

Full Length Research Paper

Characterization of biometry and the chemical and morphological properties of fibers from bagasse, corn, sunflower, rice and rapeseed residues in Iran

Majid Kiaei^{1*}, Ahmad Samariha² and Jafar Ebrahimpour Kasmani³

¹Department of Wood and Paper Science and Technology, Islamic Azad University, P. O. Box 466615/397, Postal code: 46619/61367, Chalous Branch, Iran.

² Young Researchers club, Science and Research Branch, Islamic Azad University, Tehran, Iran.

³Islamic Azad University, Savadkooh Branch, Young Researchers club, Mazandaran, Iran.

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

Key words: Agricultural residues, 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, that is, resources comprised primarily of cellulose, hemicellulose and lignin. Lignocellulosics includes 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 and pulp, and paper manufacture. In addition, plant fibers can also be used to produce fuel, chemicals, enzymes and food, biomass, agricultural crops and residues. Forest resource and residues, animal and municipal wastes, are the largest sources of cellulose in the world (Raddy and Yang, 2005).

Residues are mainly the stems or stalks of cereal plants such as corn, rice, or wheat left after harvesting the grain. In the case of wheat residues, they are important sources of post-harvest fibrous biomass. The United States produces wheat residues 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 it is particularly important in the development of Asian countries. It can be converted into varieties of useful products, including paper and construction materials. The main obstacle in the clean processing of rice is due to 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 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 that fibers of corn residues are longer than rice and wheat residues, and amount of cellulose in rice residues is greater than corn and wheat residues in Chile.

Cellulose is a main component, which is responsible to

*Corresponding author. E-mail: mjd_kia@yahoo.com.

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 a natural cementing agent that holds material together. For usage as construction materials, the lignin must be removed through refining process. The main difference, which is also a disadvantage in some industrial processes, is that, rice residue and hulls have higher silica content than wood. This means that particleboards made from residues are tougher for trimming and caused excessive usage of cutting tools. This factor should be considered in the context of the cost involved in removing residues from agricultural fields (Garay et al., 2009).

The objective of this work was to characterize the biometry and chemical properties of five types of residues namely bagasse, corn, sunflower, rice, and rapeseed residues with the aim of generating information to facilitate the incorporation of residual material in industrial processes.

MATERIALS AND METHODS

Raw material

Post harvest agricultural residues were used. The residues were from corn (*Sorghum bicolor*), sunflower (*Helianthus annuus*), rice (*Oryza sativa*), and rapeseed (*Brassica napus L*) which were obtained from an area of Babul city in the north of Iran. The depithed bagasse (*Saccharum officinarum*) used in this study was collected from a local pulp and paper mill (Pars Paper Co. Haft Tapeh) in the south of Iran. Samples were cleaned and left. Debris was separated, and the stems were depithed carefully by hand. The samples were dried at ambient temperature, and after reaching equilibrium moisture content, chips were stored in plastic bags until used.

Fiber biometry and morphology characteristics

The residues of bagasse, corn, sunflower, rice, and rapeseed were defibrated using a technique developed by Franklin (1954). The fiber length, fiber diameter, and lumen width were measured with Leica Image Analysis System. The fiber wall thickness was calculated as a difference of fiber diameter and lumen width divided in half. For dimensions, 300 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 = $2 \times (\text{Wall thickness/Lumen width})$

Chemical composition

The lignin, ash and ethanol/acetone extractive content of bagasse, corn, sunflower, rice, and Rapeseed residues were determined according to TAPPI test methods. The cellulose content of the bagasse, corn, sunflower, rice and rapeseed residues was determined in accordance with nitric acid method (Rowell and Young, 1997). All measurements were repeated five times.

Statistical analysis

Statistical significance of differences in the biometry, chemical and morphological properties between the agricultural residues were analysis using ANOVA in a statistical program SPSS and categorized by Duncan's multiple range test. The results were considered at significance level of $p \leq 0.01$.

RESULTS

Biometry properties

Fiber length

The mean fiber length of the five types of agricultural residues is shown in Table 1. Differences among the agricultural residues were evaluated at the level of $p \leq 0.01$ and significant distinctions were marked with letters a, b, and c. The results of ANOVA indicate that the effects of agricultural residues on the fiber length were significant, so that the highest and lowest fiber length were found in bagasse and rice residues.

Fiber diameter

The mean fiber diameter of the five types of agricultural residues is shown in Table 1. Differences among the agricultural residues were tested at the level of $p \leq 0.01$ and significant distinctions were marked with letters a, b, and c. The results of ANOVA indicate that the effects of agricultural residues 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 the five types of agricultural residues is presented in Table 1. Differences among the agricultural residues were tested at the level of $p \leq 0.01$ and significant distinctions were marked with letters a, b, and c. The results of ANOVA indicate that the effects of agricultural residues on the cell wall thickness were significant, so that the highest and lowest cell wall thickness were found in sunflower and rice residues.

Lumen width

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

Table 1. The results descriptive statistical of biometry properties of five agricultural residues.

Property		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. The results descriptive statistical of morphological properties of five types of agricultural residues.

Agricultural residues	Slenderness ratio	Flexibility ratio	Runkel ratio
Bagasse	62.97	46.08	1.15
Corn	44.08	54.27	0.84
Sunflower	42.03	48.68	1.05
Rice	76.58	41.96	1.38
Rapeseed	39.59	64.26	0.55

Morphological properties

The average morphological of the five types of agricultural residues is presented in Table 2. The average slenderness and Runkel ratios in rice were more than other agricultural residues, but the flexibility ratio in rapeseed residues was more than other residues.

Chemical properties

Table 3 shows the percentage of various chemical components present in bagasse, corn, sunflower, rice, and rapeseed fibers. Differences among the types of agricultural residues were tested at the level of $p \leq 0.01$, and significant distinctions were marked with letters a, b, c, d, and e. Bagasse, rice and rapeseed residues contained the highest percentage of cellulose (55.56%), ash (15.73%), and alcohol-benzene content (6.10), respectively. Also the lignin of corn and sunflower

residues was more than other agricultural residues.

DISCUSSION

In this present study, the biometry, chemical and morphology properties of bagasse, corn, sunflower, rice and rapeseed residues were investigated in Iran. The mean fiber length in Bagasse residues was 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). These value for Iranian rice plant residues (0.83 mm) was more than the Chillan rice residues (0.594 mm), (Garay et al., 2009), and also this properties of corn plant residues in this present study (0.88 mm) was lower than the Chillan corn residues (1.52 mm), (Garay et al., 2009). Also the mean thickness of the fiber walls was 5.85 µm for sunflower, which was more than *Eucalyptus globulus Labill*, (2.38 to 2.98 µm), (Saavedra, 2004), and was less

Table 3. The results descriptive statistical of chemical properties of five agricultural residues.

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.

than hornbeam (*Carpinus betulus*), (6.64 μm), (Taleaipour et al., 2010). The thickness of cell walls was determined for rice and corn that were 4.59 and 3.16 μm , respectively. These values were more than rice hulls (2.3 μm) and corn residues (2 μm), (Garay et al., 2009).

Generally, the acceptable value for slenderness ratio of papermaking fibers are more than 33 (Xu et al., 2006). By referring to this and morphological properties of all types of agricultural residues fibers, they are suitable to be used for pulp and papermaking. Slenderness ratio for rice residues was 76.58, which rate was greater than wheat fibers (Eroglu, 1980) and tobacco stem (Tank, 1980). Generally, there are four different types of fibers which are classified under flexibility ratio (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 to 75.
- (3) Rigid fibers having elasticity ratio between 30 to 50.
- (4) High rigid fibers having elasticity ratio less than 30.

According to this classification, flexibility coefficient of bagasse, sunflower, and rice residues fibers were 46.08, 48.68 and 41.26, respectively, which fall under 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 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. On studies about 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 residues fibers were similar to other softwood fibers. Depending on all of these, it is possible to conclude that corn and rapeseed residues fibers are more preferable than bagasse, sunflower, and rice residues fibers for paper production. It is because rigid fibers do not have efficient elasticity, hence they are more suitable to be used for the production of fiber plate, rigid cardboard and cardboard.

By dividing cell wall thickness by lumen diameter, Runkel classification value was obtained. When Runkel proportion is greater than 1, it indicates that a fiber has thick wall and cellulose obtained from this type of fiber is less suitable for paper production; when it is equal to 1, it specifies that a cell wall has medium thickness and cellulose obtained from this type fiber is suitable for paper production. When the rate is less than 1, it points out that a cell wall is thin and cellulose obtained from this fiber is the most suitable for production of paper (Eroglu, 1980; Xu et al., 2006). Runkel value of the Bagasse, Sunflower, and Rice were 1.15, 1.05, and 1.38 and according to the Runkel classification, they fall under thick wall fibers group. As for corn and rapeseed, their Runkel values were 0.84, and 0.55, respectively, which make them fall under thin cell wall fibers group.

It was recorded that corn and sunflower residues contained the highest percentage of lignin (21.30%), but

the lignin content was still lower than that of wood fiber (14 to 37%) (Tsoumis, 1991), the high content of lignin in corn and sunflower fibers make the fibers appear tougher and stiffer, compared to other fibers. This is because lignin provides compressive strength to plant tissue and individual fibers and stiffens the cell walls, to protect carbohydrates from chemical and physical damages (Saheb and Jog, 1999). Lignin is an undesirable polymer, and its removal during pulping requires high amounts of energy and chemicals. Rapeseed and bagasses residues exhibited the lowest lignin content, which revealed that this material can undergo bleaching easier with the utilization of lower amounts of chemicals than other agricultural residues fibers.

In producing paper, increasing the amount of cellulose and decreasing value of lignin, the extractive content, and ash caused increase of yield, decrease of chemical material consumption, and cooking time (Panshin, 1980; Nieschlag et al., 1960). Paper strength depends on the cellulose content of a raw plant material. Cellulose content was at a satisfactory level (above 40%) for each type of fiber utilized for the present study. Overall, the bagasses fibers appear to be the most suitable for producing paper products compared to the other agricultural residues due to lower lignin and extractive components as well as higher in cellulose content.

Conclusions

(1) The biometry properties among all of agricultural residues followed the order given as:

- i. Fiber length: Bagasse > sunflower > rapeseed > corn > rice (lowest)
- ii. Fiber diameter: (Highest) rapeseed > sunflower > bagasse > corn > rice (lowest)
- iii. Cell wall thickness: (Highest) sunflower > bagasse > corn > rapeseed > rice (lowest)
- iv. Lumen width: (Highest) bagasse > rice > corn > sunflower > rapeseed (lowest)

(2) The chemical composition of five types of agricultural residues followed the order given as:

- i. Lignin: (Highest): corn, sunflower > rice > bagasse > rapeseed (lowest)
- ii. Cellulose: (Highest) bagasse > rice > corn > sunflower > rapeseed (lowest)
- iii. Extractive: (Highest) rapeseed > bagasse > rice > sunflower > corn (lowest)
- iv. Ash: (highest) rice > rapeseed > sunflower > corn > bagasse (lowest)

(3) The morphology characteristics of five types of agricultural residue followed the order given as:

- i. Slenderness ratio: (Highest) bagasse > rice > corn > sunflower > rapeseed (lowest)
- ii. Flexibility ratio: (Highest) bagasse > rice > corn > sunflower > rapeseed (lowest)
- iv. Runkel ratio: (Highest) bagasse > rice > corn > sunflower > rapeseed (lowest)

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