CELLULOSE CHEMISTRY AND TECHNOLOGY

CHEMICAL COMPOSITION AND MORPHOLOGICAL PROPERTIES OF CANOLA PLANT AND ITS POTENTIAL APPLICATION IN PULP AND PAPER INDUSTRY

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In this research, the chemical composition and morphological properties of canola plant cultivated in Iran were investigated. Canola straw was collected from a cultivation farm near Babul, Mazandaran, Iran. Average width, fiber length, lumen diameter and cell wall thickness were measured as 27.95, 860, 18.86, and 4.42 µm, respectively. The typical chemical composition, involving the amounts of cellulose, lignin, ash and ethanol/acetone extractives, was determined as 44, 19.21, 6, and 13 wt%, respectively. Optimum pulping conditions were selected applying a cooking temperature of 170 ºC, and cooking time of 30 min, in addition to the introduction of a 20% sodium sulfite (based on Na_2O). The pulps were refined by a PFI mill. The obtained results showed that the mechanical properties of the handsheets made from canola NSSC pulp exhibited better properties, in comparison with mixed hardwood NSSC pulp in production of corrugating paper.

Keywords: canola, chemical composition, morphological properties, pulp and paper

INTRODUCTION

Nonwood fibers represent a substantial raw material for papermaking in Asia.[1] Canola (*Brassica napus L.*) is widely cultivated throughout the world and used as a major oilseed crop for vegetable oils and biodiesel production. European regulations in this field are promoting the use of this kind of fuel oil – biodiesel;[2] minimum consumption levels have been set to reach 10% of the total in 2020.[3] However, canola has been vastly cultivated for production of edible oil.[4] The average yield of canola straw reaches approximately 3 dry tons/ha.[4] It was estimated that 500,000 tons of canola straw are annually produced in Iran. Based on the governmental policy, it is predicted that canola production will be developed in the future.[4] Various pulping processes can be applied to obtain mechanical pulp (MP), thermomechanical pulp (TMP), chemimechanical pulp (CMP), semichemical pulp (SCP), chemithermo-mechanical pulp (CTMP) or chemical pulp (CP) from these residues.[3] In the areas of emerging markets, such as India, China, and the Middle East, the predicted growth in the demand for paper is of 4.1% per year until 2020.[3] Therefore, together with cost-effectiveness and abundance of these crop residues, it is also reasonable to consider its use in the pulp and paper production.[5-6] At the time of writing this article, some agricultural residues, such as bagasse, wheat and rice straws, sorghum stalks, and hemp are used as the raw materials for pulp and paper production.[7-8] In general, the soda pulping process is known as a more suitable chemical pulping process for annual plants.[9] In this study, the chemical composition, morphological properties, and NSSC pulping properties of canola were investigated to evaluate the potential utilization of canola as raw material for manufacturing fluting medium grades.

EXPERIMENTAL

Materials

Canola residues were obtained from the research field in Babul city (Iran). Samples were cleaned and leaves and debris were removed, while the stems were depithed carefully by hand. The depithed material was cut into 2-4 cm long chips. The pulping liquor was taken from the NSSC pulping line at Mazandaran Pulp and Paper Industries, Sari, Iran.

Methods

Chemical composition

The proportions of chemical constituents in the canola fibers were determined according to TAPPI Test Methods. Lignin, ethanol/acetone extractives, and ash of canola fiber were determined according to TAPPI T222 om-97, and T207 om-97, T267 om-85, respectively. The cellulose content of canola was determined according to the nitric acid method.[10] All measurements were repeated three times.

Fiber morphology characterization

The pieces of canola were defibrated using a technique developed by Franklin.[11] For this purpose, 120 undamaged/unbroken fibers were measured in terms of their lengths (*L*), fiber widths (*d*), lumen diameters (*l*) and cell wall thickness (*w*), using a microscope equipped with a Leica Image Analysis System (Quantimeta 100+). The fiber lengths were expressed as arithmetic average length. The calculations of Runkel ratio ($2w/l$), coefficient of flexibility (l/d) and slenderness ratio (L/d) were carried out based on the measured data. The values were then compared to those of nonwoods to assess suitability of the plant raw materials for paper production.

Experimental cooking

The Neutral Sulfite Semi Chemical (NSSC) pulping was performed under cooking conditions; the temperature of 170 °C, chemical charge (sodium sulfite) of 20%, and cooking time of 30 min were kept constant. The cooking liquor to canola ratio (L/W) was 10 to 1. The cooking trials were performed using an experimental rotating digester (HATTO), with 500 grams of canola in each trial. These cooking conditions led to a 66% yield for pulp. Canola NSSC pulp was refined by a PFI mill to 350 and 400 mL CSF, the 95% hardwood NSSC pulp was refined to 400 mL CSF and mixed with 5% unbleached softwood kraft pulp (UBSKP) refined to 520 mL CSF. The handsheets with the basis weight of 127 gm^{-2} were made according to TAPPI 205 om-88. The handsheets were kept in a conditioning chamber at 23 °C and 50% RH for 24 hours. Then caliper, tensile strength index, tear strength index, burst strength index, breaking length, ring crush test, and stiffness of the handsheets were determined according to TAPPI T411 om-89, T494 om-88, SCAN P11:73, T403 om-91, T425 om-98, and T425 om-98 test method, respectively. The reported results represent the average values obtained for 8 handsheets. Finally, in order to compare the results of testing the strength properties, a one-way analysis of variance analysis and a Duncan's multiple range test using SPSS software were performed.

RESULTS AND DISCUSSION

Chemical composition

Lignocellulosic materials contain cellulose, lignin, extractives, and ash. The chemical properties and behavior of the nonwood components are of significant importance during the pulping process. A brief review of their characteristics is, therefore, necessary as a background to the objectives of this study. The percentage values of cellulose, lignin, extractives soluble in alcohol-acetone, and ash are summarized in Table 1.

Table 1
Chemical composition of canola (% on OD basis)

Component	Value, %
Cellulose	44.00
Lignin	19.21
Extractives soluble in alcohol-acetone	6.00
Ash content	13.00

The lignin content of canola was found to be smaller than that of rice straw (21.90%), Egyptian cotton stalks (22.50%),[15] and bamboo (24.5%).[16] Moreover, the organic solvent extractives of canola were found to be greater than those of rice straw (0.56%) and bamboo (3.9%). The organic solvent extractives were lower than those of rye straw (9.2%).[16] Meanwhile, the ash content of canola was also high.

Fiber dimensions and fiber indices

The fiber dimensions and biometrical coefficient of canola are summarized in Table 2. The results show that the canola contained fibers with a mean length of 860 µm. The canola fibers are in the range of nonwoods, somewhat longer than those of wheat straw (740 µm) and cotton stalks (0.83 mm),[17] and shorter than those of bamboo (2300 µm).[18] On the other hand, cell wall thickness of the canola fibers is greater than those of aspen (1.93 µm)[19] and rye straw (1.1 µm).[16] Short fibers tend to give a dense and uniform sheet structure. Fiber width (diameter) and cell wall thickness governs fiber flexibility. Thick-walled fibers adversely affect the bursting strength, tensile strength and folding endurance of the paper. As can be seen from Table 2, the mean fiber values of width and cell wall thickness were of 27.95 and 4.42 µm, respectively, which are both in the range of tobacco straw[20] and cotton stalks.[12] It can be expected that the paper manufactured from these thin-walled fibers will be dense and well-formed.

Table 2
Fiber dimensions and biometrical coefficient of canola

Fiber dimensions	Value, %
Length	860.00 (µm)
Diameter	27.95 (µm)
Lumen width	18.86 (µm)
Cell wall thickness	4.42 (µm)
Runkel ratio	0.47
Slenderness ratio	30.89
Flexibility ratio	67.47

Arithmetic ratios calculated from dimensional measurements of the fibers contribute to assessing various properties of the paper. The most important and fundamental observation to find the potential of any raw material to be used in pulp and paper production is its Runkel ratio; the ratio of twice the fiber wall thickness to the lumen width (2 *w/l*). A standard value of this ratio is typically equal to 1. Favorable pulp strength properties are usually obtained when the value of Runkel ratio is below the standard value. Generally speaking, the fibers with a high Runkel ratio are stiffer, less flexible, and form a bulkier paper of lower bonded area in comparison with those of low Runkel ratio. This effect is related to the collapsing degree of the fiber during the drying process, a phenomenon which is affected by the cell wall thickness and degree of refining that fibers undergo prior to papermaking.[21] Jang and Seth (1998) stated that materials having a Runkel ratio less than 1 would be suitable for papermaking,[22] since they collapse (become ribbon-like) and provide a large surface area for bonding. Macerated canola fibers have a Runkel ratio of 0.47. Sheets made from short and thin-walled fibers of canola may be expected to give relatively dense papers which are weak in tearing strength, but are superior in burst and tensile properties. From this point of view, the fibers are suitable for papermaking. Other calculated fiber properties are the slenderness ratio and flexibility ratio. Slenderness is the ratio of fiber length to fiber width. A large value of this ratio provides a better forming and thus well-bonded paper. From Table 2, the average slenderness ratio of the fibers is 30.89. The fibers have a relatively good length to diameter ratio resulting in flexible fibers good for fiber bonding during papermaking. Flexibility ratio is the percentage of lumen width over fiber width. It indicates the potential of the fiber to collapse during beating, or during drying of the paper web. Collapsed fibers provide a large bonding area and stronger papers are produced subsequently. On the other hand, strength properties of the paper, such as tensile strength, bursting strength and folding endurance, are affected mainly by the way in which individual fibers are bonded together in the paper sheets. The degree of fiber bonding heavily depends on flexibility of the individual fibers. The ratio of flexibility is 67.47 and therefore it is expected to yield well-bonded fibers and form a smooth printing surface.

Physical and mechanical properties of handsheets

The statistical analysis of two NSSC pulp samples – one used as received from the factory and the other formed from unmixed canola with the freeness of 350 and 400 mL CSF, demonstrated that, with an almost equal basis weight, the unmixed canola pulp with the freeness of 350 mL CSF and 400 mL CSF had a smaller caliper in comparison with the hardwood NSSC pulp. This difference is mainly believed to be associated with a relatively larger bonding area between the fibers in the canola pulp (Fig. 1). The greatest values of breaking length, ring crush test, burst, and tear strength index were observed for the NSSC of canola pulp having a freeness of 350 mL CSF, whereas the minimum values of these characteristics were all noted for commercial fluting furnish (95% hardwood NSSC pulp and 5% UBSKP). From a statistical point of view and at a 95% confidence level, the paper made with the freeness of 350 or 400 mL CSF comprised a single group, and there was no statistically significant difference between them (Figs. 2, 3, 4, and 5). The strength characteristics, including stiffness and tensile strength index of the canola papers with a freeness of 350 mL CSF, were analyzed accordingly and showed significantly greater values than those of papers made from hardwood NSSC pulp, which was used as received from the factory.

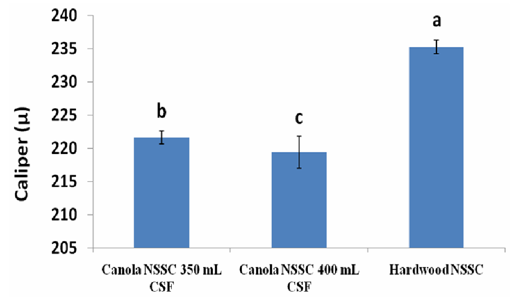

Figure 1: Comparison of caliper between papers produced from canola NSSC pulp and hardwood NSSC pulp (small letters indicate the Duncan ranking of average values at a 95% confidence level)

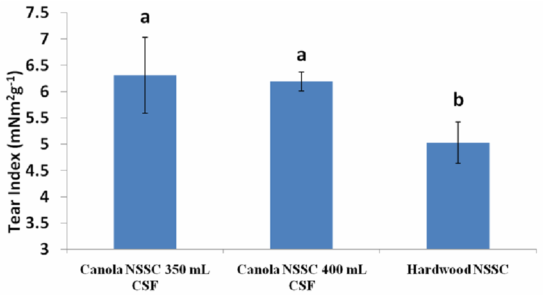

Figure 2: Comparison of tear strength index between papers produced from canola NSSC pulp and hardwood NSSC pulp (small letters indicate the Duncan ranking of average values at a 95% confidence level)

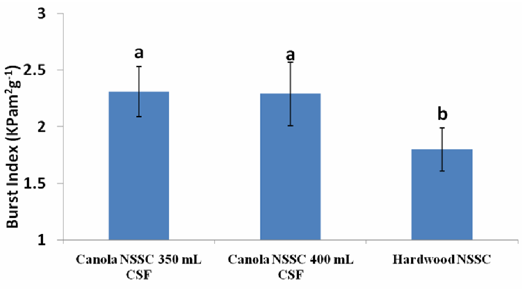

Figure 3: Comparison of burst index between papers produced from canola NSSC pulp and hardwood NSSC pulp (small letters indicate the Duncan ranking of average values at a 95% confidence level)

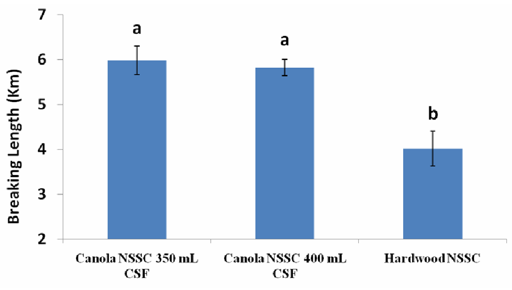

Figure 4: Comparison of breaking length between papers produced from canola NSSC pulp and factory NSSC pulp (small letters indicate the Duncan ranking of average values at a 95% confidence level)

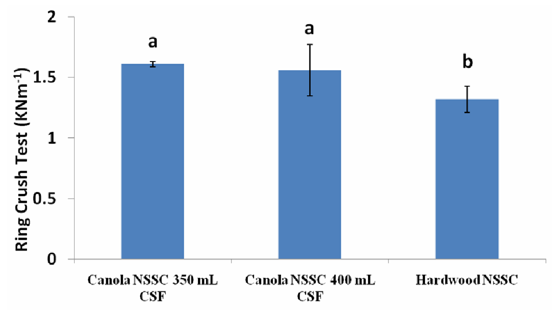

Figure 5: Comparison of ring crush test results between papers produced from canola NSSC pulp and hardwood NSSC pulp (small letters indicate the Duncan ranking of average values at a 95% confidence level)

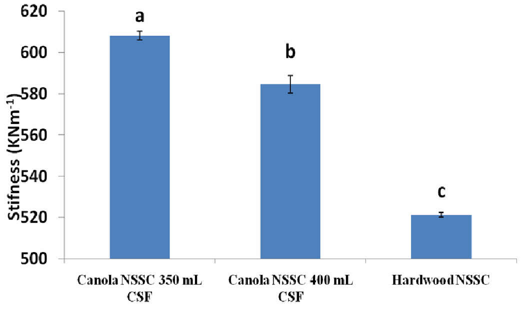

Figure 6: Comparison of stiffness between papers produced from canola NSSC pulp and hardwood NSSC pulp (small letters indicate the Duncan ranking of average values at a 95% confidence level)

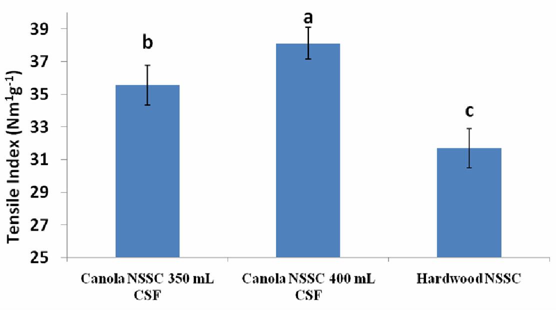

Figure 7: Comparison of tensile strength index between papers produced from canola NSSC pulp and hardwood NSSC pulp (small letters indicate the Duncan ranking of average values at a 95% confidence level)

Furthermore, the strength characteristics of the pulp with a freeness of 350 mL CSF were significantly greater than those of the papers made from pulp with a freeness of 400 mL CSF (Figs. 6 and 7). The papers from canola pulp of 400 mL CSF freeness revealed totally preferable strength parameters, as compared to those produced from the NSSC pulp of hardwoods. Taking into account the most important strength characteristics of the fluting paper, (*i.e.* ring crush test), as well as the smaller importance of the other strength indexes, unmixed canola pulp with a freeness of either 350 or 400 mL CSF can be chosen as the most appropriate composition for making fluting paper. Since there was no significant difference, from the ring crush test point of view, between the pulps with the freeness of 350 and 400 mL CSF, and considering the objective of improving drainage characteristics and the speed of the papermaking machine for the production of fluting paper, the pulp with the freeness of 400 mL CSF was preferred.

CONCLUSION

1. Based on the findings of this study, the average cellulose and lignin contents were determined as 44.00 and 19.21%, respectively. The lignin content of canola was lower than that of other resources of nonwood papermaking fibers. It was also found that canola contains great amounts of ash.
2. Fiber dimensions of canola are within the normal range for both hardwoods and nonwoods. The morphology of the fibers and their indices are reasonably good for the purpose of paper manufacturing. The short and thin-walled fibers may be expected to give relatively dense papers, which will be weak in tearing strength, but superior in burst and tensile properties.
3. It can be inferred from the obtained results that canola is suitable for NSSC pulping. In this regard, the introduction of 20% chemical charge for a 30 min pulping time at 170 °C pulping temperature and 400 mL CSF is expected to give a pulp that may be used as an appropriate supplement pulp in the production of unbleached paper. The ring crush test value, stiffness, tensile index, tear index, burst index and breaking length of this pulp (66% total yield) were evaluated and found to be of 1.56 kN m^{-1}, 584.6 kN m^{-1}, 35.56 Nmg^{-1}, 6.19 mNm^{2}g^{-1}, 2.29 kPam^{2}g^{-1}, and 5.82 km, respectively.

4. The handsheet properties of the NSSC canola pulp, such as ring crush test, stiffness, tensile index, tear index, burst index, and breaking length, were reported to have much greater values than those of a hardwood NSSC pulp.
5. The overall results revealed that canola is a promising candidate material, in combination with hardwood NSSC pulps, for the purpose of papermaking.

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