TOBACCO RESIDUALS AS PROMISING LIGNOCELLULOSIC MATERIALS FOR PULP AND PAPER INDUSTRY

Jalal Shakhes,[a] Morteza A. B. Marandi,[a,]* Farhad Zeinaly,[a] Ahmadreza Saraian,[a] and Tayebe Saghafi [b]

Fiber dimensions, chemical composition, and soda and soda-AQ pulping of tobacco stalks were examined to assess if they were suitable for pulp and paper production. The results showed that the morphological characteristics of tobacco stalks were similar to those of nonwoods and hardwoods. The average values of length, diameter, and cell wall thickness of tobacco stalks fibers were determined as 1.23 mm, 24.31 μm, and 8.93 μm, respectively. The holocellulose and alpha-cellulose in tobacco stalks were lower than those of hardwoods and common nonwoods. In addition, lignin content of tobacco stalks was lower than that of hardwood. The holocelluloses, alpha-cellulose, lignin, and ash contents of tobacco stalks were examined to be 67.79, 39.20, 18.90, and 6.86 wt%, respectively. The optimum cooking conditions for a bleachable pulp of tobacco stalks were found to be as follows: active alkali 25%, temperature 165°C, cooking time 180 min, and 0.2% anthraquinone. Addition of anthraquinone resulted in lower screening rejects and lower kappa number, higher screen yield, and higher brightness. The bleaching of tobacco stalk pulp did not respond very well. The brightness of pulp made by tobacco stalks reached about 73.06% on DED and 78.2% on DEDD bleaching sequences.

Keywords: Tobacco stalks; Morphological characteristics; Chemical compositions; Soda and soda-AQ pulping; ECF bleaching

*Contact information: a: Department of Wood and Paper Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan 49138-15739, Iran; b: Department of Forestry Science and Technology, Faculty of Agricultural Sciences and Natural Resources, University of Tehran, P. O. Box 31585-3314 Karaj- Iran; * Corresponding author: mortezamarandi@gmail.com, A.marandi@ut.ac.ir*

INTRODUCTION

Population growth and economic development will undoubtedly increase the demand for various forest products, resulting in increased competition for raw materials in paper and pulp industries (Agrupis et al. 2000). The main raw materials for paper manufacturing are wood, non-wood, and recycled fibers. Non-wood and recycled fibers offer a great opportunity to replace wood fiber (Shakhes et al. 2010). Non-wood plants are critical fiber resources in regions with insufficient forest resources and continue to play an increasingly important role in these regions. There are wide varieties of non-wood plant fibers that are being used in the manufacture of pulp and paper all over the world. In most countries, the growth rate of paper consumption is fast (Agrupis et al. 2000). Therefore, the utilization of non-woods may help to solve the fiber shortage that is anticipated to arise in the future. In Iran, the main fibrous raw material resources available for papermaking are short-fibered hardwoods, recycled papers, and non-wood fibers, especially agricultural residues. At present, some agricultural wastes, such as rice and wheat straws and sorghum stalks, and some annual plants, such as sugar cane bagasse, jute, kenaf, flax, sisal, and hemp, are used as raw materials for pulp and paper production (Enayati et al. 2009; Schall 2009). In addition, numerous lignocellulosic fiber resources, such as olive tree pruning (Diaz et al. 2005), wheat straw (Deniz et al. 2004), tobacco stalk (Agrupis et al. 2000; Kajita et al. 2002), Canola stalk (Enayati et al. 2009), residue from palm oil production (Takana et al. 2004), or fast growing-high yield crops such as kenaf (Shakhes et al. 2010) and Miscanthus (Marin et al. 2009), have been proposed by several authors for pulp and paper industries.

Tobacco (*Nicotina tabacum L.*), a very plastic species, is grown in over 125 countries and on over 4 million hectares of land, a third of which is in China alone. China, Turkey, USA, India, Italy, Greece, Indonesia, and Brazil are the largest producers of tobacco in the world. Tobacco is an annual plant of 0.8 to 2.5 meters in height, depending on the species. It is culturally managed for high quality grade leaf for cigarette manufacturing purpose only (Agrupis et al. 1999). After all the leaves are harvested, the stalks are generally incorporated into soil or burned in the field (Akpinar et al. 2010). The total amount of biomass produced per unit area by tobacco depends on irrigation and varies from 2.0 to 2.5 DMt/ha (FAO 1995; Pahkala 2001). In Iran, 0.6 million tons of tobacco stalks are available annually, which could be used in various products, including pulp and paper, MDF, particle board, and ethanol production (Najafi et al. 2009).

The objective of the present work was to prepare a utilizable tobacco pulp by soda and soda-anthraquinone with ECF bleaching. The morphological properties, chemical composition, soda, and soda-anthraquinone pulping of tobacco stalk were investigated to evaluate the potential utilization of tobacco stalk fibers in pulp and paper production.

EXPERIMENTAL

Materials

In this study, tobacco stalks (150 days) from a tobacco plantation in Mazandran province, north of Iran, was obtained (Fig. 1-A). The raw material was in good shape and free from fungal attack or other degradation. Tobacco stalks were cleaned from leaves, roots, and soil. The air-dried stalks were 1.5 to 2.0 cm in diameter and about 150 to 180 cm in length with moisture content of 15%. Tobacco stalks were cut into chips with a length of 3.0 to 3.5 cm, as shown in Fig. 1-C. The pith content (Fig. 1-D) was gravimetrically calculated as dry pith over the initial dry stalks. The pith content was determined to be 15.46% of dry weight of tobacco stalks.

Morphological and Chemical Morphological Analysis of Tobacco

Initially, several depithed chips were randomly selected and were cut into about 10 mm pieces. For measurements of fiber length, fiber width, lumen width, and cell wall thickness, the material was macerated by Franklin’s method in acetic acid and hydrogen peroxide (1:1) at 60ºC for 48 hours. The macerated fiber suspension was finally placed on a slide (standard, 7.5 cm × 2.5 cm) by means of a medicine dropper (Han et al. 1999).

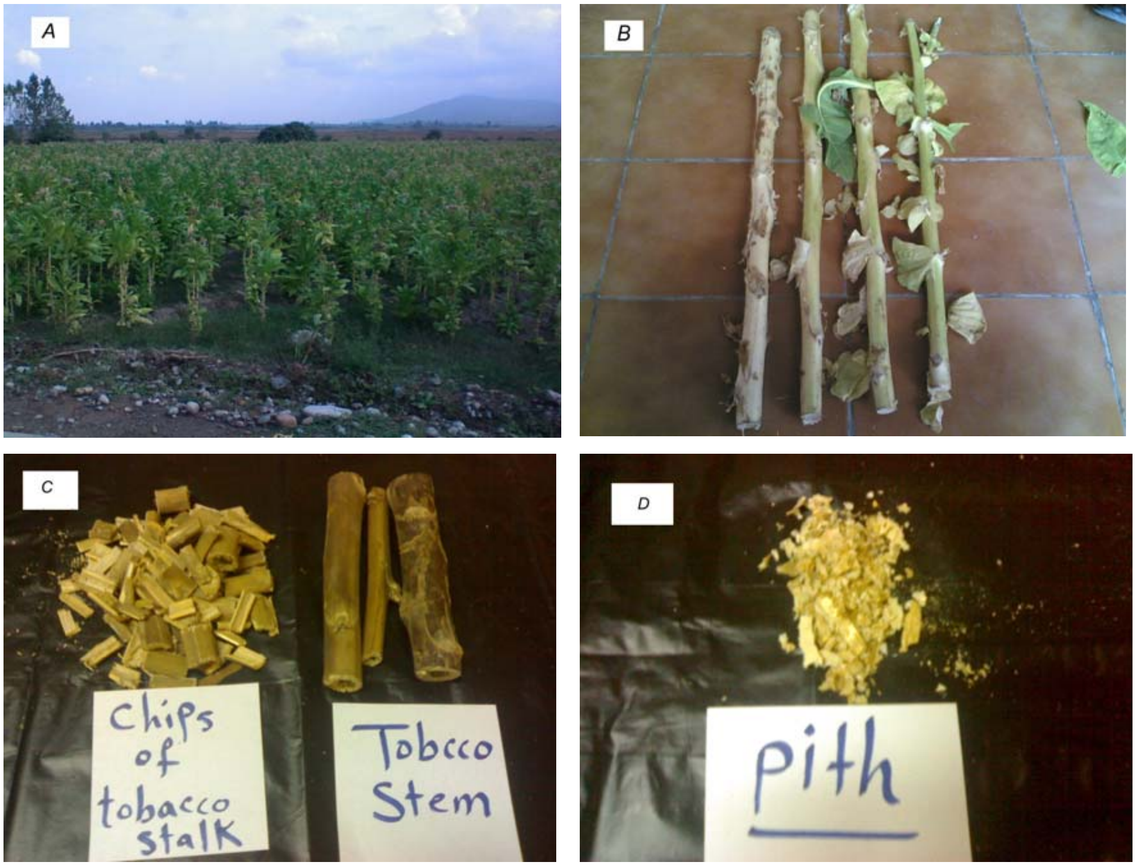

Fig. 1. (A): Tobacco plantation in Mazandran province, north of Iran; **(B):** Tobacco stalks after harvesting; **(C):** Air-dried chips and tobacco stem; **(D)** Pith of tobacco stalks

All fiber samples were viewed under a projection microscope for measuring of fiber length. The fiber diameter and lumen width were measured by a light microscopy with a magnification of 400X. The cell wall thickness was calculated as the difference of fiber diameter and lumen width, with the result divided in half. The 200 fibers were measured from 10 slides and an average reading was taken.

Three derived values were also evaluated using fiber dimensions: slenderness ratio, as fiber length divided by the diameter of fiber; flexibility ratio, as (lumen width of fiber/ diameter of fiber) × 100, and Runkel ratio, as (2 × wall thickness)/lumen width (Saikia et al. 1997). The derived values were then compared to those of non-woods and hardwoods to assay the acceptability of the plant raw materials for pulp and paper production (Ververis et al. 2004).

For chemical composition determination, 40-mesh fractions were selected. The procedures were performed according to TAPPI Method T264 om-88. The solubility of tobacco stalk in hot and cold water (T 207 om-93), one-percent caustic soda solubility (T 212 om-98), and alcohol-benzene solubility (T 204cm-97) were determined in accordance with TAPPI test methods. Alpha-cellulose, which is insoluble in 17.5% NaOH, was measured according to the procedure described in TAPPI Standard Method (T203 cm-99). The determination of lignin and ash content were performed by following the TAPPI Standard Methods T222 om-98, and T211 om-93, respectively. Holocelluloses content of the extractive-free sample was discovered according to the Wise method (Wise et al. 1946). Three replicates were done for each experiment.

Pulping Procedure

In general, soda and soda-AQ pulping are useful processes for production of non-wood pulp (Tutus et al. 2004). Pulping experiments with air-dried chips of tobacco stalks were conducted in a 2.5-L laboratory-scale batch cylindrical mini digester.

This mini digester includes an electrical heater, a motor actuator, and instruments required for measurement and control of temperature and pressure. The normal charge was 100 g air-dried chips of tobacco stalk.

Pulping conditions of soda and soda-anthraquinone to obtain bleachable grade pulps were as follows:

- Alkali charge (% NaOH) was 20% and 25% based on dry raw material. Cooking time was 30, 60, 90, 120, 150, and 180 min at maximum temperature (165 ^{o}C).
- Time to maximum cooking temperature (165 ^{o}C) was 90 min from room temperature.
- Liquor to tobacco stalk ratio was 7.
- AQ charge was 0.2% on air-dried raw material in soda-AQ process.

At the end of the cooking process, after turning off the heating system mini, the digester was discharged under ambient conditions. The pulp was washed with tap water, and a mechanical standard disintegrator (TAPPI T205 sp-95) disintegrated the pulp. Then the cooked pulp was screened with a screen plate with slots of 0.15 mm (TAPPI T275 sp-98).

The yield contents of the pulps and rejects were determined by gravimetric measurements in the laboratory environment. The screened yield was determined from duplicate analyses. Adding the yield of rejects to the screened yield gave total pulp yield. The kappa number (T236 om-99) of pulp samples was also determined by duplicate experiments.

Pulp Bleaching and Testing of Papermaking Properties

At present, the ECF bleaching processes are known as well-established technologies for bleaching of chemical pulps. For bleaching the soda-AQ pulp prepared from the tobacco stalks, we applied two simple D_0ED_1 and $D_0ED_1D_2$ sequences (where D is chlorine dioxide and E is alkaline extraction). Bleaching stages were carried out in polyethylene bags in a water bath. The bleaching conditions and chemical charges for each stage are presented in Table 1.

After each stage, the pulp was washed thoroughly with distilled water. Standard, 1.2-gram (60 g/m^2) handsheets for physical testing and optical testing were prepared according to TAPPI test method T205-om88 and TAPPI test method T272 om-92, respectively. The brightness of standard handsheets was measured using a Technibrite TB-1C (Technidyne Corp., New Albany, Ind., USA). The tear, tensile, and burst strength of standard handsheets were measured according T414 om-04, T404 om-92, and T 403 om-02 TAPPI test methods, respectively.

Table 1. Pulp Bleaching Conditions

Conditions	Bleaching stage			
	D_0	E	D_1	D_2
ClO_2 (% on dry pulp)	3.04	-	0.76	0.38
NaOH (% on dry pulp)	-	1.5	-	-
Consistency %	10	10	10	10
Time, min	90	60	150	150
Temperature, ºC	70	70	70	70
Final pH	2.5-2.8	11	3.5	4.0

RESULTS AND DISCUSSION

Morphological and Chemical Characterization

The fiber dimensions characteristics of tobacco stalks and their comparison with other fibrous materials are summarized in Table 2.

Table 2. The Mean Value of Tobacco Stalk Fiber Dimensions Comparison with Common Papermaking Fibers

Fiber properties	Tobacco stalk	Canola stalk (a)	Corn stalk (b)	Bambo (c)	Reed (d)	Musa paradisiaca stalk (e)	Rice straw (f)	Paulownia (g)
Length (mm)	1.23	1.17	1.32	2.3	1.39	2.9	0.89	0.82
Diameter (µm)	24.31	23.02	24.3	15.1	13.5	37.5	14.80	36.3
Lumen width (µm)	15.38	12.50	10.7	6.9	7	20.6	6.40	19.2
Cell wall thickness (µm)	8.93	5.26	6.8	4.17	3.2	8.5	6.36	8.6

a:(Enayati et al. 2009), b: (Usta et al. 1990), c:(Deniz and Ates 2002), d:(Kirci et al. 1998), e:(Ogunsile et al. 2006), f: (Tutus et al. 2004), g: (Ates et al. 2008)

The average fiber length of tobacco stalks was 1.23 mm, which was shorter than some nonwood fibers such as bamboo, corn stalks, musa paradisiaca stalks, and reed, and close to maximum value of hardwood fibers (0.7 to 1.6mm). However, fiber length of tobacco stalks was longer than canola stalks, rice straw, and paulownia fibers. Fiber length and strength has been shown to be particularly important for tearing resistance (Wangaard and Williams 1970). On the other hand, longer fibers tended to give a more open and less uniform sheet structure. The results for fiber diameter, lumen width, and cell wall thickness of tobacco stalks were 24.31, 15.38, and 8.93 µm, respectively. The fiber diameter of tobacco stalks was in normal range when compared to hardwood fiber (20.2 to 40.0 mm) (Atchison 1987). The mean fiber diameter of tobacco stalks was almost the same with canola and corn stalk fibers, which was lower than *Musa paradisiaca* stalks and paulowina fibers. The thickness of the fiber wall had an important bearing on most paper properties. Paper manufactured with thick-walled fibers would be bulky with lower tensile, burst, and folding endurance but with a high tearing strength (Haygreen and Bowyer 1996). The mean lumen width of tobacco stalks fibers was 15.38 µm, which was higher than bambo, reed, corn stalks, rice straw, and canola stalks fibers.

Fiber lumen width affected the beating of pulp. The larger the fiber lumen width, the better would be the beating of pulp because of the penetration of liquids into empty spaces of fibers. The derived values (indices) of tobacco stalks fibers are shown in Table 3.

Table 3. Derived Values (indices) for Tobacco Stalk Fibers Comparison with Common Papermaking Fibers

Ratios	Tobacco stalk	Canola stalk	Corn stalk	Bambo	Reed	Musa paradisiaca stalk	Rice straw	Paulownia
Runkel ratio, 2e/l	1.16	0.84	1.27	1.20	0.91	0.82	1.98	0.89
Slenderness ratio, L/d	50.59	50.83	54.32	152.3	102.96	77.33	60.13	22.58
Flexibility ratio, l/d	63.26	54.30	44.03	46.35	51.85	54.93	43.24	53.08
Note: e- cell wall thickness, l- lumen diameter, L- fiber length, d- fiber diameter.								

The strength properties of papers were positively correlated with the slenderness ratio (fiber length/fiber diameter). The slenderness ratio of tobacco stalks fibers was 50.59 and is similar to canola stalks fibers, and lower than corn stalks, bambo, reed, *Musa paradisiaca* stalks, and rice straw fibers. It was stated that if slenderness ratio of a fibrous material was lower than 70, it was not valuable for quality pulp and paper production (Yang 1981). The shorter and thicker fibers produced a poor slenderness ratio, which in turn reduced tearing resistance dramatically. The determined Runkel ratio for tobacco stalks fibers (1.16) was higher than canola stalks, reed, *Musa paradisiaca* stalks, and paulownia fibers. Higher Runkel ratio fibers were stiffer, less flexible, and form bulkier paper of lower bonded areas in comparison with lower Runkel ratio fiber (Ververis et al., 2004).

The proximate chemical analysis of tobacco stalks and its comparison with other fibrous materials is presented in Table 4 in order to assay its acceptability for pulp and papermaking.

Table 4. Chemical Composition of Tobacco Stalk with Different Papermaking Raw Material

Component	Tobacco Stalk	Canola Stalk	Corn stalk	Cotton stalk	Reed	Rice straw	Paulownia
Holocellulose (%)	67.79	73.6	64.80	72.20	77.90	70.85	75.74
Alpha-cellulose (%)	39.20	42.00	35.60	41.60	47.50	35.62	43.61
Lignin (%)	18.90	17.30	17.40	19.30	18.70	17.2	20.5
Ash content (%)	6.86	8.2	7.50	2.4	3.90	16.6	0.21
Extractive :							
Alcohol benzene (%)	7.10	2.50 [(a)]	9.50	6.10	4.00	3.52	3.76
1% NaOH (%)	42.00	46.10	47.10	42.90	28.30	49.15	24.50
Cold water (%)	16.85	n/a	n/a	16.70	3.30	16.24	8.50
Hot water (%)	20.02	18	14.8	17.80	3.80	10.65	10.05
n/a: not available, (a):Acetone extractives							

The holocellulose content of tobacco stalks was found to be 67.79%, which was lower than that of reed, rice straw, paulownia, canola, and corn stalks. Holocellulose defined the total content of carbohydrate materials. High holocellulose content, therefore, is considered desirable for the pulp and paper industry because it has been correlated with higher pulp yield (Mabilangan and Estiudillo 1996). As shown in Table 3, the amount of α-cellulose, namely the fraction insoluble in 17.5% NaOH, was determined to be 39.20%, which was lower than that of canola stalks, cotton stalks, reed, and paulownia, but higher than that of corn stalks and rice straw. According to the rating system designated by Nieschlag et al. (1960), plant materials with 34% and higher α-cellulose content were characterized as promising for pulp and paper manufacture from a chemical composition point of view. For chemical pulping, the pulp yield had generally been found to be positively correlated with holocellulose and α-cellulose contents (Amidon 1981). Paper strength properties depended on the cellulose content of raw materials.

The lignin contents were also at satisfactory levels (<30%) for tobacco stalks. Lignin content of tobacco stalks was found to be 18.90%, which was slightly higher than that of reed, rice straw, canola, and corn stalks, but lower than that of cotton stalks and paulownia. The lignin content of tobacco stalks was lower than that of wood fiber (14-37%) (Tsoumis 1997). Lignin is considered to be an undesirable polymer, and the removal during pulping and bleaching required high amounts of energy and chemicals.

The mineral component of lignocellulosic material was generally indicated as ash content. The ash content mostly included different metal salts such as carbonates, silicates, oxalates and potassium phosphates, magnesium, calcium, iron and manganese, as well as silicon. The ash content of tobacco stalks was found to be 6.86%. Like most of the nonwood fibers, ash content of tobacco stalks was markedly higher than that of the wood species but still lower than rice straw 16.6 (Tutus et al. 2004). The ash content was undesirable during refining and recovery of cooking liquor (Rodra-Gueza et al. 2008), and as trace elements interfere with H_2O_2 and O_2 bleaching and alkali earth metals passed in the pulp (Dutt et al. 2009).

The average alcohol-benzene solubility, 1% NaOH solubility, hot water solubility, and cold water solubility of tobacco stalks were 7.1%, 42%, 20.02%, and 16.85%, respectively.

The solubility in different solvents indicated the extractive contents, which were not cell wall components. Alcohol-benzene extractives of the wood consisted of waxes, fats, resins, photosterols, non-volatile hydrocarbons, low-molecular-weight carbohyd-rates, salts, and other water soluble substances. The alcohol-benzene of tobacco stalks solubility was lower than corn stalk, but higher than that of reed, paulownia, canola, and cotton stalks. The water solubility estimates a part of extraneous components, such as inorganic compounds, tannins, gums, sugars, and coloring matter present in the wood and hot water estimates, in addition, starches (Dutt et al. 2009). As shown in Table 3, tobacco stalks contain significantly higher content of soluble compounds in hot and cold water and dilute alkali. The hot and cold water solubility of tobacco stalks was higher than the other fibrous materials presented in Table 4. Generally, the presence of extractives in woody materials increased the pulping effluent load and consumption of pulp reagents and reduced the pulp yield (Azizi et al. 2010).

Pulp Characterization

The two principal alkaline processes used for the pulping of lignocellulosic materials are the soda and sulfate (kraft) processes. In both, sodium hydroxide is the principal cooking chemical; in the sulfate process sodium sulfide is also involved. Several digester additives had been tried to enhance the effectiveness of soda and kraft pulping processes. Polysulfides, anthraquinone, and amines are three common additives used in chemical pulping. Anthraquinone (AQ) and its derivates have been investigated as pulping additives since 1970. With the presence of anthraquinone (AQ) as a chemical additive in the chemical pulping process, the delignification rate and the preserved pulp yield could be improved (Chai et al. 2007), and the dose of sulfide applied in kraft pulping could be reduced without sacrificing pulping performance (Allen et al. 1981).

As a redox catalyst, anthraquinone stabilized the carbohydrates by the oxidation of the reducing groups and accelerated delignification by reducing lignin or some solubilized lignin fragments (Blain 1993). Table 5 showed the pulp properties of total yield, screen yield, rejects, kappa number, and brightness values for soda and soda-AQ pulps.

In the soda process, pulp yield, kappa number, and rejects values were decreased with increasing alkali concentration and cooking time. The screened pulp yield for soda pulping at 90 min of cooking dropped from 37.32% to 31.8%, whereas kappa number dropped from 85.6 to 67.3, when alkali concentration increased from 20% to 25%. The highest kappa number in soda pulping was attained at 20% active alkali after 40.6 screen pulp and 30 min of cooking. The lowest kappa number for the soda process was obtained at 25% active alkali after 33.17% screen yield and 180 min of cooking. This finding could be explained by high water and alkali solubility of tobacco stalk (Table 4).

Rejects were the fraction of pulp retained on a screen, which could be a good indicator of the uniformity of the raw material or the efficiency of chemical treatment (Wanrosli et al. 2004). Table 4 showed the reject values of tobacco stalk pulps. The results indicated that the cooking 1 yielded the highest reject content (14.3%). By increasing active alkali and cooking time, reject content decreased due to better delignification and separation of fiber bundles. In 180 min, if alkali charge was increased to 25% from 20%, the screened reject decreased from 6.9% to 4.69%.

Significant improvements on pulp yield, kappa number, and brightness were obtained when 0.2% AQ was added to soda pulping. The effect of adding AQ into soda pulping (cooking 1 to 6) showed that the addition of 0.2% AQ (based on o.d. fiber) led to a screen yield increase of 3.34, 5.33, 4.44, 5.54, 4.5, and 4.32 points and led to kappa number decrease of 45.7, 44.7, 45.2, 41.5, 32.34, and 29 points, respectively. In the soda-AQ process, when the alkali concentration increased from 20% to 25% in constant time of cooking (30 min), the screened pulp yield was reduced from 43.94% to 41.4%. With an increase of cooking time from 30 to 180 min for 25% alkali charge, kappa number and screened pulp yield decrease from 41.75 to 20.5 and 41.4 to 37.06, respectively. Due to faster delignification and stabilization of the carbohydrate fraction, a dramatic decrease in kappa number and an increase in pulp yield occurred when AQ was used as a pulping additive. The reduction of pulp kappa number also led to reduced consumption of bleach water, which in turn led to decreasing the effluent load.

Table 5. Data on Pulp Characteristics

Cooking no.	NaOH charge (%)	Max. Temp. (ºC)	Time to Max. Temp (min)	Cook in time Temp. (min)	AQ (%)	Kappa number	Total Yield (%)	Screen Yield (%)	Rejects (%)	% ISO Brightness
1	20	165	90	30	-	96.3	54.91	40.6	14.3	-
2	20	165	90	60	-	91.2	51.7	37.9	13.8	-
3	20	165	90	90	-	85.6	48.92	37.32	11.6	-
4	20	165	90	120	-	80	46.43	37.2	9.23	-
5	20	165	90	150	-	67	44.82	37.12	7.7	-
6	20	165	90	180	-	61	43.65	36.75	6.9	-
7	20	165	90	30	0.2	50.6	54.98	43.94	11.04	-
8	20	165	90	60	0.2	46.5	52.65	43.23	9.42	-
9	20	165	90	90	0.2	40.4	49.4	41.76	7.64	-
10	20	165	90	120	0.2	38.5	48.45	42.74	5.71	-
11	20	165	90	150	0.2	34.66	46.5	41.62	4.88	-
12	20	165	90	180	0.2	32.00	44.8	41.07	3.73	-
13	25	165	90	30	-	78.1	42.6	31.34	11.26	17.3
14	25	165	90	60	-	72.5	41.9	31.73	10.17	17.0
15	25	165	90	90	-	67.3	40.05	31.8	8.25	17.6
16	25	165	90	120	-	60.5	39	32.7	6.3	18.4
17	25	165	90	150	-	51.3	38.26	32.92	5.34	20.1
18	25	165	90	180	-	48.6	37.86	33.17	4.69	21.0
19	25	165	90	30	0.2	41.75	43.91	41.4	2.51	21.6
20	25	165	90	60	0.2	37.0	42.8	40.63	2.17	22.3
21	25	165	90	90	0.2	34.2	40.93	39.51	1.42	22
22	25	165	90	120	0.2	27.0	39.81	39.31	0.5	23.6
23	25	165	90	150	0.2	24.4	38.54	38.24	0.3	26.2
24	25	165	90	180	0.2	20.05	37.06	37.06	0	30.2

Despite use of different pulps with kappa numbers ranging from 50.6 to 32, cooking of tobacco stalk chips using alkali charge of 20% and 0.2% AQ did not provide bleachable grade pulps. Bleachable grade pulps only were produced using 25% alkali charge and 0.2% AQ charge for a 180 minute cooking time. The Elrepho brightness of unbleached hand sheets of soda and soda-AQ pulps (25% alkali charge) was measured (Table 4). The handsheets from soda-AQ pulps gave 4.3, 5.3, 4.4, 5.2, 6.1, and 9.2 points higher brightness compared to soda pulp, respectively. The increase in pulp brightness with adding AQ could be explained by the lower lignin content of soda-AQ pulps.

With respect to pulping results, it could be concluded that soda and soda-AQ pulping of tobacco stalks provided mainly average-yield pulp. This was mostly because of significant presence of soluble components of tobacco stalks in water and diluted alkali. Compared to soda-AQ pulp from cotton stalks (Ali et al. 2001) and holm oak trimmings (Alaejos et al. 2006), soda-AQ pulping of tobacco stalks produced higher and lower yield pulp, respectively, at a similar kappa number.

Bleaching Properties of Tobacco Stalk Pulp

The focus on decreasing absorbable organic halides (AOX) and total organic chlorides (TOCL) in bleach effluents led to the development of the elemental chlorine-free (ECF) and the totally chlorine-free (TCF) bleaching processes (Chirat and Lachenal, 1997). ECF pulp bleached with chlorine dioxide accounts for roughly two-thirds of the bleached pulp produced world-wide. TCF pulp only accounts for about 6%, most of which is produced in mills in Northern and Central Europe. Roughly 25% of the pulp produced world-wide is still bleached with elemental chlorine.

With respect to kappa number and screen yield, the attained pulp using 25% active alkali, 0.2% AQ, and 180 min cooking at maximum temperature was chosen for bleaching and handsheet strength investigation. The initial kappa number, screen yield, and initial brightness for ECF bleaching were 20, 37.07%, and 30.2%, respectively. The bleachability of tobacco stalk pulp was assessed by simple D_0ED_1 and $D_0ED_1D_2$ sequences (where D is chlorine dioxide and E is alkali extraction). Table 6 summarizes the mechanical and optical properties of tobacco bleached pulp.

Table 6. Properties of Bleached Pulp

Conditions	Bleaching stage	
	D_0ED_1	$D_0ED_1D_2$
Freeness, SR°	30	30
PFI, rev.	6000	5500
Brightness, %	73.06	78.2
Opacity, %	81	80
Yellowness, %	13.5	11
Kappa number	3.5	2.3
Tear index, mN.m^2/g	8.62	8.14
Burst index, mPa.m^2/g	4.36	3.98
Breaking length, m	7425	7552

It can be seen that tobacco pulp can be bleached to 73.06% brightness by elemental chlorine-free (ECF) bleaching sequence (D_0ED_1). However, the brightness would be improved to 78.2% by a $D_0ED_1D_2$ bleaching sequence. The opacity was increased with both bleaching sequences, but there were no significant differences between bleaching sequences. In addition, the results indicated that with increasing the chlorine dioxide charge, a clear decrease in Kappa number and yellowness occurred. The total chlorine dioxide charge used in the D_0ED_1 and $D_0ED_1D_2$ bleaching sequences were 38 and 41.8 kg/ton of dry pulp, respectively.

The papermaking properties of bleached tobacco stalk pulp after beating to about SR° 30 are also given in Table 5. Tobacco pulp after ECF bleaching showed excellent properties, especially breaking length and tear index. The reported results pertaining to bleaching properties of tobacco stalks by Kajita et al. (2002) were similar to results of this investigation. The burst index and breaking length of soda-AQ pulp from tobacco stalks was comparable to that of tobacco stalks bleached kraft pulp.

CONCLUSIONS

The agricultural wastes from the harvesting of tobacco farms are useful substitutes for traditional wood raw materials in the pulp and paper industry. The results of the fiber dimensions and derived values investigate showed that tobacco stalks included short fibers with morphological properties similar to those of the common nonwood and hardwood fibers, except that the cell wall thickness of tobacco stalks fibers was much thicker. The holocellulose and alpha cellulose in tobacco stalks were lower than those of hardwood and common nonwood. In addition, lignin content of tobacco stalks analysis showed that it's was lower than that of hardwood. Tobacco stalks have substantially higher alcohol benzene, cold water, hot water, and alkali solubility, as well as ash contents than those of hardwoods. Due to high ash and extractive contents of tobacco, a higher requirement for cooking chemicals and lower pulp yield was obtained. The soda pulping results showed that tobacco stalks required high alkali charge and cooking time. Therefore, higher screen pulp, lower kappa number, superior brightness, and bleachable pulp were obtained when AQ was added in soda pulping. The soda-AQ pulp was bleached by three and four stage ECF bleaching. The bleached pulp showed relatively good brightness and superior mechanical properties.

REFERENCES CITED

Agrupis, S., Maekawa, E., and Suzuki, K. (2000). "Industrial utilization of tobacco stalks II: Preparation and characterization of tobacco pulp by steam explosion pulping," *J. Wood. Sci.* 46, 222-229.

Agrupis, S., and Maekawa, E. (1998). "Industrial utilization of tobacco stalks. I. Preliminary evaluation for biomass resources," *Holzforschung*. 53, 29-31.

Akgül, M., and Tozluoglu, A. (2009). "A comparison of soda and soda-AQ pulps from cotton stalks," *African J. Biotechnol.* 8(22), 6127-6133.

Alaejos, J., Lopez, F., Eugenio, M. E., and Tapias, R. (2006). "Soda-anthraquinone, kraft and organosolve pulping of holm oak trimmings," *Biores. Technol.* 97, 2110-2116.

Ali, M., Byrd, M., and Jameel, H. (2001). "Soda-AQ pulping of cotton stalks," TAPPI Fall Technical Conference.

Allen, V. N., Hatton, J. V., and Gee, W. Y. (1981). "Effect of sulfidity in alkaline pulping of white spruce with anthraqunione," *TAPPI J.* 64(6), 64.

Amidon, T. (1981). "Effect of the wood properties of hardwoods on Kraft paper properties," *TAPPI J.* 64, 123-126.

Ates, S., Ni, Y., Akgul, M., and Tozluglu., A. (2008). "Characterization and evaluation of Paulownia elongota as a raw material for paper production," *Afr. J. Biotechnol.* 7(22), 4153-4158.

Ates, S., Atik, C., Ni, Y., and Gumuskaya, E. (2008). "Comparison of different chemical pulps from wheat straw and bleaching with xylanase pre-treated ECF method," *Turk. J. Agric. For.* 32, 561-570.

Azizi, M. A., Harun, J., Fallah, Sh. S. R., Resalati, H., Tahir, Md. P., Ibrahim, R., and Zuriyzti, M. A. (2010). "A review of literature related to kenaf as alternative for pulpwoods," *Agric. J.* 5(3), 131-138.

Blain, T. J. (1993). "Anthraqunione pulping, fifteen years later," *Tappi J.* 76, 137-146.

Chai, X. S., Samp, J., Hou, Q. X., Yoon, S.-H., and Zhu, J. Y. (2007). "Possible mechanism for anthraquinone species diffusion in alkaline pulping," *Ind. Eng. Chem. Res.* 46, 5245-5249.

Chirat, C., and Lachenal, D. (1997). "Pulp producers race to keep up with technology," In: Patrick, K.L. (Ed.), *Advances in Bleaching Technology*, Miller Freeman Books, CA, p. 20.

Deniz, I., Kirci, H., and Ates, S. (2004). "Optimization of wheat straw triticum drum kraft pulping," *Industrial Crops and Products* 19, 237-247.

Deniz, I., and Ates, S. (2002). "Determination of optimum kraft pulping conditions using bamboo (*Pyllotachys bambusoides*)," 2nd. National Black Sea Forestry Congress Proceedings, Artvin, Turkey, 1072-1084.

Dutt, D., Upadhyay, J. S., Singh, B., and Tyagi, C. H. (2009). "Studies on *Hibiscus cannabinus* and *Hibiscus sabdariffa* as an alternative pulp blend for softwood: An optimization of Kraft delignification process," *Industrial Crops and Products* 29, 16-26.

Enayati, A. A., Hamzeh, Y., Mirshokraie, S. M., and Molaii, M. (2009). "Paper making potential of canola stalk," *BioResources* 4(1), 245-256.

Han, J. S., Mianowski, T., and Lin, Y.-Y. (1999). "Validity of plant fiber length measurement - A review of fiber length measurement based on kenaf as a model," In: Sellers, T., and Reichert, N. A. (eds.), *Kenaf Properties, Processing and Products*, Mississippi State University, 149-167.

Haygreen, J. G., and Bowyer, J. (1996). *Forest Products and Wood Science: An Introduction,* Third edition, Iowa University Press, Ames.

Kajita, S., Ishifuji, M., Ougiya, H., and Hara, S. (2002). "Improvement in pulping and bleaching properties of xylem from transgenic tobacco plants," *J. Sci. Food Agric.* 82, 1216-1223.

Kamathai, S. (2007). "Preliminary study of anthraquinone in sweet bamboo (*Dendrocalamus asper* Backer) alkaline sulfite pulping," *Chiang Mai J. Sci.* 34(2), 235-247.

Kirci, H., Usta, M., and Eroglu, H. (1998). "Soda-air pulping of *Phragmites reed*," The 5th Meeting of Pulp and Paper Industry of Balkan Countries, October 7-9, Constanta, Mamaia, Romania.

Najafi, G., Golbadian, B., Tavakoli, T., and Yuasf., T. (2009). "Potential of bioethanol production from agricultural wastes in Iran," *Renewable and Sustainable Energy Reviews* 13, 1418-1427.

Nieschlag, H. J., Nelson, G. H., Wolf, J. A., and Pedro, R. E. (1960). "A search for new fiber crops," *TAPPI J.* 43(3), 193-194.

Ogunsile, B. O., Omotoso, M. A, and Onilude, M. A. (2006). "Comparative soda pulps from the mid-rib, pseudostem and stalk of *Musa paradisiaca*," *J. Biol. Sci.* 6(6), 1047-1052.

Saijonkari-Pahkala, K. (2001). “Nonwood plants as raw material for pulp and paper,” Dissertation, MTT, Agrifood Research, Finland.

Saikia, S. N., Goswami, T., and Ali, F. (1997). “Evaluation of pulp and paper making characteristics of certain fast growing plants,” *Wood Sci. Technol.* 31, 467-475.

Schall, N., Kruger, E., Blum, R., and Rubenacker, M. (2009). "Soda-AQ pulping of wheat straw and its blending effect on old corrugate cardboard (OCC) pulp properties,” *Tappsa J.* 35-39.

Shakhes, J., Rezayati-Charani, P., and Zeinaly, F. (2010). “Evaluation of harvesting time effects and cultivars of kenaf on papermaking,” *BioResources* 5(2), 1268-1280.

Shatalov, A. A, and Pereira, H. (2006). “Papermaking fibers from giant reed (*Arundo Donax* L.) by advanced ecologically friendly pulping and bleaching technologies,” *BioResources*1(1), 45-61.

Shatalov, A. A, and Pereira, H. (2001). “*Arundo donax* L. reed: New perspectives for pulping and bleaching -1. Raw material characterization,” *TAPPI J.* 84(1),1-10.

Tsoumis, G. (1991). *Science and technology of wood: Structure, Properties and Utilization*, Van Nostrand Reinhold, New York.

Tutus, A., Deniz, I., and Eroglu, H. (2004). “Rice straw pulping with oxide added soda-oxygen-anthraquinone,” *Pakistan J. Biol. Sci.* 7(8), 1350-1354.

Usta, M., Kırcı, H., and Eroglu, H. (1990). “Soda-oxygen pulping of corn (*Zeamays indurata* Sturt),” In: Tappi Pulping Conference, Toronto, Ontario, Canada, Proceeding Book 1, 307-312.

Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P., and Santas, R. (2004). “Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production,” *Industrial Crops and Products* 19, 245-254.

Wangaard, F. F., and Williams, D. L. (1970). “Fiber length and fiber strength in relation to tearing resistance of hardwood pulp,” *TAPPI J.* 53(11), 2153.

Article submitted: June 3, 2011; Peer review completed: August 30, 2011; Revised version received: Sept. 11, 2011; Published: Sept. 14, 2011.