Journal of Forest Science
Vol. 26, No. 2, pp. 75~82, August 2010

Characterization of Biometry and Chemical and Morphological Properties of Fibers from Bagasse, Corn, Sunflower, Rice, and Rapeseed Residues in Iran

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ABSTRACT : The biometry, morphological properties and chemical composition of bagasse, corn, sunflower, rice, and rapeseed residues plants were analyzed. The results revealed differences in biometry properties and chemical composition of the different types of agricultural resides investigated. The greatest proportion of fiber length (1.32 mm) and cellulose (55.56%) was found in residues of bagasse plants, with a low ash (1.78%) and lignin (20.5%). The lignin of all types of agricultural resides was less than hardwood and softwood. In addition, the rice and rapeseed residues plants had highest amount of ash and extractive component. The slenderness and flexibility ratios of the all types of agricultural resides fibers were similar to some of hardwood and softwood species.

Keywords : Agricultural resided, Biometry properties, Chemical composition, Morphological properties.

Introduction

Wood has traditionally been the most widely used lignocellulosic matter in the production of pulp, furniture and boards of diverse types, as well as being a source for energy (Fao, 1973). Increasing demand for these raw materials, together with economic and environmental factors, makes it necessary to research alternative sources of lignocellulosic matter (Garay, 2002a; 2002b). Plant waste fibers can be described as lignocellulosics, i.e. resources comprised primarily of cellulose, hemicellulose, and lignin. Lignocelluloseics include wood, agricultural residues, water plants, grasses, and other plant substances (Rowell et al. 2000). Plant waste fibers have the composition, properties, and structure that make them suitable for uses such as composite, textile, pulp, and paper manufacture. In addition, plant fibers can also be used to product fuel, chemicals, enzymes, and food, biomass, including agricultural crops and residues, forest resources, residues, animal and municipal wastes, is the largest source for cellulose in the world (Raddy and Yang 2005).

Residues are mainly the stems or stalks of cereal plants such as wheat, corn or rice, left after harvesting the grain. In the case of wheat residues are an important source of fibrous biomass after harvest. The United States produces approximately 10 million tons annually. Residues can be converted into paper, particleboards, fuel, and other products (Fiber Futures, 2007). Rice residue is the major source of agricultural residue fiber in the world and is particularly important in the development of Asian countries. It can be converted into a variety of useful products, including paper and construction materials. The main obstacle in the clean processing of rice is its high silica content (Fao, 1973; Potivaral, 2005; Fiber Futures, 2007). New technologies may soon overcome this obstacle. Corn is the major source of agricultural residues in the United

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States, with more than 250 million tons per year. The fiber lends itself to paper production and many studies have been undertaken to investigate the commercial use of this fiber (Fiber futures, 2007). Garay et al. (2009) stated fiber length of corn residues is longer than rice and wheat resides. But the cellulose content in rice residues is higher than corn and wheat resides in Chile.

Cellulose is the main component responsible for the structure and rigidity in particleboard. The cellulose content is slightly lower in plant residue than in wood. The type of hemicellulose in plant residue is less pure than that of wood. Lignin is the natural cementing agent that holds material together. For certain construction materials, the chemical components must be removed through a refining process (Garay et al. 2009).

The objective of this work was to characterize the biometry, chemical, and morphological properties of five types of residues, of bagasse, corn, sunflower, rice, and rapeseed residues, and to determine the best material raw for paper productions.

Methods and materials

Raw Material

The depithed bagasse (*Saccharum officinarum*) used in this study was collected from a local pulp and paper mill (Pars Paper Co. Haft Tapeh) in south of Iran. Corn (*Sorghum bicolor*), sunflower (*Helianthus annus*), rice (*Oryza sativa*), and rapeseed (*Brassica napus L*) residues were collected from the fields in Babul city. Samples were cleaned and leaves and debris were separated, and then the stems were depithed carefully by hand. Depithed material was cut into 2-4 cm length chips. Chips were dried at ambient temperature, and after reaching equilibrium moisture content, chips were stored in plastic bags until used.

Characterization of Fiber Biometry

The pieces of bagasse, corn, sunflower, rice, and rapeseed residue were defibrated using the technique developed by Franklin (1954) and then the fiber length, fiber diameter, and lumen width were measured with a Leica Image Analysis System. The fiber wall thickness was calculated as a difference of fiber diameter and lumen width divided in half. For dimensions of 120 fibers were randomly measured. From these data, the average fiber dimensions were calculated and then the following derived indexes were determined:

Slenderness ratio = (Length of fiber/Diameter of fiber)

Flexibility ratio = (Lumen width of fiber/Diameter of fiber) × 100

Runkel ratio = (2 ×Wall thickness)/(Lumen width)× 100

Chemical Composition

The lignin, ash and ethanol/acetone extractive of bagasse, Corn, sunflower, rice, and rapeseed residue were determined according to TAPPI Test Methods. The cellulose content of bagasse corn, sunflower, rice, and rapeseed residue were determined according to the nitric acid (Rowell and Young 1997) method respectively. All measurements were repeated three times.

Statistical Analysis

Statistical significance of differences in the biometry, chemical and morphological properties between the agriculture resides was analysis using ANOVA in a statistical program SPSS software and categorized by Duncan's multiple range test (Garay et al. 2009). The results were considered at significance level of $p \leq 0.01$.

Results and discussion

Biometry properties

Fiber length: The mean fiber length of five types of agricultural resides are shown in Table 1. Differences among the agricultural resides were tested at the level of $p \leq 0.01$ and significant distinctions were marked with letters a, b, and c (Table 2, Figure 1). The results of

ANOVA indicate that the effects of agricultural resides on the fiber length were significant, so that the highest and lowest of fiber length values were found in bagasse and rice residues. The mean fiber length values in bagasse resides is 1.32 mm, very similar to species such as hornbeam (*Carpinus betulus*, Taleaipour et al. 2010), and *Eucalyptus globulus Labill*, with 0.93 to 1.17 mm (Saavedra, 2004). The residues of rice and rapeseed plants had fiber lengths that fluctuated between 0.83 and 0.96 mm. Also the value of Iranian rice plant residues (0.83 mm) is more than the Chillan rice residues (0.594 mm, Garay et al. 2009), and this properties of corn plant residues in this present study (0.88 mm) is lower the Chillan corn residues (1.52 mm, Garay et al. 2009).

Table 1. The results deceptive statistical of biometry properties of five agricultural resides

Properties		Bagasse	Corn	Sunflower	Rice	Rapeseed
Fiber length (mm)	Mean	1.32±0.30	0.88±0.23	0.96±0.21	0.83±0.15	0.95±0.18
	Max	1.82	1.43	1.43	1.28	1.38
	Min	0.76	0.43	0.57	0.45	0.68
	Duncan	c	a	b	a	b
Fiber diameter (μm)	Mean	20.96±5.03	20.12±3.63	22.84±3.96	10.89±1.30	24.12±6.02
	Max	36.14	26.71	36.14	15.50	34.10
	Min	12.15	12.12	16.12	8.06	6.20
	Duncan	b	b	c	a	d
Single cell wall thickness (μm)	Mean	5.58±1.54	4.59±0.98	5.85±1.19	3.16±0.53	4.31±1.88
	Max	9.44	6.57	9.44	5.61	9.30
	Min	1.45	2.41	2.24	2.08	1.55
	Duncan	c	b	c	a	b
Lumen width (μm)	Mean	9.66±3.32	10.92±3.86	11.12±3.32	4.57±1.37	15.50±5.24
	Max	19.12	20.19	24.67	8.77	27.90
	Min	1.01	2.45	3.20	1.12	3.10
	Duncan	b	c	c	a	d

± Standard deviation

Table 2. ANOVA test for biometry properties of five agricultural resides

Properties		Sum of Squares	df	Mean Square	F
Fiber length (mm)	Between Groups	18.161	4	4.540	90.505*
	Within Groups	29.747	593	.050	
	Total	47.908	597		
Fiber diameter (μm)	Between Groups	13016.627	4	3254.157	176.433*
	Within Groups	10955.831	594	18.444	
	Total	23972.458	598		
Single cell wall thickness (μm)	Between Groups	557.902	4	139.476	81.248*
	Within Groups	1017.985	593	1.717	
	Total	1575.887	597		
Lumen width (μm)	Between Groups	7328.672	4	1832.168	138.076*
	Within Groups	7868.674	593	13.269	
	Total	15197.345	597		

Significant at 99% confidence

Fiber diameter: The fiber diameter value of five types of agricultural reside are shown in Table 1. Differences among the agricultural resides were tested at the level of $p \leq 0.01$ and significant distinctions were marked with letters a, b, and c, (Table 2). The results of ANOVA indicate that the effects of agricultural resides on the fiber diameter were significant, so that the highest and lowest of fiber diameter were found in rapeseed and rice residues.

Single cell wall thickness: The mean cell wall thickness of five types of agricultural resides are presented in Table 1. Differences among the agricultural resides were tested at the level of $p \leq 0.01$ and significant distinctions were marked with letters a, b, and c (Table 2). The results of ANOVA indicate that the effects of agriculture resides on the cell wall thickness were significant, so that the highest and lowest of cell wall thickness were found in sunflower and rice residues. The mean thickness of the fiber walls is 5.85 μm for sunflower, which is more than *Eucalyptus globulus Labill*, (2.38 to 2.98, Saavedra, 2004), and is less than hornbeam (*Carpinus betulu)*, (6.64 μm, Taleaipour et al. 2010). Also, the thickness of cell walls was determined for rice and corn 4.59 and 3.16 μm, respectively. Such that these value is more than rice hulls (2.3 μm) and corn plants resides (2 μm, Garay et al. 2009).

Lumen width: The mean lumen width of five types of agricultural resides are shown in Table 1. Differences among the agricultural resides were tested at the level of $p \leq 0.01$ and significant distinctions were marked with letters a, b, c, and d (Table 2). The results of ANOVA indicate that the effects of agriculture resides on the lumen width were significant, so that the highest and lowest of lumen width were found in rapeseed and rice residues.

Morphological properties: The average morphological properties of five types of agricultural resides are presented in Table 3. The average slenderness and runkel ratios of rice are the highest among the agricultural resides while the flexibility ratio of rapeseed resides is the highest.

When the slenderness ratio is higher, the quality of the manufacture paper would be better. Therefore, in attention to this terms it would be expected that the paper made from the rice plant resides would have better quality. This rate was measured as 76.58 for rice plants residues, that this rate is more than wheat fibers (Eroglu 1980) and tobacco stem (Tank 1980). Generally, the acceptable vale for slenderness ratio of papermaking fibers are more than 33 (Xu et al 2006). Referring to this and morphological properties of all types of agricultural resides plants fibers, it can be used for pulp and paper manufactures.

Whatever the flexibility ratio is higher, the burst strength of the manufacture paper would have more. Therefore, in attention to this terms it would be expected that the paper made from the rapeseed plant resides would have more strength. According to flexibility ratio there are 4 groups of fibers (Istas et al. 1954, Bektas et al. 1999):

1- High elastic fibers having elasticity coefficient greater than 75.
2- Elastic fibers having elasticity ratio between 50-75.
3- Rigid fibers having elasticity ratio between 30-50.
4- High rigid fibers having elasticity ratio less than 30.

According to this, flexibility coefficient of bagasse, sunflower, and rice resides fibers are 46.08, 48.68, and 41.26, respectively. Thus they can be considered as high rigid fibers group. On other studies about hardwoods, elasticity coefficient was found as 43.30 for plane (Bektas et al. 1999), 45.20 for eucalyptus (Hus et al. 1975), 41.00

Table 3. The results deceptive statistical of morphological properties of five types of agricultural resides.

Agricultural residues	Slenderness ratio	Flexibility ratio	Runkel ratio
Bagasse	62.97	46.08	115.52
Corn	44.08	54.27	84.06
Sunflower	42.03	48.68	105.21
Rice	76.58	41.96	138.29
Rapeseed	39.59	64.26	55.61

for *Carpinus orientalis* (Tank 1978) and 46.37 for robinia (Liao et al 1981) and it was found that bagasse, sunflower, and rice fibers are in uniformity with other hardwoods in terms of elasticity coefficient.

In case of softwoods, elasticity coefficient was found as 60.02 for *Pinus sylvestris* (Akkayan 1983), 62.71 for *Pinus brutia* (Bektas et al 1999), and 66.92 for *Picea orientalis* (Bostanci 1976). Examining this information given, it seems that corn and rapeseed resides fibers are included in elastic fibers like other softwoods species.

Depending on all of these, it is possible to say that corn and rapeseed resides fibers will be more suitable than bagasse, sunflower, and rice residues fibers in terms of paper production. Because rigid fibers don't have efficient elasticity, they aren't suitable for paper production and they are used more on fiber plate, rigid cardboard and cardboard production.

When Runkel proportion is greater than 1, it is assessed as fiber having thick wall and cellulous obtained from this type fibers is least suitable for paper production; when it is equal to 1, cell wall have medium thickness and cellulose obtained from this type fibers is suitable for paper production, when the rate is less than 1, cell wall is thin and cellulose obtained from these fibers is most suitable for production of paper (Eroglu 1980; Xu et al. 2006). According to this, Runkel value of the bagasse, sunflower, and rice are 115.52 (1.15), 105.21 (1.05), and 138.29 (1.38) and it is included in thick wall fibers group, and the runkel value of corn and rapeseed are 84.06 (0.84), and 55.61 (0.55), respectively, and it is classification in thin cell wall fibers group.

Chemical properties

Table 4 shows the percentage of various chemical components present in bagasse, corn, sunflower, rice, and rapeseed fiber. Differences among the types of agricultural resides were tested at the level of $p \leq 0.01$ (Table 5 and Figure 1) and significant distinctions were marked with letters a, b, c, d, and e. The data show that rapeseed residues exhibited the highest solubility in alcohol-benzene extractive content may be advantageous for decay resistance and will provide good strength in fiber processing, because of its higher specific gravity (Abdul Khalil et al.

Table 4. The results deceptive statistical of chemical properties of five agricultural resides

Properties		Bagasse	Corn	Sunflower	Rice	Rapeseed
Lignin (%)	Mean	20.50±0.5	21.33±0.57	21.33±0.57	21±0.50	19.33±0.57
	Max	21	22	22	21.5	20
	Min	20	21	21	20	19
	Duncan	b	b	b	b	a
Cellulose (%)	Mean	55.56±0.51	47.33±0.58	46±1	50.33±0.57	44±0.86
	Max	56	48	47	51	44
	Min	55	47	45	50	43
	Duncan	e	c	b	d	a
Extractive alcohol-benzene (%)	Mean	3.41±0.52	2.40±1	3.16±0.15	3.23±0.25	6.10±0.52
	Max	4.00	2.50	3.30	3.50	6.50
	Min	3.00	2.30	3.00	3.00	5.50
	Duncan	b	a	b	b	c
Ash (%)	Mean	1.78	4.79	7.60	15.73	12.87
	Max	1.85	4.90	7.80	16	13
	Min	1.70	4.60	7.50	15.50	12.60
	Duncan	b	c	c	a	d

± Standard deviation

Table 5. ANOVA test for chemical properties of five agricultural resides

Properties		Sum of Squares	df	Mean Square	F
Lignin	Between Groups	8.400	4	2.100	7.000*
	Within Groups	3.000	10	.300	
	Total	11.400	14		
Cellulose	Between Groups	243.157	4	60.789	113.413*
	Within Groups	5.360	10	.536	
	Total	248.517	14		
Extractive component	Between Groups	24.077	4	6.019	46.481*
	Within Groups	1.295	10	.130	
	Total	25.372	14		
ash	Between Groups	390.961	4	97.740	3002.46*
	Within Groups	.326	10	.033	
	Total	391.286	14		

Significant at 99% confidence

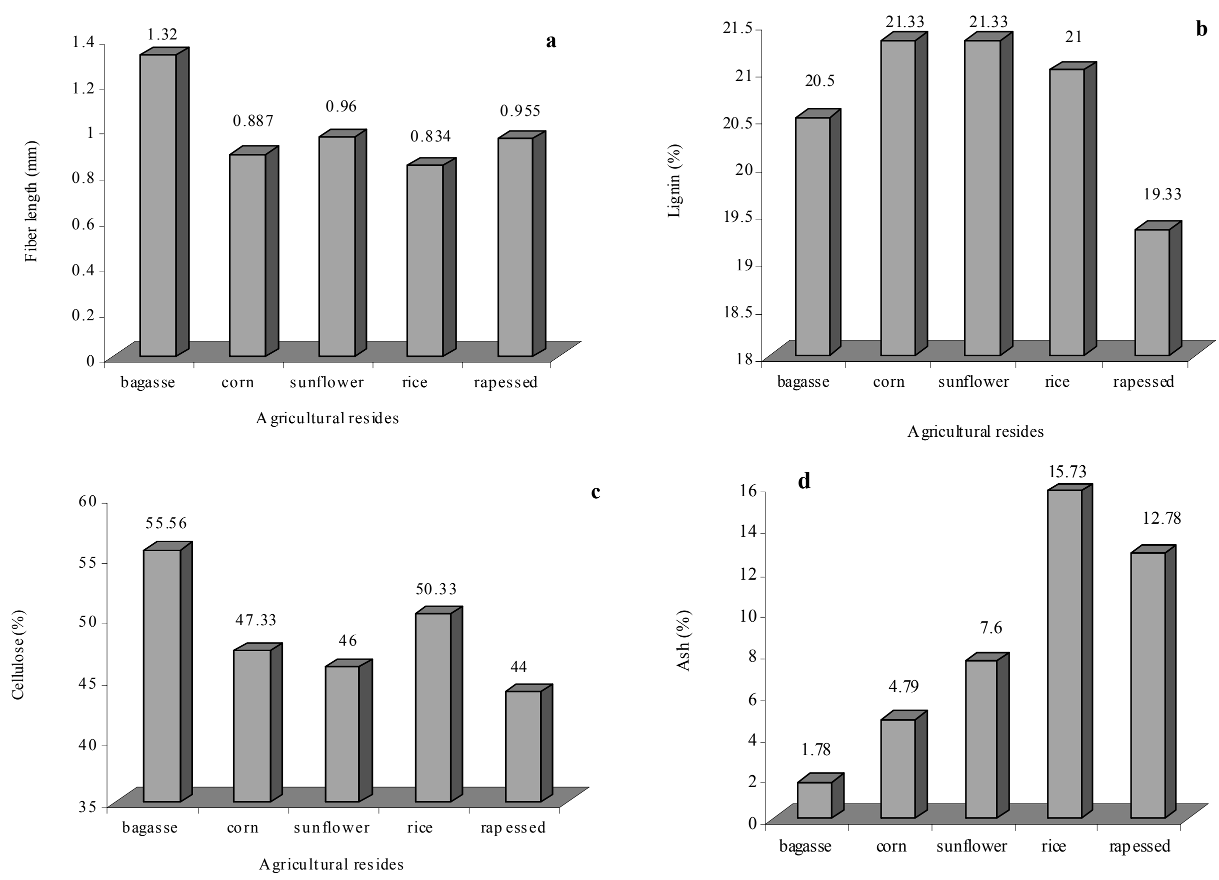

Fig. 1. The fiber length and chemical properties in five types of agricultural resides

2006).

Generally, corn and sunflower residues fibers contained the highest percentage of lignin (21.30%), but the lignin content of corn and sunflower fibers was still lower than that of wood fiber (14-37%) (Tsoumis 1991). Generally, the high content of lignin in corn and sunflower fibers made the fiber tougher and stiffer, compared to other fibers. Because the wood lignin provides plant tissue and individual fibers with compressive strength and stiffens the cell wall of the fibers, to protect the carbohydrates from chemical and physical damage (Saheb and Jog 1999). Lignin is an undesirable polymer, and its removal during pulping requires high amounts of energy and chemicals. Rapeseed fibers had the lowest lignin content, which suggests that this material can undergo bleaching more easily and with the utilization of lower amounts of chemicals than other agricultural residues fibers.

In producing paper, increasing the amount of cellulose and decreasing vale of lignin, the exertive compound, and ash cause to increasing of yield, decreasing consumption of chemical material, and cooking time (Panshin 1980). Paper strength depends on the cellulose content of raw plant material. Plant material with 34% and over of α-cellulose content were characterized as promising for pulp and paper manufacture, from chemical composition point of view (Nieshlag et al. 1960). Cellulose content was also at a satisfactory level (above 40%) for each type of fiber considered in the present study. Bagasse residues contained the highest percentage of cellulose content (55.56%), which was higher than other agricultural resides. Rice resides contained the highest percentage of ash content (15.73%), which was higher than other agriculture resides.

Conclusions

The above studies can be summarized as follows:

1- In general, the chemical composition of five types of agricultural resides followed the order given below:

Lignin: (highest): corn, sunflower > rice > bagasse > rapeseed (lowest)

Cellulose: (highest) bagasse > rice > corn > sunflower > rapeseed (lowest)

Extractives: (highest) rapeseed > bagasse > rice > sunflower > corn (lowest)

Ash: (highest) rice > rapeseed > sunflower > corn > bagasse (lowest)

2- The biometry and morphological properties among all of agricultural residues followed the order given below:

Fiber length: baggase > sunflower > rapeseed > corn > rice (lowest)

Fiber diameter: (highest) rapeseed > sunflower > bagasse > corn > rice (lowest)

Cell wall thickness: (highest) sunflower > bagasse > corn > rapeseed > rice (lowest)

Lumen width: (highest) bagasse > rice > corn > sunflower > rapeseed (lowest)

Slenderness ratio: (highest) bagasse > rice > corn > sunflower > rapeseed (lowest)

Flexibility ratio: (highest) bagasse > rice > corn > sunflower > rapeseed (lowest)

Runkel ratio: (highest) bagasse > rice > corn > sunflower > rapeseed (lowest)

3- The best of material raw for paper productions due to higher length fiber values and extractives contents are bagasses and rapeseed residues.

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(Received August 1, 2010; Accepted September 30, 2010)