World Applied Sciences Journal 27 (1): 01-09, 2013
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2013.27.01.13600

Effect of Cooking Time, Active Alkali Concentration and Refining Process on the Pulping and Papermaking Properties of Buttonwood Residues (*Conocarpus erectus* L.)

[1,2]*M.A. Abdel-Aal*

[1]Department of Plant Production, Food and Agricultural Sciences Collage, King Saud University, Saudi Arabia.
[2]Department of Wood Technology and Forestry, Horticulture Research Institute, Agricultural Research Centre, Egypt

Abstract: The physical, chemical and morphological characteristics of *Conocarpus erectus* residues were evaluated to determine its suitability for papermaking. The effects of active alkali, cooking time and the refining process were studied. Active alkali was added in the form of white liquor containing concentrations of 17, 20 and 23% NaOH based on w/w oven dry raw materials. The cooking times at the maximum temperature were 60, 90 and 120 min. The chips were cooked at 170°C with a liquor-to-wood ratio (L/W) of 5.0. The concentration of anthraquinone was 0.1% w/w with respect to oven-dried material. Handsheets were formed using three levels of refining. Ten handsheets of each treatment were made and the five best handsheets were selected and tested. The results indicated that buttonwood residues should be considered suitable for pulp and paper production because they have the appropriate values of cellulose (42%) and hemicelluloses (23%) for such use. The fiber length of *C. erectus* was in the range of 0.55 mm to 1.07 mm, with an average length of 0.7 mm, this length is considered short fiber. The fiber diameter of buttonwood was in the range of 7µm to 16 µm, with an average diameter of 13 µm. The fiber wall thickness values were between 0.8 µm and 1.9 µm and the slenderness ratios were between 36 and 123, this ratio is considered suitable for pulp and paper production. With regard to the pulping process, the results illustrate that increasing the alkali concentration from 17 to 23% and the cooking time from 60 to 120 min resulted in a decrease in the kappa number, total pulp yield, reject pulp yield and lignin content, as well as an increase in screened pulp yield and ash content. The increase in cooking time from 60 to 120 min resulted in an increase in the tensile index from 54.35 to 77.45 N*m/g, the elongation from 1.08 to 1.27% and the tensile energy absorption from 26.22 to 27.56 J/m^2, the breaking length from 5.54 to 7.90 km and the tear index from 4.01 to 5.01 mN*m^2/g. The average values of tensile index, elongation, tensile energy absorption, breaking length and tear index at 23% active alkali gave the highest value for all properties under study, followed by 20%, while the lowest average was found at 17% active alkali. The refining process caused an increase in all handsheet property values compared to unbeaten pulp and the increase in the degree of refining caused an increase in the property values of the handsheets.

Key words: Cooking time · Fiber · Kappa number · Pulping · Papermaking

INTRODUCTION

In many countries, wood is not available in sufficient quantities to meet the rising demand for pulp and paper [1, 2]. In recent years, active research has been undertaken in Europe and North America to find a new, non-wood raw material for paper production. The driving forces in the search for new pulp sources are twofold: a shortage of short-fiber raw material (hardwood) in Nordic countries, which export pulp and paper and a parallel

Corresponding Author: M.A. Abdel-Aal, Department of Plant Production, Food and Agricultural Sciences Collage, King Saud University, Saudi Arabia.

overproduction of agricultural crops. At the same time, the consumption of paper, especially fine paper, continues to grow, increasing the demand for short fiber pulp [3]. Commercial non-wood pulp production has been estimated to be 6.5% of the global pulp production and is expected to increase [4]. China produces 77% of the world's non-wood pulp [3, 4]. In China and India, over 70% of the raw material used by the pulp industry comes from non-woody plants. The main sources of non-wood raw materials are agricultural residues from monocotyledons, including cereal straw and bagasse, a fibrous residue from processed sugar cane (*Saccharum officinarum* L.). Bamboo, reeds and some grass plants are also grown or collected for the pulp industry [3]. Paper consumption is continuously increasing in the world, even in countries where wood resources are very limited, such as Saudi Arabia. The total consumption of pulp and paper products in Saudi Arabia was approximately 700,000 m^3 in 2006, at a cost of 450 million dollars and increased to approximately 1.5 million m^3 in 2008, at a cost of 1.3 billion dollars [5]. The money spent for importing pulp and paper is a great burden on the budget of the kingdom. The regular practice of seasonal pruning to maintain their forms yields huge quantities of *Conocarpus erectus* L. biomass annually. No data are currently available in this field on the amount of Conocarpus tree residues, but it is known that large amounts of residues are created annually in Saudi Arabia. Pulping is performed to reduce wood or other fibrous material into a fibrous mass through chemical reactions. During pulping, lignin, cellulose and hemicelluloses are attacked and degraded by chemicals. The different degrees of cellulose chain decrease and molecular weight loss have different influences on the pulp properties. An increased pulp yield at constant lignin content implies an increased amount of hemicelluloses because the cellulose yield can only be varied to a small extent. The goal of pulping is to achieve both high yields and optimal strength properties. Many factors have an effect on pulp and papermaking, such as the chemical composition of raw materials (cellulose, hemicellulose, lignin and extractives), wood anatomy, active alkali and cooking times.

The objective of this study was to investigate the effects of active alkali concentrations and cooking times on the properties of pulp and paper produced from buttonwood (*Conocarpus erectus* L.). The study also focused on the characteristics of paper strength properties obtained from the soda-anthraquinone method at three levels of refining.

MATERIALS AND METHODS

Raw Materials: Tree prunings of *Conocarpus erectus* were collected from different locations in the Kingdom of Saudi Arabia for use as raw material for pulp and paper production. The materials were chipped and screened into two sizes: particles passed through a 12-mm sieve and retained on a 4-mm sieve ("-12/+4") used for the pulping process and particles passed through a 0.4-mm sieve and retained on a 0.27-mm sieve ("-0.4/+0.27") used for wood chemical analysis.

Moisture Test: The moisture content of pruning chips is affected by the air humidity and room temperature during storage. The raw materials used for cooking were based on oven-dried chips, so the moisture content of the chips was determined before cooking using the conventional oven-dried method outlined in ASTM D-2016 [6].

Chemical Analysis: Air-dried lignocellulosic particles were extracted in a Soxhlet extractor apparatus using the standard method according to ASTM D 1105-56 [7] to determine the total content of wood extractives based on the oven-dried weight of the samples. Then, extractive-free meal samples were used to determine the contents of cellulose, hemicelluloses and lignin according to the methods described by Nikitin [8], Rozmarin and Simionescu [9] and ASTM D 1106-84 [10], respectively. In addition, the ash content of wood was determined according to the method outlined by NREL [11].

White Liquor Preparation: To prepare the chemical solution (white liquor), the amounts of sodium hydroxide (NaOH) and water required for the desired cooking were calculated. Then, the solution was stirred in a beaker to aid dissolution. The white liquor was then stored in a cold room for later use.

Cooking Conditions: The pulping of raw materials was carried out according to the procedure described by Khristova *et al*. [12]. Certain processing conditions were selected, including the active alkali (AA) and the time of cooking at maximum temperature (T). AA is defined as the hydroxide concentration and the concentrations used were 17, 20 and 23%, expressed in NaOH based on the w/w oven dry raw materials. The cooking times at maximum temperature were 60, 90 and 120 min. The concentration of anthraquinone was 0.1% w/w with respect to the oven-dried material. Two kilograms of buttonwood chips (oven-dried) were utilized in each batch. Chips were cooked at 170°C and had a liquor-to-wood ratio (L/W) of 5.0, while the active alkali (AA) was adjusted to 17%, 20% and 23%. The moisture content of the buttonwood chips was tested each time before the preparation of the cooking chemicals (white liquor) to keep the liquor-to-wood ratio (L/W) constant. The cooking times varied from 60 minutes to 120 minutes. The temperature rose to 170°C in approximately 30 min. All the experiments were conducted using a laboratory rotary digester model AU/E-20.

Beating Process (Freeness Test): The beating process is a necessary step before making the handsheets. It improves the paper quality by subjecting the pulp to a controlled mechanical treatment in a laboratory beater. The beater run is a useful method for defibrillating and swelling the fiber. This procedure was performed according to Tappi Standard T 200 om-89 [13] and the freeness test procedures were performed according to Tappi Standard T 227 om-92 [14].

Handsheet Making: The handsheet forming process was performed according to Tappi Standard T 205 om-88 [15]. After pressing, the handsheets were kept in a room with constant humidity for a couple of days before testing. The handsheets were air-dried under the standard conditions specified in Tappi Standard T 402 om-93 [16], without allowing for drying below the normal moisture content. A total of two hundred seventy handsheets were formed, representing twenty-seven treatments (3 AA levels, 3 cooking times and 3 beating levels). Ten handsheets of each treatment were made and the five best handsheets were selected and tested.

Pulp and Handsheet Properties:

Kappa Test: The kappa number is a measure of the lignin content of pulp. It is the volume (in milliliters) of potassium permanganate solution (0.1N $KMnO_4$) that is consumed per gram of moisture-free pulp under certain specified and carefully controlled conditions. The kappa testing was conducted according to Tappi Standard T236 cm-85 [17].

Handsheet Tests: According to the Tappi standard methods, the thickness of each handsheet (T411 om-89) [18], tensile strength (T494 om-81) [19] and tearing strength (T414 om-88) [20] were tested and measured.

Experimental Design and Statistical Analysis: Analysis of variance was carried out using a three factorial experiment in a complete randomized design (CRD) according to Neter *et al*. [21]. The studied factors were active alkali, cooking time and beating level. The data were exported to a PC-SAS data set for statistical analysis using the GLM procedure.

RESULTS AND DISCUSSION

Chemical Composition of Wood: Table 1 shows the main values of the chemical composition of buttonwood. The lignin content ranged between 34 and 35%, with an average of 35% and the hemicellulose content between 22 and 23%. Lignin and hemicelluloses are two of the most important components in wood relating to its pulp and paper properties and they constitute a major proportion of chemical composition. Lignin supplies the adhesive bonding between fibers in wood, while hemicelluloses supply strength to the fibers. With the exception of lignin and ash content, all chemical constituents of buttonwood were in the normal range of hardwood species according to Monica *et al.* [22]. Both the lignin and ash contents of the wood were higher than those found in other hardwood species [23]. From these results, it can be concluded that buttonwood should be considered suitable for pulp and paper production because it has the appropriate content of cellulose (42%) and hemicelluloses (23%), however, it also has high ash and lignin values, which are the disadvantages of this species.

Fiber Analysis of *Conocarpus* Residues: *Conocarpus erectus* wood is diffuse-porous, the vessels occur in clusters and the rays are uniseriate. The results of the fiber analysis of buttonwood are shown in Table 2 and Fig 1. Three main fiber properties, including fiber length, fiber diameter and fiber wall thickness, were measured and the fiber slenderness ratio was calculated. The fiber length of *C. erectus* was in the range of 0.55 mm to 1.07 mm, with an average of 0.7 mm, these values are in the range of hardwood (0.7-1.6 mm) and are considered to indicate short fiber according to Hale [24]. The fiber diameter of buttonwood was in the range of 7 µm to 16 µm, with an average of 13µm. Fiber wall thickness values ranged between 0.8µm and 1.9 µm and the slenderness ratios ranged between 36 and 123. The slenderness ratio falls within the range of hardwood (61). The slenderness ratio is a measure of the tearing property of pulp in paper making and is determined using the fiber length and fiber diameter. The fibers with a high slenderness ratio are long and thin and have high tearing resistance, whereas short and thick fibers have a lower slenderness ratio and therefore lower tearing resistance. Buttonwood prunings

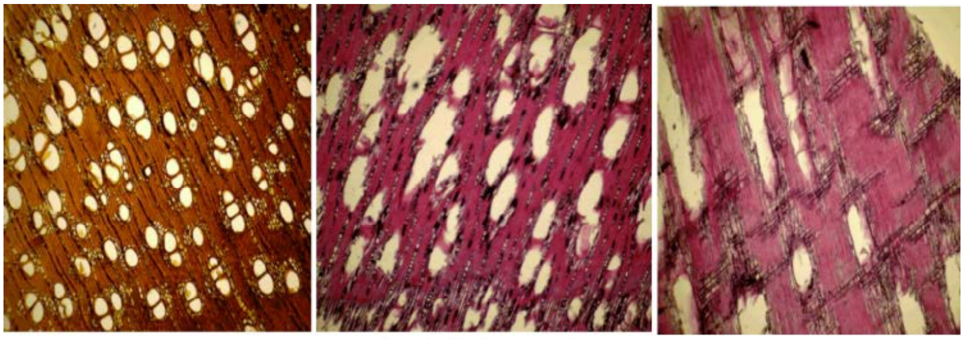

Fig. 1: Transverse, radial and tangential sections (X 40) of Conocarpus erectus.

Table 1: Mean values and range of the chemical composition of Conocarpus tree prunings compared with hardwood.

Constituent (%)	Mean*	Range	Hardwood**
Extractives	11	10-11	10-20
α-cellulose	42	41-42	40-45
Hemicelluloses	23	22-23	20-35
Lignin	35	34-35	25-30
Ash	2.2	2.1-2.3	0.2-1.5

*Each value is an average of three samples.
** Ref [22, 23].

Table 2: Fiber analysis results of *Conocrapus* wood.

Property	Mean *	Range	Hardwood**
Fiber length (mm)	0.7	0.55-1.07	0.7-1.6
Fiber diameter (μm)	13	7-16	12-36
Fiber wall thickness (μm)	1.1	0.8-1.9	2-5
Slenderness ratio	61	36-123	55-75

* Each value of mean is an average of twenty five samples except fiber length is an average of fifty samples.
**Ref. [26]

Table 3: Effect of active alkali concentration and cooking time on the pulp properties of *Conocarpus erectus*.

	Active alkali (%)				Cooking times (min)			
Property	17	20	23	$L.S.D_{0.05}$	60	90	120	$L.S.D_{0.05}$
*Total pulp yield (%)	55.46	51.90	48.36	1.72	54.90	51.50	49.33	1.72
*Screened pulp yield (%)	32.56	36.93	44.13	2.23	36.26	38.53	38.83	2.23
*Reject pulp yield (%)	22.90	14.96	4.23	1.62	18.63	12.96	10.50	1.62
**Kappa number	40.06	36.86	33.22	0.48	39.80	37.09	33.27	0.48
**Lignin content (%)	6.01	5.53	4.98	0.07	5.97	5.56	4.99	0.07
**Ash content (%)	2.67	2.76	2.89	0.05	2.55	2.83	2.95	0.05

*Each value is an average of three samples.
**Each value is an average of nine samples.

are considered suitable for pulp and paper production because the buttonwood fiber has a slenderness ratio above 33. This result is in agreement with those reported by Xu [25], who found that a slenderness ratio of more than 33 in fibrous material is considered suitable for pulp and paper production.

Effects of Cooking Conditions on Pulp Properties: The effects of the active alkali (white liquor) concentration on the properties of unbleached pulps and *C. erectus* paper are shown in Table 3. The results indicate that an increase in the alkali concentration from 17 to 23% results in a decrease in the kappa number from 40.06 to 33.22, total pulp yield from 55.46 to 48.36%, reject pulp yield from 22.90 to 4.23% and lignin content from 6.01 to 4.98%, whereas the screened pulp yield increases from 32.56 to 44.13% and ash content increases from 2.67 to 2.89%. It can be observed that increasing the cooking time from 60 to 120 min results in a decrease in the kappa number from 39.80 to 33.27, total pulp yield from 54.90 to 49.33%,

Table 4: Analysis of variance results for handsheet properties of unbleached soda pulps.

		Mean Squares				
Source of variances	d.f	Tensile index	Elongation	TEA+	Breaking length	Tear index*
Cooking time (CT)	2	26**	0.82**	40**	127**	11**
Active alkali (AA)	2	7838**	2.56**	642**	81**	8**
Beating (B)	2	93768**	12.35**	27604**	975**	55**
Cooking time*Active alkali	4	179**	0.01**	35**	1.87**	0.36**
Cooking time*Beating	4	1475**	0.04**	21**	15.35**	0.96**
Active alkali*Beating	4	110**	0.12**	147**	1.15**	0.21**
CT*AA*B	8	77**	0.003ns	21**	0.81**	0.17**
Error	243	17	0.002	6.05	0.18	0.06
Total	269					

** Significant at the 0.01 level of probability, ns not significant, *d.f of error for tear index equal 108, the total 134. +TEA is the tensile energy absorption,

Table 5: Effects of cooking time on handsheet properties.

Cooking times, min	Tensile index, N*m/g	Elongation, %	TEA*, J/m^2	Breaking length, km	Tear index, mN*m^2/g
60	54.35	1.08	26.22	5.54	4.01
90	63.2	1.17	27.04	6.45	4.32
120	77.45	1.27	27.56	7.9	5.01
L.S.D $_{0.05}$	1.24	0.01	0.72	0.13	0.09

*TEA is tensile energy absorption, Each value is an average of ninety samples except that tear index is an average of forty five, L.S.D is the least significant difference at 0.05 level of probability.

reject pulp yield from 18.63 to 10.50% and lignin content from 5.97 to 4.99%, whereas the ash content increases from 2.55 to 2.95% and the screened pulp yield increases from 36.26 to 38.83% (Table 3). After the short cooking time (60 min), a high kappa number and high reject percentage were observed due to inadequate delignification. The total pulp yield increased as the cooking time decreased. The experimental results are consistent with the theoretical trends and demonstrate that an increase in the alkali charge reduces the kappa number, lignin percentage and pulp yield. The cooking results demonstrate that it was not difficult to produce pulp from buttonwood chips. These findings are in agreement with work carried out by Tutus *et al.* [27], who found that total pulp yield, screened pulp yield, kappa number and lignin content differed according to pulping method, with the total pulp yield ranging from 42 to 47%, screened pulp yield ranging from 40 to 44%, kappa number ranging from 14 to 52% and residual lignin ranging from 2 to 8% using spruce wood pulp. Additionally, the results are in agreement with those obtained by Lopez *et al.* [28], who found that the screened pulp yield was 41.9% with olive wood pulp.

Effects of Cooking Time, Active Alkali and Beating on the Paper Properties: Table 4 shows the analysis of variance results for tensile index, elongation, tensile energy absorption, breaking length and tear index according to cooking time, active alkali and beating process of unbleached soda pulps. The results indicate that the differences in cooking time, active alkali, beating process and their interaction are highly significant except for the trilateral interaction of elongation.

Effects of Cooking Time on Handsheet Quality: The tensile index and breaking length are alternate means of reporting tensile strength and both use the units of N*m/g [29]. The effects of different cooking times treatments on the tensile index of unbleached soda pulps are listed in Table 5. These results indicate that increasing the cooking time from 60 to 120 min resulted in an increase in the tensile index from 54.35 to 77.45 N*m/g, in the elongation from 1.08 to 1.27%, in the tensile energy absorption from 26.22 to 27.56 J/m^2, in the breaking length from 5.54 to 7.90 km and in the tear index from 4.01 to 5.01 mN*m^2/g. From these results, it can be observed that increasing the cooking time from 60 to 90 min caused an increase in the values for all of the handsheet properties.

Effects of Active Alkali on Handsheet Properties: The average values for tensile index, elongation, tensile energy absorption, breaking length and tear index at 23% active alkali gave the highest values for all of the properties being studied, followed by 20%, while the lowest averages were observed at 17% active alkali. The averages observed at 23%, 20% and 17% AA were 73.98, 65.68 and 55.35 N*m/g, respectively, for tensile index and 1.35, 1.17 and 1.01%, respectively, for

Table 6: Effects of active cooking time on handsheet properties.

Active alkali (%)	Tensile index, N*m/g	Elongation, %	TEA*, J/m^2	Breaking length, km	Tear index, mN*m^2/g
17	55.35	1.01	24.37	5.65	3.96
20	65.68	1.17	26.74	6.7	4.54
23	73.98	1.35	29.7	7.55	4.81
L.S.D $_{0.05}$	1.24	0.01	0.72	0.13	0.09

*TEA is tensile energy absorption, Each value is an average of ninety samples, except for the tear index values, which are averages of forty five, L.S.D is the least significant difference at the 0.05 level of probability.

Table 7: Effects of beating process on handsheet properties.

Beating	Tensile index, N*m/g	Elongation, %	TEA*, J/m^2	Breaking length, km	Tear index, mN*m^2/g
Unbeaten	29.03	0.75	7.56	2.96	3.18
30	74.57	1.34	31.63	7.6	4.87
50	91.42	1.43	41.63	9.32	5.27
L.S.D $_{0.05}$	1.24	0.01	0.72	0.13	0.09

*TEA is tensile energy absorption, Each value is an average of ninety samples, except for the tear index values, which are averages of forty five, L.S.D is the least significant difference at the 0.05 level of probability.

elongation. The averages for tensile energy absorption were 29.70, 26.74 and 24.37 J/m^2 for 23, 20 and 17% active alkali, respectively and the averages for breaking length were 7.55, 6.70 and 5.65 km for 23, 20 and 17% of active alkali, respectively. Finally, the average tear index was 4.81 for 23% AA, followed by 4.54 for 20% and 3.98 for 17% (Table 6).

Effects of Beating Process on Handsheet Quality: Pulp beating refers to the mechanical treatment of pulp fibers to improve their papermaking properties. Pulp samples were taken at 30° SR, 50° SR and initial freeness to make handsheets for physical testing, which included the tensile, burst and tear indexes. Ten handsheets were made and five of them were used for the tests at each freeness level. The effects of different beating pulp treatments on the tensile index, elongation, tensile energy absorption, breaking length and tear index of unbleached soda pulps are shown in Table 7. These results indicate that increasing the beating pulp treatments from unbeaten pulp to 50° SR results in an increase in the tensile index from 29.03 to 91.42 N*m/g, elongation from 0.75 to 1.43%, tensile energy absorption from 7.56 to 41.63 J/m^2, breaking length from 2.96 to 9.32 km and tear index from 3.18 to 5.27 mN*m^2/g. From these results, it can be observed that beating causes an increase in all handsheet property values compared to unbeaten pulp and that increasing the degree of SR causes an increase in the handsheet property values.

Effects of the Interaction among Cooking Time, Active Alkali and Beating on Handsheet Properties: The effects of the interaction among tensile index, elongation, tensile energy absorption, breaking length and tear index of unbleached soda pulps are presented in Table 8. These results indicate that treatment 27 gave the highest average values for tensile index, breaking length and tear index (117.44 N*m/g, 11.98 km, 6.17 mN*m^2/g, respectively), followed by treatment 24 (110.64 N*m/g, 11.28 km, 6.02 mN*m^2/g, respectively), while treatment 1 resulted in the lowest average value (15.96 N*m/g, 1.63 km, 2.48 mN*m^2/g, respectively). In addition, treatment 27 gave the highest value for elongation (1.77%), followed by treatment number 30 (1.72%), while the lowest average value was obtained from treatment 1 (0.61%). By contrast the highest tensile energy absorption value was recorded (47.34 J/m^2) with treatment 27, followed by treatments 9 and 18 (46.67 J/m^2), while the lowest average value was obtained from treatment 1 (6.67 J/m^2). It can be concluded that treatment with a cooking time of 120 min, 23% active alkali and 50° SR is the best the treatment with respect to all the properties under study, whereas the treatment with a cooking time of 60 min, 17% active alkali and no beating is the worst with respect to the properties under study (Table 8). This result is in agreement with the findings of Feria *et al.* [30], who found that the tensile index increased as refining degree increased, although less obviously, until values above 95 N*m/g were recorded for paulownia unbleached kraft pulp. The tensile index was different among the treatments, which is in agreement with the work carried out by Spiridonova and Petkova [31], who found that the tensile index was different among different conditions in the production of pulp from poplar wood, the values recorded in their study ranged from 4.6 to 44.4 N*m/g. The tensile index values are in agreement with those obtained by Jahan *et al.* [32], who found that the tensile index of *Acacia auriculiformis* was 45.1 N*m/g at 46° SR in soda-AQ pulp, whereas it was 45.4 N*m/g at 44°

Table 8: Effects of cooking time, active alkali treatment and beating process on the properties of handsheets of unbleached soda pulps.

Cooking time, min	Active Alkali, %	Beating	Treatment number	Tensile index, Nm/g	Elongation, %	TEA, J/m^2	Breaking length, km	Tear index, mN*m^2/g
60	17	Unbeaten	1	15.96	0.61	6.67	1.63	2.48
		30	2	47.27	1.02	27.33	4.82	3.57
		50	3	65.76	1.13	33.33	6.71	4.29
	20	Unbeaten	4	23.37	0.7	6.67	2.38	3.04
		30	5	64.01	1.21	32.66	6.53	4.47
		50	6	78.82	1.32	40	8.04	5.06
	23	Unbeaten	7	33.61	0.79	9.33	3.43	3.09
		30	8	72.95	1.43	33.33	7.44	4.94
		50	9	87.41	1.52	46.67	8.92	5.11
90	17	Unbeaten	10	23.57	0.65	6.67	2.4	2.97
		30	11	60.77	1.14	26.67	6.19	3.86
		50	12	75.23	1.25	40	7.67	4.45
	20	Unbeaten	13	31.56	0.74	6.67	3.22	3.25
		30	14	69.16	1.33	33.99	7.05	4.66
		50	15	86.89	1.43	40.67	8.86	5.15
	23	Unbeaten	16	35.74	0.85	9.33	3.64	3.57
		30	17	87.09	1.53	32.66	8.88	5.39
		50	18	98.81	1.58	46.67	10.08	5.54
120	17	Unbeaten	19	25.42	0.71	6.67	2.59	2.98
		30	20	82.38	1.23	31.99	8.4	5.43
		50	21	101.77	1.34	40	10.38	5.69
	20	Unbeaten	22	33.62	0.81	6.67	3.43	3.58
		30	23	93.06	1.44	33.33	9.49	5.69
		50	24	110.64	1.53	40	11.28	6.02
	23	Unbeaten	25	38.35	0.9	9.33	3.91	3.69
		30	26	94.39	1.72	32.67	9.63	5.81
		50	27	117.44	1.77	47.34	11.98	6.17
$L.S.D_{0.05}$				1.24	0.01	0.72	0.13	1.02

*Each value is an average of ten samples, except for the tear index values, which are averages of five samples, TEA is tensile energy absorption

SR in the kraft pulp. The tear index of *C. erectus* was low in unbeaten pulp and it improved with increasing beating degree. These results are in agreement with Jahan *et al.* [32], who found that the tear index values for *Acacia auriculiformis* differed by treatment and were in the range of 3.7 to 6.7 mN*m^2/g for soda-AQ pulping and the tear index improved from 5.0 to 7.1 mN*m^2/g due to an increase in active alkali from 16 to 20%. Additionally, these results are in agreement with Jimenez and Lopez [33], who found that the tear index increased from 1.51 to 3.08 mN*m^2/g with an increase in the degree of refining from 9.0 to 55° SR for olive tree pulp, but the results do not agreement with Gulsoy and Erglu [34], who found that the tear index decreased from 30.7 to 13.3 mN*m^2/g with increasing freeness levels for kraft pulp from European black pine.

CONCLUSIONS

On the basis of these results, it can be concluded that buttonwood residues should be considered suitable for pulp and paper production because they have the appropriate values of cellulose (42%) and hemicelluloses (23%) and a slenderness ratio above 33 for fibers. It can be concluded that increases in cooking time and active alkali result in a decrease in the kappa number, total pulp yield, reject pulp yield and lignin content, while the same factors (cooking time and active alkali) resulted in an increase in the ash content and screened pulp yield. After the short cooking time, a high kappa number and high reject percentage were observed due to the inadequate delignification. The total pulp yield increased as cooking time decreased. These experimental results are consistent with the theoretical estimates and demonstrate that increasing the alkali charge reduces the kappa number, lignin percentage and pulp yield. The cooking results demonstrate that is not difficult to produce pulp from buttonwood chips. These results regarding buttonwood at different active alkali concentrations suggest that the tensile index, elongation, breaking length and tear index at 23% active alkali are higher than those at 20% active alkali and that those at 20% active alkali are higher than those at 17% active alkali. Cooking time also affects the properties of paper sheets, with the120 min cooking time resulting in higher paper property values than the 90 min cooking time and 90 min cooking time resulted in higher values than did the 60 min cooking time. The values for the paper sheet properties at 50° SR are higher than those at 30° SR and those at 30° SR are higher than those for unbeaten pulp.

ACKNOWLEDGEMENTS

With sincere respect and gratitude, we express deep thanks to the Deanship of Scientific Research and the NPST program of King Saud University, Saudi Arabia for financial support (project no 11-AGR1746-02), sponsorship and encouragement.

REFERENCES

1. Atchison, J.E., 1987. Data on non-wood plant fibers. In: Hamilton, F. Leopold, B. & Kocurek, M.J. (eds.) Pulp and paper manufacture. Secondary fibers and nonwood pulping. Vol.3. TAPPI and CPPA, Atlanta and Montreal pp: 4-16.
2. Judt, M., 1993. Non-wood plant fibres, will there be a comeback in paper-making? Industrial Crops and Products, 2: 51-57.
3. Paavilainen, L., 1996. Reed canary grass. A new Nordic material for high-quality fine papers. Know-How Wire. Jaakko Pöyry Magazine, 2: 8-11.
4. Paavilainen, L., 1998. European prospects for using nonwood fibers. Pulp and Paper International, 40(6): 61- 66.
5. FAOSTAT. 2010. FAO Statistics Division 2010.
6. ASTM (American Society for Testing and Materials). 1989. Standard test method for moisture content of wood. ASTM, D2016. Philadelphia. Pa. U.S.A.
7. ASTM (American Society for Testing and Materials), 1989. Standard test methods for preparation of extractive-free wood. ASTM D 1105-56. Philadelphia, Pa. U.S.A.
8. Nikitin, V.M., 1960. Himia drevesini i telliulozi. Goslesbumiz_dat, M_L. Pg.233. Chimia Lemnului SI A Celuloze I Vol I si II, 1973.
9. Rozmarin, G. and C. Simionescu, 1973. Determining hemicellulose content. Wood Chemistry and Cellulose (Romanian) 2: 392.
10. STM (American Society for Testing and Materials). 1989. Standard test method for acid-insoluble lignin in wood. ASTM D 1106-84. Philadelphia, Pa. U.S.A.
11. NREL CAT Task Laboratory Analytical Procedure #005. 1994 “Standard Method for ash in Biomass”.
12. Khristova, P., O. Kordsachia and T. Khider, 2005. Alkaline pulping with additives of date palm rachis and leaves from Sudan. Bioresource Technology, 96: 79-85.
13. TAPPI (Technical Association of the Pulp and Paper Industry). Standard T 200 om-89 (Laboratory processing of pulp beating method).
14. TAPPI (Technical Association of the Pulp and Paper Industry). Standard T 227 om-92 (Freeness of pulp).
15. TAPPI (Technical Association of the Pulp and Paper Industry). Standard T 205 om-88. (Forming handsheets for physical tests of pulp).
16. TAPPI (Technical Association of the Pulp and Paper Industry). Standard T 402 om-93 (Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets and Related Products).
17. TAPPI (Technical Association of the Pulp and Paper Industry). Standard T236 cm-85. (Kappa testing in pulp).
18. TAPPI (Technical Association of the Pulp and Paper Industry). Standard T411 om-89 and T426 wd-70 (Handsheet thickness).
19. TAPPI (Technical Association of the Pulp and Paper Industry). Standard T494 om-81 (Tensile breaking properties of paper and paper board).
20. TAPPI (Technical Association of the Pulp and Paper Industry). Standard T414 om-88 (Internal Tearing Resistance of Paper).
21. Neter, J. Wasserman and M. H. Kutner, 1990. Applied linear statistical models. Third Edition, Irwin Boston, MA02116, pp: 1181.
22. Monica, E.K., G. Gellerstedt and G. Henriksson 2009. Wood Chemistry and Wood Biotechnology. Volume 1. Walter de Gruyter GmbH and Co. KG, Berlin.
23. Rowell, R.M., 2005. Handbook of Wood Chemistry and Wood Composites, Taylor and Francis, Boca Raton, FL, pp: 487.
24. Hale, J.D., 1959. Physical and anatomical characteristics of hardwoods. Tappi, 42: 670-677.
25. Xu, F., F.C. Zhang, R.C. Sun and Q. Lu, 2006. Anatomy, ultrastructure and lignin distribution in cell wall of Caragana korshinskii. Ind. Crops Prod., 24: 186-193.
26. Smook, G.A., 2002. Handbook for Pulp and Paper Technologists, 2nd Ed. Angus Wilde Publications, Vancouver.
27. Tutus, A., S. Ates and I. Deniz, 2010. Pulp and paper production from spruce wood with kraft and modified kraft methods. African J. Biotechnol., 9: 1648-1654.

28. Lopez, F., J. Ariza, I. Perez and L. Jimenez. 2000. Comparative study of paper sheets from olive tree wood pulp obtained by soda, sulphide or kraft pulping, Bioresour. Technol., 71: 83-86.
29. Biermann, C.J., 1996. Handbook of Pulping and Papermaking. 2nd Ed. Academic Press, San Diego, California, pp: 754.
30. Feria, M.J., J.C. Garcia, M.A. Zamudio, J.L. Gomide, J.L. Colodette and F. Lopez, 2013. Kraft pulping and bleaching of paulownia wood. Cellulose Chemistry and Technology, 47: 595-601.
31. Spiridonova, R.B. and E. Petkova, 2007. Utilization of various chemical reagents and additives for production of chemical-mechanical pulp from poplar wood. Journal of the University Chemical Technology and Metallurgy, 42: 41-44.
32. Jahan, M.S., R. Sabina and A. Rubaiyat, 2008. Alkaline pulping and bleaching of acacia auriculiformis grown in Bangladesh. Turk. J. Agric. For., 32: 339-347.
33. Jimenez, L. and F. Lopez. 1993. Characterization of paper sheets from agricultural residues. Wood Science and Technology, 27: 468-474.
34. Gulsoy, S.K. and H. Eroglu, 2011. Biokraft pulping of European black pine with Ceriporiopsis subvermispora. International Biodeterioration and Biodegradation, 65: 644-648.