

The fiber length, fiber width, and fiber coarseness of the unbleached pulp were 2.075 mm, 32.2 µm, and 0.182 mg/m, respectively. These values were higher than a range of tropical hardwoods. The unbleached pulp contained a high content of primary fines. After fines removal, the fiber fraction had higher holocellulose and cellulose content, while lignin, kappa number, acetone extractives, and ash content were lower.

The fiber fraction was easier to bleached than the unbleached pulp. The bleached pulp and bleached fiber fraction contained low viscosity and low hexenuronic acid.

Due to higher fines content, the unbleached- and bleached pulps had a faster response on beating, compared to the fiber fraction.

The total pulp yield of bleached pulp was higher than that of the bleached fiber fraction. Although the fiber fraction had good properties for bleaching, the pulp yield was considered as an important parameter in determining the pulp mill productivity.

At a given freeness, the tensile and bursting indices of the unbleached fiber fraction were similar to those of the bleached pulps and the bleached fiber fraction while the unbleached pulp had the lowest strength. The tear index and folding endurance of both fiber fraction were higher than that of the unbleached- and bleached pulps.

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