Nonwood Plant Fiber Characteristics

By **Robert W. Hurter**, P.Eng., MBA, President, **HurterConsult Incorporated**.
Extracted from "Agricultural Residues", TAPPI 1997 Nonwood Fibers Short Course Notes, updated and expanded August 2001.

There is considerable variability within a particular species of nonwood plant fiber raw material. Unlike wood which takes years to grow to pulpwood size, most commonly used nonwood plant fibers (some exceptions include bamboo, sisal, hesperaloe) are annual plants and the entire plant develops within a fairly short growing period. Plant genus, climate, soil conditions and farming practices all have a large impact on the plants and the ultimate pulp fiber.

Generally, nonwood plant fiber pulps can be grouped into two broad categories:

- common nonwoods or hardwood substitutes such as cereal straws, sugarcane bagasse, bamboo, reeds and grasses, esparto, kenaf, corn stalks, sorghum stalks etc.
- specialty nonwoods or softwood substitutes such as cotton staple and linters; flax, hemp and kenaf bast fibers; sisal; abaca; bamboo; hesperaloe etc.

Physical Characteristics

Softwoods are relatively uniform consisting of over 90% tracheid fibers and only 10% stubby ray cells and other fines. Hardwoods by comparison are more heterogeneous and contain only about 50% tracheid fibers and a large number of vessel cells and ray cells.

Nonwoods, however, have large differences in their physical and chemical characteristics, and they all contain to varying degrees a wide variety of fiber and cell types. Monocots such as cereal straws, sugarcane bagasse and corn stalks are more similar to hardwoods as the “fiber” fraction is in the same order; however, they are much more heterogeneous and contain a large proportion of very thin-walled cells, barrel-shaped parenchymous cells, and vessel and fine epidermal cells in a wide range of dimensions. Dicots such as flax straw, kenaf and hemp contain two distinct fiber types: an inner core of short fibers surrounded by a layer of longer bast fibers. Core fibers typically contain more lignin and are more difficult to pulp.

Fiber dimensions of various nonwoods are provided in the following table.

HurterConsult Incorporated
4-5330 Canotek Road
Ottawa, Ontario
Canada K1J 9C1

Phone: (613) 749-2181
Fax: (613) 749-1382
e-mail: **bobhurter@hurterconsult.com**
info@hurterconsult.com
URL: **www.HurterConsult.com**

Fiber dimensions of various nonwoods

Fiber Source		Length (microns)			Diameter (microns)			L/D Ratio
		Maximum	Minimum	Average	Maximum	Minimum	Average	
Bast Fibers								
Common (industrial) hemp		55000	5000	20000	50	16	22	1000:1
Jute (1)		4520	470	1060	72	8	26	45:1
Jute (2)		5000	500	2000	68	8	20	100:1
Kenaf		7600	980	2740			20	135:1
Oilseed flax tow		45000	10000	27000	30	16	22	1250:1
Textile flax tow		55000	16000	28000	28	14	21	1350:1
Core Fibers								
Kenaf		1100	400	600	37	18	30	20:1
Leaf Fibers								
Abaca		12000	2000	6000	36	12	20	300:1
Sisal		6000	1500	3030			17	180:1
Seed Hull Fibers								
Cotton staple		50000	20000	30000	30	12	20	1500:1
Cotton linters		6000	2000	3500	27	17	21	165:1
Stalk Fibers								
Canes	sugarcane bagasse	2800	800	1700	34	10	20	85:1
	bamboo (wide range)	3500 - 9000	375 - 2500	1360 - 4030	25 - 55	3 - 18	8 - 30	135 - 175:1
Cereal straw	wheat, rye, oats, barley, mixed	3120	680	1480	24	7	13	110:1
	rice	3480	650	1410	14	5	8	175:1
Grasses	esparto	1600	600	1100	14	4	9	120:1
	lemon			1320			9	145:1
	sabai	4900	450	2080	28	4	9	230:1
	switchgrass			1370			12.5	110:1
Reeds	arundo donax			1180			15	78:1
	papyrus	8000	300	1500	25	5	12	125:1
	phragmites communis	3000	100	1500	37	6	20	75:1
Stalks	corn	2800	680	1260	20	10	16	80:1
	cotton	2000	700	860			19	45:1
	grain sorghum			1650	80	30	47	35:1
	hesperaloe funifera			3200			15	213:1
Woods - for comparison								
Coniferous (softwood)		3600	2700	3000	43	32	30	100:1
Deciduous (hardwood)		1800	1000	1250	50	20	25	50:1

Sources:
1. Hurter, Robert W., "Agricultural Residues", TAPPI 1997 Nonwood Fibers Short Course.
2. Hurter, A.M., "Utilization of Annual Plants and Agricultural Residues for the Production of Pulp and Paper", Nonwood Plant Fiber Pulping Progress Report #19, TAPPI Press, pp. 49-70.

HurterConsult Incorporated
4-5330 Canotek Road
Ottawa, Ontario
Canada K1J 9C1

Phone: (613) 749-2181
Fax: (613) 749-1382
e-mail: **bobhurter@hurterconsult.com**
info@hurterconsult.com
URL: **www.HurterConsult.com**

Chemical Characteristics

The chemical composition of nonwood plant fibers varies widely depending on the type of plant and the soil and growing conditions. The following table gives chemical characteristics of various nonwoods for well-cleaned raw materials. Regarding chemical composition,

- all nonwoods are characterized by a lower lignin content than wood and a higher pentosan or hemicellulose content
- stalk fibers are closer to hardwoods in chemical properties than to softwoods - the major difference is in the higher ash and silica content of these nonwoods
- oilseed flax bast fiber has similar chemical properties to hardwoods; however, it has physical properties superior to softwoods
- cotton staple and linters fibers are in a class of their own with respect to chemical properties - they contain an alpha cellulose content double that of softwoods and only a fraction of the lignin contained in all of the other fibers

Chemical characteristics of various nonwoods are provided in the following table.

Papermaking

The wide variety of physical and chemical properties offered by nonwood plant fibers provides virtually endless opportunities for papermaking. Combinations of common and specialty nonwood pulps will permit the production of virtually any grade of paper to meet any quality requirements demanded in the global market. Adding possible combinations which include wood pulp, nonwood pulp and recycled wastepaper pulp increases the possibilities for developing paper with specific sheet properties designed to meet specific customers needs. See **Nonwood Plant Fiber Uses in Papermaking** for just some of the many possibilities for the use of various nonwoods in papermaking.

HurterConsult Incorporated
4-5330 Canotek Road
Ottawa, Ontario
Canada K1J 9C1

Phone: (613) 749-2181
Fax: (613) 749-1382
e-mail: **bobhurter@hurterconsult.com**
info@hurterconsult.com
URL: **www.HurterConsult.com**

Chemical properties of various nonwoods

Fiber Source		Cross & Bevan Cellulose (%)	Alpha Cellulose (%)	Lignin (%)	Pentosans (%)	Ash (%)	Silica (%)
Bast Fibers							
Jute (1)		57 - 58	39 - 42	21 - 26	18 - 21	0.5 - 1	<1
Jute sticks (whole jute)			43				
Kenaf - bast		47 - 57	31 - 39	15 - 18	21 - 23	2 - 5	
Kenaf - core			34	17.5	19.3	2.5	
Oilseed flax tow		47	34	23	25	2 - 5	
Textile flax tow		76 - 79	50 - 68	10 - 15	6 - 17	2 - 5	<1
Leaf Fibers							
Abaca		78	61	9	17	1	<1
Sisal		55 - 73	43 - 56	8 - 9	21 - 24	0.6 - 1	<1
Seed Hull Fibers							
Cotton staple			85 - 90	3 - 3.3		1 - 1.5	<1
Cotton linters			80 - 85	3 - 3.5		1 - 1.2	<1
Stalk Fibers							
Canes	sugarcane bagasse	49 - 62	32 - 44	19 - 24	27 - 32	1.5 - 5	0.7 - 3
	bamboo	57 - 66	26 - 43	21 - 31	15 - 26	1.7 - 5	1.5 - 3
Cereal straw	barley	47 - 48	31 - 34	14 - 15	24 - 29	5 - 7	3 - 6
	oat	44 - 53	31 - 37	16 - 19	27 - 38	6 - 8	4 - 7
	rice	43 - 49	28 - 36	12 - 16	23 - 28	15 - 20	9 - 14
	rye	50 - 54	33 - 35	16 - 19	27 - 30	2 - 5	0.5 - 4
	wheat	49 - 54	29 - 35	16 - 21	26 - 32	4 - 9	3 - 7
Grasses	arundo donax		29 - 33	21	28 - 32	4 - 6	1.1 - 1.3
	esparto	50 - 54	33 - 38	17 - 19	27 - 32	6 - 8	2 - 3
	sabai	54 - 57		17 - 22	18 - 24	5 - 7	3 - 4
	switchgrass		43	34 - 36	22 - 24	1.5 - 2	
Reeds	phragmites communis	57	45	22	20	3	2
Woods - for comparison							
Coniferous (softwood)		53 - 62	40 - 45	26 - 34	7 - 14	1	<1
Deciduous (hardwood)		54 - 61	38 - 49	23 - 30	19 - 26	1	<1

Note: **For well cleaned raw material** - the composition of uncleaned raw material will be different with respect to pentosans, solubles, ash and silica content in many cases.

Sources:

1. Hurter, Robert W., "Agricultural Residues", TAPPI 1997 Nonwood Fibers Short Course.
2. Hurter, A.M., "Utilization of Annual Plants and Agricultural Residues for the Production of Pulp and Paper", Nonwood Plant Fiber Pulping Progress Report #19, TAPPI Press, pp. 49-70.

HurterConsult Incorporated
4-5330 Canotek Road
Ottawa, Ontario
Canada K1J 9C1

Phone: (613) 749-2181
Fax: (613) 749-1382
e-mail: **bobhurter@hurterconsult.com**
info@hurterconsult.com
URL: **www.HurterConsult.com**