Mixing Bleached White Poplar and Wheat Straw Chemimechanical Pulps to Improve the Mechanical and Optical Characteristics

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The aim of this study was to determine the optimum combination of wheat straw and white poplar (*P. alba*) chemimechanical pulps (CMPs) for producing newsprint paper. The CMP was prepared separately from the two raw materials. Cooking conditions included 10%, 12%, and 14% chemical charge based on w/w oven dry raw materials, maximum cooking temperatures of 120, 140, and 160 °C, and cooking time of 45 min. Hydrogen peroxide was used for bleaching the selected pulp. The results indicated that screened pulp yields were in the range of 54.3% to 61% and 80.9% to 85.9% for 18 cooking trials of wheat straw and white poplar, respectively. Handsheet brightness reached up to 52.9% and 61.9% for wheat straw and white poplar, respectively. The highest breaking length and burst index were related to CMP produced from 25% white poplar/75% wheat straw pulp blend. The best tear index was obtained using a mixture of 50% white poplar and 50% wheat straw pulp. Averages of breaking length, burst and tear indices ranged between 4.61 and 3.80 km, 2.31 and 2.55 kPa•m^2/g, and 7.29 and 11.1 mN•m^2/g, respectively. The strength properties of handsheets were higher than those reported for commercial newsprint except the breaking length of 50%/50% blend.

Keywords: White poplar; Wheat straw; CMP; Yield; Bleaching; Newsprint; Optical and Mechanical properties

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INTRODUCTION

Agroforestry science, which refers to the plantation of woody plants and agricultural crops, is regarded as one of the approaches to solve the problems related to natural resources. By implementing this system, production capability is enhanced. Research results have indicated that net income achieved by agroforestry systems is likely to be higher than that of monoculture (Ataei Gilgoo *et al*. 2010). Agroforestry plays an important role in supplying wood and agricultural crops. Plantation of fast-growing trees in short-rotation periods and potential of high biomass production along with a guarantee to purchase the produced woods have led to a success in the commercialization of agroforestry system. Among different agroforestry tree species, farmers give prime importance to poplar and eucalypts because of their short rotation (Deswal *et al.* 2014).

Although wood is primarily used as the raw material for papermaking, the use of non-woods is of considerable importance in many countries where wood is in short supply (Guo *et al.* 2009). Iran is regarded as one of several countries that have suitable capabilities and competences to grow and harvest fast-growing woods such as eucalypti and poplars (Ghasemi *et al.* 1999).

Poplars, especially aspen, have been successfully used in producing chemical and mechanical pulps (Sundholm 1998; Retulainen *et al*. 1998). The total carbohydrate fraction (*i.e*., holocellulose) found in wheat straw is approximately equal to that of hardwood because of straw’s high hemicellulose content, which is primarily composed of pentose sugars. Wheat straw contains low levels of lignin, which means that it requires moderate pulping conditions to obtain a satisfactory kappa number. Pulp prepared from wheat straw has many kinks and fines (Singh *et al.* 2011).

On the other hand, wheat straw is one of the abundant agricultural residues produced in Asia, which includes Iran; this could also be an appropriate fiber resource for papermaking. The amount of this residue produced in Iran was about 16 million tons in 2014 (IANA 2014). If only 10% of this residual was utilized for papermaking industry, then about 1.6 million tons of this raw fiber source would be available to paper makers. This amount of raw straw fiber is greater than the amount of potential raw fiber obtained from the northern forests of Iran (Mahdavi *et al.* 2006; Resalati 2006).

Various proportions of wheat straw, based on technical and economic constraints, have been used to make printing and writing paper, glassine and greaseproof paper, duplex and triplex paper, corrugating medium, strawboard, and “B” grade wrapping paper (Wong 1995). Newsprint is an important paper grade that has experienced a notable increase in consumption by developing countries, such as Iran (FAO 2014). Newsprint grades require good opacity and printing properties, as well as sufficient strength to be run through high-speed printing presses without breaking (Wood and Karnis 1991). Over the years, a number of different attempts have been made to produce newsprint paper grades using various processes and different combinations of wood and non-wood fibers (Rangamannar *et al.* 1990; Ryrberg *et al*. 1994). Chemimechanical pulping (CMP) is more appropriate than chemical pulping (*e.g*., kraft) for making newsprint because of its high yield, low chemical consumption, and low environmental pollution (Khojasteh 1997).

Published experimental research on CMP of wheat straw has shown that the range of defibration occurs at a pulp yield of 53.4% to 62%. In this respect, the highest brightness attained was 61.2% ISO by pulp bleaching (Jahan Latibari *et al.* 2012). In another study, unbleached CMP was produced from wheat straw using sodium hydroxide or sodium sulfite buffered by sodium carbonate. The results showed that the yields and rejects of alkaline sulfite pulp, as well as refining energy consumption, were greater than pulps treated by sodium hydroxide. Conversely, the soda paper strength was higher than that from alkaline sulfite pulp (Moradian *et al.* 2003).

Bleached wheat straw pulp (BWSP) is made of thin fibers with a high length/width ratio, offering a good paper surface smoothness; however, it has low bulk, low opacity, and poor drainage because of its high content of parenchyma cells (Zhang *et al.* 2012). Many studies have reported remedies for issues associated with the use of wheat straw (Liu and Li 1994; Guo *et al.* 2009).

An unexpected synergistic effect has been observed when mixing different types of furnish (Resalati 2006; Xu *et al.* 2008). Predicting the behavior of pulp prepared from different furnish and the associated synergistic effects is still poor (Honkasalo 2004).

This study was conducted to determine the optimum proportion of wheat straw and white poplar (*P. alba*) chemimechanical bleached pulp (BWSP and BWPP) for producing newsprint paper. The other objective was to obtain the required brightness for newsprint paper through peroxide brightening.

EXPERIMENTAL

Raw Materials

Three white poplar trees (*P. alba*) and wheat straw were provided from one of the agroforestry farming systems in Borujerd (Lorestan province, Iran). Wood samples were cut at breast height; after debarking the log, the chips were prepared in the laboratory using a Pallmann chipper. The chips were thoroughly washed with tap water to remove impurities and were air dried and kept in bags prior to cooking.

Pulping

To prepare chemimechanical pulp (CMP), 18 cooking treatments were utilized with various separate conditions for white poplar and wheat straw. Cooking variables for both raw materials were the same and involved the use of sodium hydroxide and sodium sulfite with a weight ratio of 2 to 3, respectively; three chemical charge levels of 10%, 12%, and 14% (based on w/w oven dry raw materials); and maximum cooking treatment temperatures of 120, 140, and 160 °C. Cooking time and liquor-to-raw material ratio were set as 45 min and 7:1 and 10:1 for wood and straw, respectively. Cooking treatments was performed in a 2-L double rotating digester (Ghomes Wood and Paper Equipment Manufacturing Co., Iran). The pretreated material was washed on a 200-mesh screen to remove the liquor and then defiberized using Lorentzen & Wettre (Sweden) 20-cm-diameter single disk refiner with a 2-mm clearance. The CMP was screened using a set of two screens, an 18-mesh screen on top of a 200-mesh screen. The material retained on the 18-mesh screen was considered rejects, and the fibers that passed the 18-mesh screen but were retained on the 200-mesh screen were classified as accepted pulp (screened yield).

Bleaching

Selected CMP was bleached using peroxide. For this purpose, the pulp consistency was adjusted to 10% and the pH to 5. Diethylene triamine-pentaacetic acid (DTPA) was applied at 0.3% of the O.D. weight of pulp for 30 min at ambient temperature (about 25 °C) to remove transition metal ions by chelation. Then, the treated pulps were thoroughly washed with deionized water and dewatered manually. Two CMPs from each raw material were selected for bleaching (in triplicate) by applying 1.5% and 2% H_2O_2, 2% and 3% NaOH, and 2% sodium silicate at a temperature of 80 °C for 60 and 120 min. Thus, 96 bleaching trials were conducted on selected pulps. Optical properties that included brightness, opacity, and yellowness were measured in accordance with TAPPI T 452 (2008), T 425 (2006), and T1216 (2006), respectively.

Refining

The bleached white poplar and wheat straw CMPs were refined to obtain a freeness level of approximately 300 mL CSF using a PFI mill beater in accordance with TAPPI T 248 (2000).

Handsheet Making

Laboratory handsheets were made individually from the refined pulps of white poplar, wheat straw, and blends of the two pulp types at ratios of 50:50, 25:75, and 75:25. Handsheets were made at a grammage of 60 g•m^{-2} in accordance with TAPPI T 205 (2002). Physical and mechanical testing of the handsheets was conducted using the relevant TAPPI test methods:

- Physical testing of pulp handsheets: TAPPI T220 (2001)
- Standard conditioning and testing atmosphere: TAPPI T402 (2003)
- Grammage of paper and paperboard: TAPPI T410 (2008)
- Bursting strength of paper: TAPPI T403 (2002)
- Internal tearing resistance of paper: TAPPI T414 (2004)
- Tensile breaking properties of paper and paperboard: TAPPI T494 (2001)

Commercial Newsprint

Commercial newsprint is currently produced by Mazandaran Wood and Paper Industries (MWPI) from a mixture of hardwood CMP and 17% imported bleached softwood kraft pulp in Iran (Resalati 2006). CMPs produced from poplar and wheat straw were compared with properties of the newsprint as control as follows:

Brightness: 51%, opacity: 91%, yellowness: 10%, burst index: 1.55 kPa.m^2/g, breaking length: 4 km, and tear index: 5 mN.m^2/g.

Statistical Analysis

Statistical data analysis was performed using SPSS 15.0 software (SPSS Inc., Chicago, IL, USA). Factorial experiments were performed using completely randomized design (CRD). The average values of accepted yield, strength, and optical properties were compared and grouped using the Duncan multiple-range test (DMRT) at $p \leq 0.05$, if there was significant difference among the averages. DMRT makes use of the studentized range distribution in order to determine critical values for comparisons between means.

RESULTS AND DISCUSSION

Pulping

The utilization of non-woods, particularly wheat straw, for pulp and paper production has some benefits, but also some problems. Soda pulping of wheat straw has some deficiencies, such as low pulp yield, the need for high chemical pulping temperature (and pressurization), and problems with the recovery of spent pulping liquors (Jahan Latibari *et al.* 2012). The pulp yields from CMP at various conditions for wheat straw and white poplar are shown in Table 1. Nine trials for each raw material were obtained using the various CMP conditions. The variations of accepted yield ranged from 80.9% to 85.9% for white poplar pulp (WPP), which is similar to the literature (Habibi *et al.* 2013). The range was lower for wheat straw pulp (WSP) (54.3% to 61%), but was higher than other published studies (Moradian *et al.* 2003; Singh *et al.* 2011; Jahan Latibari *et al.* 2012) because of the CMP conditions and the chemical usage. WSP yield was between the yields of WSP produced individually by sodium sulfite and sodium hydroxide (Moradian *et al.* 2003). The low fiber content in wheat straw (39.20%), high proportion of parenchyma (32.10%) and epidermal cells (23.56%), as well as the high solubility in sodium hydroxide, can explain the low yield of WSP compared with WPP (Singh *et al.* 2011).

Statistical analysis showed that pulping temperature and chemical charge had significant effect on the pulp yield, but the effect of the second factor (chemical charge) was statistically more significant $p < 0.01$. Furthermore, the reject portion of the pulps produced applying lower pulping temperature (120 °C) was high for the both pulps, so the accepted yield was lower than that of the pulps produced at 140 °C and 160 °C pulping temperatures for WPP. The mean values of accepted yield were compared and classified using the DMRT, and results can be seen by superscript small letters in Table 1. Trials P_8 and P_6 belonging to white poplar (group a) were selected for peroxide bleaching based on the highest accepted pulp yield, 85.9% and 85.1%, respectively (Table 1). Accordingly, optimum pulps prepared from wheat straw were selected as W_2 and W_4. It was found that more severe conditions were required for the production of CMP from white poplar as compared with wheat straw. The lignin content of wheat straw is low, so it requires moderate pulping conditions to reach a satisfactory kappa number (Singh *et al.* 2011).

Table 1. CMP Yield of Raw Materials using Various Cooking Conditions

Chemical charge (%)	NaOH to Na_2SO_3	Time (min)	Temp. (°C)	Trial code	Yield (*P. alba*)			Trial code	Yield (*wheat straw*)		
					Accept (%)	Reject (%)	Total (%)		Accept (%)	Reject (%)	Total (%)
10	2:3	45	120	P_1	80.9^{*d}	13.1	94	W_1	58.1^{c}	14.4	72.5
12	2:3	45	120	P_2	82.2^{c}	10.2	92.4	W_2	61^{a}	7.3	68.3
14	2:3	45	120	P_3	82.5^{c}	8.6	91.1	W_3	59.7^{b}	4.2	63.9
10	2:3	45	140	P_4	83.8^{b}	9.2	93	W_4	60.2^{ab}	10.8	71
12	2:3	45	140	P_5	84^{b}	6.3	90.3	W_5	59.9^{b}	6.4	66.3
14	2:3	45	140	P_6	85.1^{a}	2.4	87.5	W_6	52.4^{e}	5.7	58.1
10	2:3	45	160	P_7	84.1^{b}	5.6	89.5	W_7	59.4^{b}	9.9	70.5
12	2:3	45	160	P_8	85.9^{a}	1.3	87.2	W_8	57.7^{c}	6.1	63.8
14	2:3	45	160	P_9	83.7^{b}	0.7	84.4	W_9	54.3^{d}	2.2	56.5

* Superscript italic letters show the mean statistical grouping by DMRT at $p < 0.05$

Bleaching

The combination of four factors in bleaching of the selected pulp led to 96 trials that were analyzed by 2×2×2×4 factorial experiment in RCD with 3 replications. Each of the optical properties of 4 types of pulp in Fig. 1 is an average of 24 trials (2×2×2×3). Variance analysis of the independent variables and their interaction effects on the optical properties of bleached pulps (BWSP and BWPP) showed significant differences at the 99% confidence level.

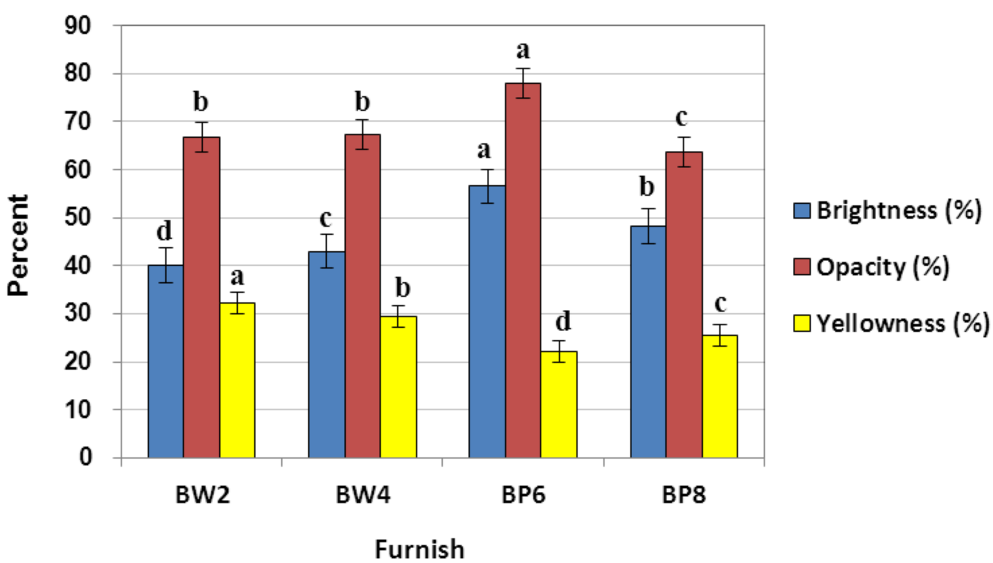

Fig. 1. Means of optical properties of BSWP and BWPP from 32 trials

The highest and lowest effects were found on opacity and brightness, respectively. Figure 1 shows the optical properties of the pulps and grouping of the means by DMRT. Accordingly, BP_6 and BW_4 treatments are more suitable between BWPP and BWSP, respectively. The maximum brightness of BSWP was 52.89% ISO using 2% hydrogen peroxide, 3% sodium hydroxide, and a reaction time of 120 min (BW_4 treatment, Fig. 2). Optical properties of BWSP with moderate bleaching conditions are better than those of wheat straw CMP cooked only with sodium hydroxide (Jahan Latibari *et al.* 2012).

Applying 2% NaOH and 2% H_2O_2 while using a bleaching time of 120 min afforded the highest brightness for the BWPP at 61.93% ISO (BP_6 treatment, Fig. 2). Thus, the mentioned treatments (BW_4 and BP_6) were selected according to Duncan grouping of optical properties for handsheet testing.

When considering the handsheet brightness values of this study, all laboratory results were acceptable when compared with newsprint made by MWPI; however, the laboratory results exhibited lower opacity and higher yellowness, especially for BWSP. Lower light scattering coefficient and opacity have been reported for BWSP in previous published studies (Honkasalo 2004; Resalati 2006). This problem could probably be solved by adding long fiber pulp and mineral pigment, like kaolin. Figure 2 shows that optical properties have been improved by blending BWPP to BWSP. Optimal optical properties were achieved using 100% BWPP and using 75% BWPP/25% BWSP.

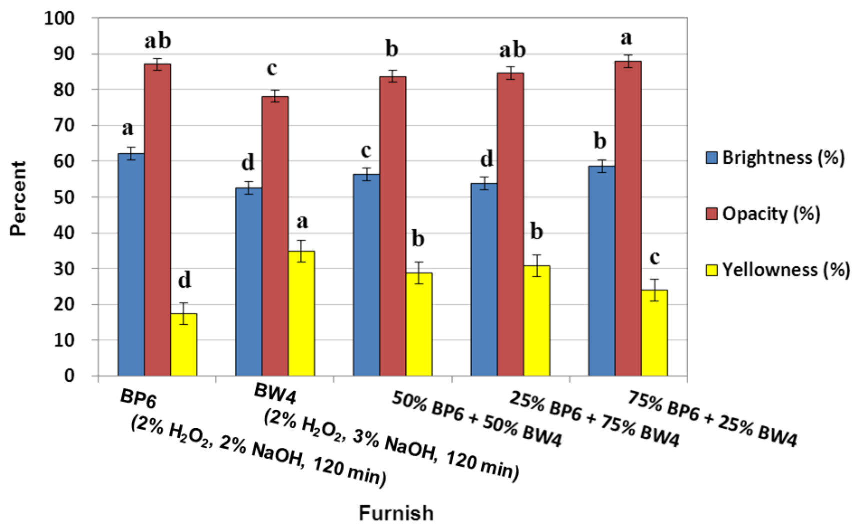

Fig. 2. Optical properties of pure and blended BSWP and BWPP

Refining

Bleached pulps were refined to about 300 mL CSF, and results showed that the wheat straw pulps respond to refining more easily than the white poplar pulps. BWPP with higher initial freeness and PFI refining revolutions (8200) require more energy consumption compared to BWSP (1650) to reach the target freeness. On the other hand, dewatering time of refined WSP was higher due to high fine content. BWSP is well known for being much easier to be refined to low freeness in comparison with BWPP pulp. The morphological and ultrastructural differences as well as high fine content and xylan content of wheat straw was mentioned as low energy consumption for pulp refining (Guo *et al*. 2009). Conversely, good flexibility, especially in poplar, can cause slipping under the beater bars, so refining energy consumption is usually high (Mahdavi *et al.* 2012).

Handsheet Strength

Figure 3 presents the effects of various blending levels of the two pulps types on the strengths of the handsheets. The highest burst index was observed with a blend of 75% BWSP/25% BWPP, which was ranked in the group a by the statistical Duncan test. This pulp blend showed the best synergistic effect on handsheet strengths. There were no significant differences between breaking length and burst and tear indices of pure BWPP and the 75% BSWP/25% BWPP blend. Biometric and morphological differences of wheat straw fiber, such as low fiber diameter and small lumen (Resalati 2007; Singh 2011), considerable levels of fines and curled fiber, and high hemicellulose and low lignin content *versus* white poplar fibers can affect the synergy.

The tear strength of 50% BWSP/50% BWPP was the highest, whereas the lowest breaking length resulted using this pulp blend. It would seem that a synergistic improvement was achieved, as indicated by a significant increasing of this parameter. A 70% increase in tear strength of unrefined BWSP was reported by adding 40% aspen high-yield pulp (HYP), while the tensile index decreased by only about 10%.The increase of tear index was stated due to the fact that aspen HYP has higher average fiber length (Zhang *et al.*2012). Tear strength represents the force required for further tearing of the paper from an initial cut (Samariha *et al.* 2013). This parameter is affected by several factors, including the length and strength of the fiber, refining intensity, inter-fiber bonding degree and strength, coarseness, fiber orientation, and surface area (Fadavi *et al.* 2012; Zhang *et al.* 2012). Synergistic effects of these factors could result from the mixing of the two pulps produced by the CMP process. Breaking length and burst strengths of handsheets made with BWPP were lower than the values reported by the other researchers (Habibi 2013), but tear strength was higher because of the different cooking conditions. Also, the tear and burst strengths of BWSP handsheets were lower than those reported by Jahan Latibari *et al*. (2013), and the breaking length strength was higher because of the difference in yield and type of chemical used in the two studies. In this study, the breaking length and burst index of BWSP fell between the CMP of wheat straw cooked by sodium hydroxide and sodium sulfite (Moradian 2003), but it had a higher tear index. According to Fig. 3, the variation trend of tear index among treatments was in contrast with the breaking length.

The laboratory studies showed that a mixture of fine groundwood and well-bonding thermomechanical pulp (TMP) can have synergy in supercalendared paper. Synergy advantage was achieved especially in tear strength, and to some extent in fracture energy, tensile energy absorption, and stretch, while no synergy was found in tensile strength or Scott bond. The longer fibers of TMP and high fines contents of groundwood pulp were considered reasons for the synergy (Honkasalo 2004). BWSP has relatively high fines content, including primary fines (mostly parenchyma cells) and secondary fines (generated during refining). The important role of secondary fines of mechanical pulps in increasing paper strength is due to the creation of links between the fibers, as has been mentioned previously. This role depends on the type and size of fines contributing to the paper structure. They are able to appropriately fill the small interstices in the structure and provide bonding sites between the long fibers (Chen *et al.* 2013). The properties of chemical BWSP can be improved by 5% to 20% aspen high-yield pulp (Zhang *et al.* 2012). In particular, the relatively higher specific surface area of HYP fibers and fines (Li *et al.* 2002; Liu *et al.* 2009) may enhance the absorption of the broken parenchyma cells of BWSP, resulting in improved drainage of BWSP. The role of secondary fines with WSP was specified as a binder to improve the link between fibers in the paper network (Zhang *et al.* 2012).

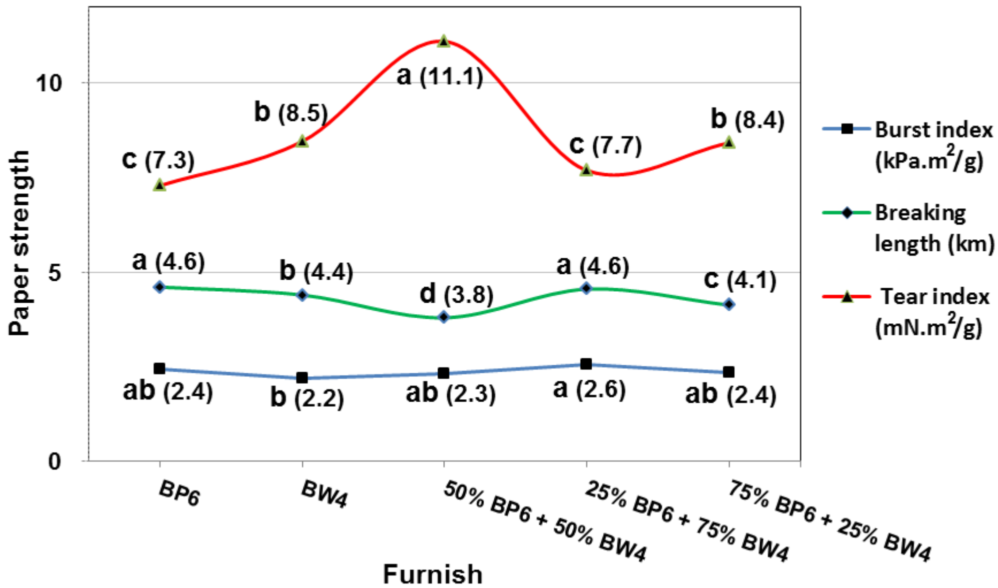

Fig. 3. Comparison of strength handsheets made from various ratios of BSWP and BWPP

CONCLUSIONS

There were some benefits in mixing wheat straw and white poplar bleached pulps.

1. Increasing bleached white poplar pulp blend ratio from 25% to 75% could improve the optical properties.
2. The mixing led to synergistic improvement of sheet properties including 30% increase in tear index that was achieved with a 50%/50% blend of both pulps.
3. A suitable chemimechanical pulp can be produced from wheat straw by mixing of white poplar CMP for making newsprint, in which it is not necessary to use imported long fiber as reinforcement pulp.
4. Moderate cooking conditions for CMP are required to produce wheat straw pulp as compared to that of white poplar pulp.
5. Chelated peroxide pulp bleaching results showed that wheat straw had inferior optical properties in comparison with white poplar.
6. High dewatering time of wheat straw pulp in the papermaking process could be improved by adding white poplar pulp despite of lower refining energy consumption for wheat straw CMP.
7. Handsheets made from a fiber furnish of 25% BWPP/75% BWSP afforded the better breaking length and burst index.
8. The results of this study suggest that the potential of poplar and wheat straw-based agroforestry system in supplying fiber for papermaking should be further considered.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to Ms. Razmpour and Mr. Fuladi for their kind assistance with paper testing.

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Article submitted: September 25, 2015; Peer review completed: January 14, 2016; Revised version received and accepted: January 24, 2016; Published: February 3, 2016.
DOI: 10.15376/biores.11.2.2987-2997