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Substituting Wood with Nonwood Fibers in Papermaking: A Win-Win Solution for Bangladesh

M. Sarwar Jahan, Bernhard G. Gunter, and A. F. M. Ataur Rahman[*]

Abstract

Bangladesh is facing an acute shortage of fibrous raw materials for the production of pulp and paper. On the other hand, the demand for paper and paper products is increasing day by day. This study reviews the availability and suitability of nonwood raw materials for pulp production in Bangladesh. It shows that Bangladesh has a huge amount of unused jute fiber, which is highly suitable for papermaking in Bangladesh. Other agricultural wastes like rice straw, dhaincha, golpata fronds, cotton stalks, corn stalks, and kash are also available and may be used for some pulp production. Given the different properties of these different nonwood fibers, jute pulp can be used as a reinforcing agent with other nonwood pulps for the production of high quality paper in Bangladesh.

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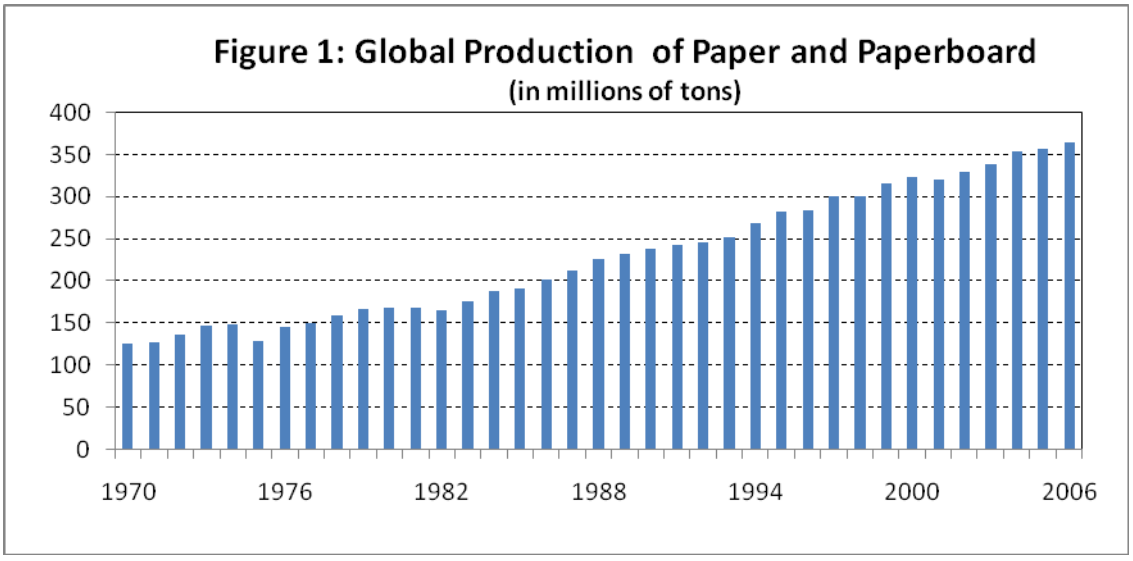
I. Introduction

Papermaking (defined as being made of pulped cellulose) was invented from nonwood materials in China almost 2000 years ago. Textile rags, cereal straw, reeds, grasses, and sugar cane bagasse have been used in pulping and papermaking ever since, especially in Asia. The invention of industrial printing in the 15th century implied a rapid increase in demand for paper. Yet, it was not until 400 years later, that the use of wood to make pulp had been invented in Germany by Friedrich Gottlob Keller in 1840. The annual production of paper from wood pulp has grown since to a multi-billion dollar industry, concentrated mostly in a few industrialized countries. Today, about 90 percent of all pulps are being produced from wood.

As Figure 1 shows, the global production of paper and board increased—with two exceptions (1975 and 1982)—continuously over the last few decades from 125 million tons in 1970 to 365 million tons in 2006.[1] It is projected that the market for paper and paper board will continue to grow globally at 2.3 percent per year until 2030,[2] with particularly sharp increases in developing countries (due to increases in population, literacy rates, and quality of life) and a slight decline in the most advanced industrialized counties (due to advances in electronic communications).



Source: FAO-STAT Forestry Database (http://www.fao.org/corp/statistics/en/)

The continued growth in paper consumption as well as the emergence of bio-fuel will lead to an increased demand for wood; creating additional pressure on the world's diminishing forest resources. Some efforts at the national and international levels are ongoing to find suitable substitutes for wood fibers, which are commonly called nonwoods. Some of these nonwoods are already used for papermaking, accounting for about 10 percent of the world's pulp production. Most nonwood pulp is produced from wheat straw in China and India. These two countries account for about 80 percent of the

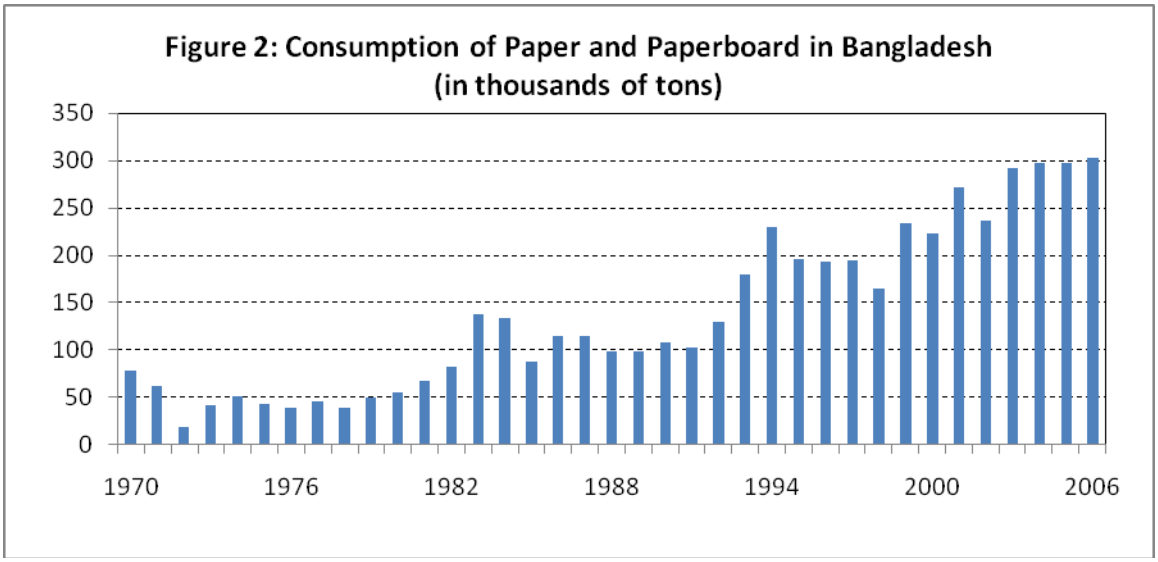
[1] In this paper, ton and tons refer always to metric ton and metric tons (i.e., containing 1000 kg).
[2] Organisation for Economic Co-operation and Development (OECD) (2008), p. 401.

total nonwood pulp production. [3] Over the last three decades, the share of nonwoods for papermaking has increased considerably in India.[4] Other nonwood fibers have been identified and used, but have not reached yet efficient industrial production levels.

Bangladesh is facing an acute shortage of fibrous raw materials for the pulp and paper industry. On the other hand, the demand for paper and paper products is increasing day by day in Bangladesh. This paper reviews the feasibility of utilizing nonwood raw materials for pulp production in Bangladesh. The paper is structured as follows. Following this introduction, the next section provides an overview of Bangladesh's paper industry. The third and fourth sections summarize the availability and suitability of nonwoods for papermaking in Bangladesh before the last section provides some concluding remarks.

II. Overview of Bangladesh's Paper Industry

As Figure 2 shows, Bangladesh's consumption of paper and paperboard has been slightly more volatile than consumption at the global level shown in Figure 1, but still shows a clearly increasing trend.



Source: FAO-STAT Forestry Database (http://www.fao.org/corp/statistics/en/)

In Bangladesh, the paper industry uses mostly bamboo and mixed hardwood. Both of these raw materials come from Bangladesh's forests,[5] which is however not sufficient to

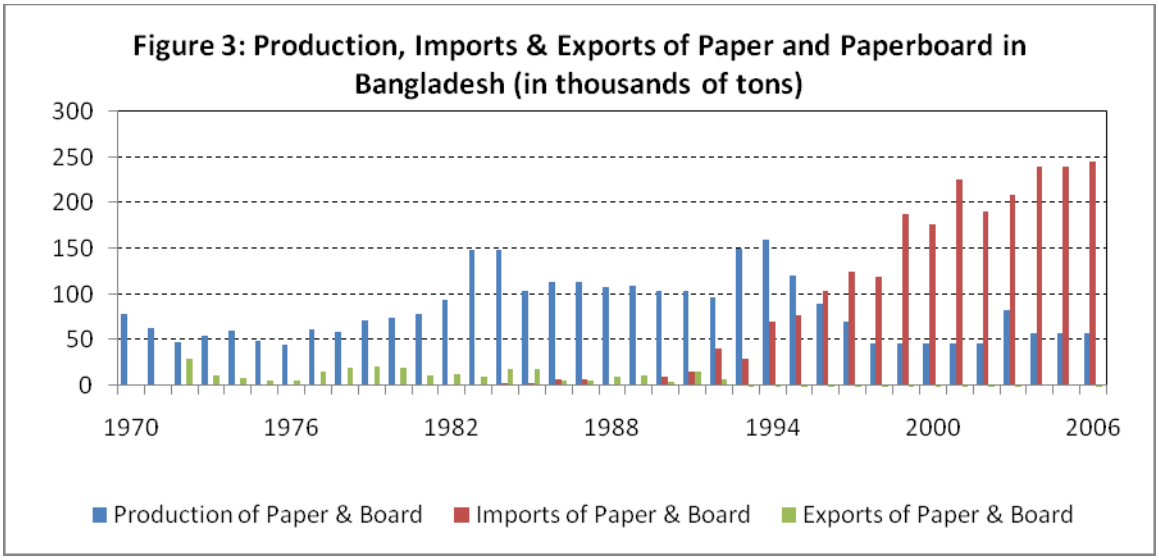
[3] Pande (1998) provides a useful table with information on non-wood paper fibers in the 18 countries that account for nearly 98 percent of world supply of non-wood paper. Atchison (1995) showed that during the early 1990s, China produced 86.9 percent of its paper pulp from nonwood plant fibers, while at least 47 countries in the world produced some nonwood plant fiber pulp, with some of them producing 100 percent of their pulp and some 10 countries more than 50 percent of their pulp from nonwood plant fibers.

[4] As the President of the Indian Paper Manufacturers' Association, Mr. Rajiv R. Vederah (2006) has shown, the share of nonwoods has increased in the Indian paper industry from 9 percent in 1970 to 31 percent in 2000.

satisfy the demand for paper in Bangladesh. Hence, as shown in Figure 3, beginning in the mid-1980s, Bangladesh has imported increasing amounts of pulp and paper. Today, Bangladesh imports about 250 thousand tons of paper and paperboard a year, which amounts to about US$300 million.

With increasing imports, the domestic production of paper and paperboard has decreased drastically in Bangladesh. Today, Bangladesh produces less than 20 percent of its paper and paperboard consumption. As documented by FAO (2002), Bangladesh's capacity to produce paper and paperboard has remained constant at 121,000 tons during 1997-2001, which implies that Bangladesh's paper mills are producing paper and paperboard at only half of their capacities. Though Bangladesh continues to export some paper and paperboard, the current amounts exported are so small (about 100 tons a year) that they do not even show up in Figure 3. In practical terms, the export of paper and paperboard from Bangladesh has ceased in 1992.

These developments are mostly due to the increasing shortages of wood fiber in Bangladesh, though they are also influenced by falling paper prices at the global level, due to an oversupply of paper and paperboard that built up at the global level mostly during the 1990s.



Source: FAO-STAT Forestry Database (http://www.fao.org/corp/statistics/en/)

These changes in the global and Bangladeshi paper industry had (and continue to have) considerable economic implications for Bangladesh, especially in terms of employment. Instead of importing pulp and paper in the amount of currently about US$300 a year,[6] the

[5] Presently, about 38,000 acres of forest are allocated and used for Bangladesh's pulp and paper industry. Most of these forests are occupied by tribal peoples, who traditionally apply a slash and burn (jhoom) cultivation, destroying huge amounts of forest, aggravating the increasing shortage of wood in Bangladesh.

[6] Estimation by authors based on 2000-2004 data provided in the International Trade Centre (UNCTAD/WTO) Database as of December 12, 2008 (www.intracen.org/tradstat/sitc3-3d/ir050.htm).

domestic production of Bangladesh's imported pulp and paper could create about 100,000 jobs in agriculture and industry.

III. Availability of Nonwood Fibers in Bangladesh

Nonwood fibers available in Bangladesh and potentially suitable for papermaking are straw, jute, golpata fronds, dhanicha, bagasse, corn stalks, cotton stalks, and kash. Though there is no comprehensive data available on the amount of agricultural wastes in Bangladesh, it is possible to estimate such amounts of waste based on the production of crops and the typical ratios of wastes to crops in Bangladesh. The following paragraphs provide more details on each of current availability of these nonwoods. Table 1 also provides the data for the current production, yields per hectare, and pulp yield per hectare in Bangladesh.[7] Similar assessments and analyses have been provided by Atchison (1998), Ashori (2006), De Jong and Begg (1999), Paper Task Force (1996), and Saijonkari-Pahkala (2001), and Saha, Kawata and Furukawa (1997).

III.1. Straw

As already mentioned, wheat straw is a major source of pulp for paper production in some Asian countries. The average yield of straw is 1.3-1.4 kg per kg of grain. In North America and Europe, nearly 300 million tons of wheat straw are produced yearly (Montane, Farriol, Salvado, Jollez and Chornet, 1998) and used for a variety of agricultural purposes, though not for papermaking. In Bangladesh, the availability of wheat straw is currently very limited (about 26,000 tons/year). On the other hand, rice straw is abundantly available in Bangladesh (though it is used extensively as animal food), amounting to about 34 million tons annually.

III.2. Jute

Jute (*Corchorus capsularis/olitorius*) is abundantly grown in Bangladesh, amounting currently to about 1 million tons a year, which constitutes nearly 40 percent of the world's jute production. Jute has a long historical role in the socioeconomic development of Bangladesh. Once, jute was known as the golden fiber of Bangladesh. It provided considerable employment opportunities to the country's work force as well as foreign currency. For example, during 1975-1979, exports of jute and jute-products accounted for 73 percent of Bangladesh's total exports.[8] Over the last two decades, the traditional uses of jute have—due to the emergence of synthetic fibers—declined drastically. Today, jute and jute products amount to less than 5 percent of Bangladesh's total exports.

III.3. Golpata Fronds

Golpata (*Nypa fruticans*) is a regal palm that grows abundantly in monotypic stands along the banks of the numerous rivers and canals that bisect the dense mangrove forests of the Sundarban. Every year, from December to May, thousands of *bawalis* (traditional forest users) collect an average of 60,000 tons of golpata fronds (palm leaves) from

[7] One hectare is equal to 2.471 acres or 10,000 square meters. Thousand hectares are equal to 3.9 square miles or 10 square kilometers.

[8] Calculations by authors, based on annual data provided in the Bangladesh Bank's *Economic Trends*.

throughout the Sundarban reserve forest. This number, however, could be a fraction of the actual amount harvested.

III.4. Dhaincha

Dhaincha (*Sesbania aculeate / Fussbnia rostata*) is a jute-like crop of which some species are known for their large showy flowers. It grows throughout Bangladesh, especially in the sandy region, where it protects land from erosion. It also fixes nitrogen to the soil and is therefore a very useful annual plant for Bangladesh's agricultural system. It is cultivated during the monsoon season almost throughout Bangladesh It is an ideal green manure crop as it is quick-growing, succulent, easily decomposable with low moisture requirements and produces maximum amount of organic matter and nitrogen in the soil. The plant is extremely fast growing and can produce yields in excess of 20 bone dry tons per hectare during its short life. It has presently no industrial use, though it is occasionally used for the production of rope.

III. 5. Bagasse, Corn Stalks, Cotton Stalks, and Kash

Bagasse is the outer stalk of sugar cane, a by-product of sugar mills. About 0.7 million tons of bagasse are produced in Bangladesh annually. Sugar mills in Bangladesh use bagasse as fuel for steam generation. Therefore, sugar mills consume almost all bagasse. Bangladesh produces 64,000 tons of corn a year, which is estimated to come with about 128,000 tons of corn stalks. Cotton stalks are agricultural waste that needs to be removed after the collection of cotton. Despite negative environmental implications, it is typically burnt in the field to minimize the removal costs. It is rarely also used as domestic fuel in rural areas. Finally, Kash (*Saccharum spontaneum*), which is the Bangladeshi term of what is called Kan in India, grows in the wet and sandy lands of Bangladesh and some parts of India. It is currently used in a limited extent as fencing in rural areas. Its production may increase to a few folds if proper planning is taken.

Table 1. Current Production, Yields per Hectare, and Pulp Yield per Hectare of Nonwoods in Bangladesh

Plant	Current Production (thousands of tons)	Annual fiber yield (tons/hectare)	Annual pulp yield (tons/hectare)
Rice straw	34,020	3	1.2
Wheat straw	25.8	4	1.9
Jute	963	15	7
Golpata fronds	60	n.a.	n.a.
Dhanicha	50	15-18	7-9
Bagasse	700	9	4.2
Corn stalks	128	8-10	3.2-4.3
Cotton stalks	36	8-10	3.5-4.3

Source: See Jahan (2003b) for details.

IV. Suitability of Nonwood Fibers

In papermaking, it is very often the case that more than one type (or grade) of pulp is used to develop paper sheet properties necessary for both machine runnability and end user's requirement. In many paper grades, long fiber from softwood bleached kraft pulp traditionally is used in combination with short fiber from hardwood bleached kraft pulp (HBKP). In this combination, the long fiber component provides the strength (especially tear resistance) to the paper sheet, while the short fiber helps to improve the paper functional properties, such as sheet smoothness and formation. With regards to nonwood fibers, jute fiber provides long fiber furnish, where cotton stalks, corn stalks, straw and other nonwood fibers available in Bangladesh provide short fiber furnish, which for example make the combination of jute and cotton fibers highly suitable for papermaking; see Jahan and Farouqui (2001) for further details. Yet, fiber length is only one of many criteria that need to be considered when assessing the suitability for papermaking. Furthermore, the chemical and morphological characteristics of nonwood fibers vary by geographical location. Unless noted otherwise, the chemical and morphological characteristics as well as the pulping properties described below are based on experimental analyses carried out by Jahan et al. in the BCSIR laboratories, based on nonwoods as they are grown in Bangladesh. Further details on the chemical composition and properties of nonwoods are provided by Han (1998), Hurter (2001), Hurter and Hurter (2003), Jahan, Mun and Rashid (2004), Reddy and Yang (2005), and Tajvidi, Najafi, Shekaraby and Motiee (2006).

IV.1. Straw

While the very limited amount of wheat straw Bangladesh has is suitable for some papermaking, the high silica content (amounting to 9-14 percent) in Bangladesh's abundant rice straw currently prohibits its economic use as pulping raw material. The silica causes problems in the recovery of chemicals used in the pulping process. Other shortcomings with the use of all kinds of straw for pulp are the higher water retention capacity of straw, the lower yield per ton of raw material compared to wood, and the low bulk density of straw. It is generally accepted that fibers such as straw are currently not optimal to be used on a 100 percent basis for paper manufacturing, as their poor drainability and low tearing strength make it necessary to add a certain amount of long fibers from other sources. For further details, see Jahan, Lee and Jin (2005 and 2006). Similarly, Garg, Gautam and Singh (2008) have shown that straw can be a useful aid for softwood pulping.

IV.2. Jute

Over the last 20 years, many studies have been done on the suitability of jute pulping in Bangladesh and other countries.[9] Jute fiber, which is coming from the bark of the jute plant, produces pulp of good quality pulp with a yield above 60 percent. The papermaking properties are similar to softwood pulp (Akhtaruzzaman and Shafi 1995).

[9] Some of these are Gupta, Shivhare, Roy and Mohindru (1998); Hurter (2001); Jahan, Al-Maruf and Quaiyyum (2007); Jahan, Chowdhury, Islam and Islam (2007); Jahan and Farouqui (2005); Jahan, Kanna, Mun and Chowdhury (2008); Jahan, Rawsan, Chowdhury and Al-Maruf (2008); Kulkarni (1999); Lutfar and Rahman (2008); and Nahar (1987). Mohiuddin (2004) provides a useful non-technical summary.

The Schopper-Riegler (SR) number[10] of unbeaten pulp is below 15, which is acceptable for subsequent processing. Jute fiber pulp could be used in high quality paper and adding anthraquinone or amine in soda liquor results in excellent quality pulp (Jahan, 1999). Furthermore, alkaline sulfite anthraquinone methanol (ASAM)-processed jute pulp had also excellent strength properties and bleachability (Jahan, Chowdhury and Islam, 2005), further attracting jute fiber for high quality paper pulp.

If instead of jute fiber the whole jute plant (stick and bark) is used in pulping, pulp yield is about 45-55 percent, with a satisfactory Kappa number (which provides a measure of the lignin content relevant for the bleachability of pulp) of about 20-35. The stick of jute contains high lignin and has short fiber length, hence pulp produced from whole jute plant shows higher tensile but moderate tear strength compared to jute fiber pulp. The SR number is around 15, which is acceptable in respect to pulp washing, screening, and paper machine running. Experiments have also shown that whole jute plants produce pulp of very high tensile-tear if applying the ASAM process.

Table 2: Chemical and Morphological Characteristics of Woods and Nonwoods

Type of fibers	α-cellulose	Lignin (percent)	Pentosan (percent)	Fiber length (mm)	Fiber diameter (mm)	Ash (percent)
Softwood	40-45	26-34	7-14	2.7-4.6	32-43	<1
Hardwood	38-49	23-30	19-26	0.7-3.0	20-40	<1
Bamboo	26-43	21-31	15-16	2.7	14	1.7-5.0
Wheat straw	29-35	16-21	26-32	1.4	13	4.5-9.0
Jute fiber	45-63	16-Dec	18-22	2.5	20	0.5-2.0
Bagasse	32-44	19-24	27-32	1.7	20	1.5-5.0
Golpata fronds	36.3	18.1	24.9	1.73	10	7.0
Corn stalks	45.5	30.87	19.86	1.0-1.5	18	6.0-6.9
Cotton stalks	36.15	16.7	27.1	1.3	20-30	3.1
Kash	52	16.82	24	1.52	16	3.9

Source: See Jahan (2003b) for details.

IV.3. Bagasse

Pith is the main problem for bagasse pulping as it creates problems during pulp washing, clogging in machine wire, etc. Adequate removal of pith is essential to produce a satisfactory pulp and to avoid wastage of chemicals. De-pithing is possible with dry, moist or wet bagasse. The strength of bagasse pulp is slightly lower than that of hardwood pulp. Bagasse pulps are generally smooth and soft. Bagasse has been used in

[10] The SR number is a relative value for the filtration property of pulp. It is based on the reduction of filtration rate due to the formation of a fiber pad on the wire of the apparatus. The filtration rate decreases as the thickness of the fiber pad on the wire increases. Therefore, the faster the filtration rate decreases, the larger is the SR number of the pulp.

many grades where local factors limit the availability of better pulp. Paper grades in which bagasse have proven to be particularly suitable include writing, printing, tissue grades, corrugating medium and newsprint. For further details, see Covey, Rainey and Shore (2006), Jahan (2006), and Panwar, Upadhyay, Sharma and Marwal (2008).

IV.4. Golpata Fronds

While the pulp yield of golpata fronds is very low, the chemical and morphological properties of golpata fronds are comparable to some common nonwood and hardwood raw materials. The anatomical properties showed that the vascular bundles in golpata fronds are very low. The observed fiber length of 1.73 mm is a little bit shorter than the length of softwood fiber, though longer than that of hardwood fiber. The Kappa number of golpata fronds pulp was high and its strength properties are better than that of some common nonwood pulps (Jahan, Chowdhury and Islam, 2006b).

IV.5. Dhaincha

The chemical and morphological properties of dhanicha favor it as pulping raw material. The higher slender ratio of dhaincha fiber produces pulp of better tear strength than the other similar fiber length raw material. The pulp yield (42-44 percent) and Kappa number (20-29) of dhaincha are similar to tropical hardwood. Other papermaking properties of dhaincha pulp are also similar to hardwood. Unbleached dhaincha pulp is highly suitable for packing paper. Experiments have also shown that the tear index of dhaincha pulp can be improved by adding jute pulp (Jahan, Chowdhury and Islam, 2007).

Table 3: Pulping Properties of Nonwood Raw Materials

(Physical properties at oSR 35-45)

Nonwood	Pulp yield, %	Kappa number	Breaking length, m	Burst index kPa.m2/g	Tear index mN.m2/g	Initial oSR
Bamboo	45.9	24.6	5,511	4.9	18.1	12
Rice straw	38.8	13.6	6,590	3.8	6.7	
Wheat straw	46.7	16	8,680	3.9	5.79	28
Whole jute plant	55.6	30.3	7,336	7	9.8	15-17
Jute fiber	64.9	18.7	8,393	7.6	15.2	12-15
Bagasse	50.5	13.3	5,600	3.6	6.8	
Golpata fronds	37.2	27.2	7,228	4.5	11.6	45
Dhanicha	43.3	29	9,745	7	9.8	15
Corn stalks	50.5	23.4	7,307	5.1	4.7	23
Cotton stalks	44.5	33	5,500	5.4	7.1	15
Kash	57.9	20	5,536	3.2	6.5	23

Source: See Jahan (2003b) for details.

IV.6. Corn Stalks

The chemical and morphological characteristics of corn stalks are comparable to hardwood species. Corn stalks are easier to delignify than wood. Corn stalks also require lower temperatures for pulping. The pulp yield is about 50 percent at the Kappa number is 20. The papermaking properties are very good except tear strength. However, it was

observed that the blending of corn stalks pulp with jute pulp increased tear strength. Experiments have also shown that applying the ASAM process improves the bleachability of corn stalks pulp, while the so-called Soda-Anthraquinone (AQ) process improves the pulp yield and the Kappa number of corn stalk pulp (Jahan, Chowdhury, Russel, Shamim, Mun and Quaiyyum, 2006). Due to corn pulp's high fine content, its water retention is very high.

IV.7. Cotton Stalks

The chemical and morphological properties of cotton stalks are comparable to hardwoods. Anatomically, cotton stalks are similar to hardwood. The pulp yield is about 40-45 percent and the Kappa number of soda-AQ processed cotton stalk pulp is 30-35. The SR number of unbeaten cotton stalks pulp is about 12-15. The tensile strength of cotton stalks pulp is good but its tear index is low. However, as Islam and Jahan (2001) have shown, blending of cotton stalks pulp with jute pulp increased the tear index. The bleachability of cotton stalks pulps is very good even if applying ECF bleaching.[11] For further details, see Jahan, Quaiyyum, Islam and Shafique (2001) and Jahan, Chowdhury, Islam and Hasan (2004), and Jahan, Chowdhury, Islam and Ahmed (2006).

IV.8. Kash

Pulp yield from kash is very high and the Kappa number is very low (Jahan, Islam, Hasan, and Chowdhury, 2002). The initial brightness (about 50 percent) of kash pulp is suitable for newsprint. The papermaking properties are comparable to tropical hardwood. Kash pulp provides very good bleachability in both ECF and totally chlorine free (TCF) bleaching. See also Tyagi and Dutt (2007).

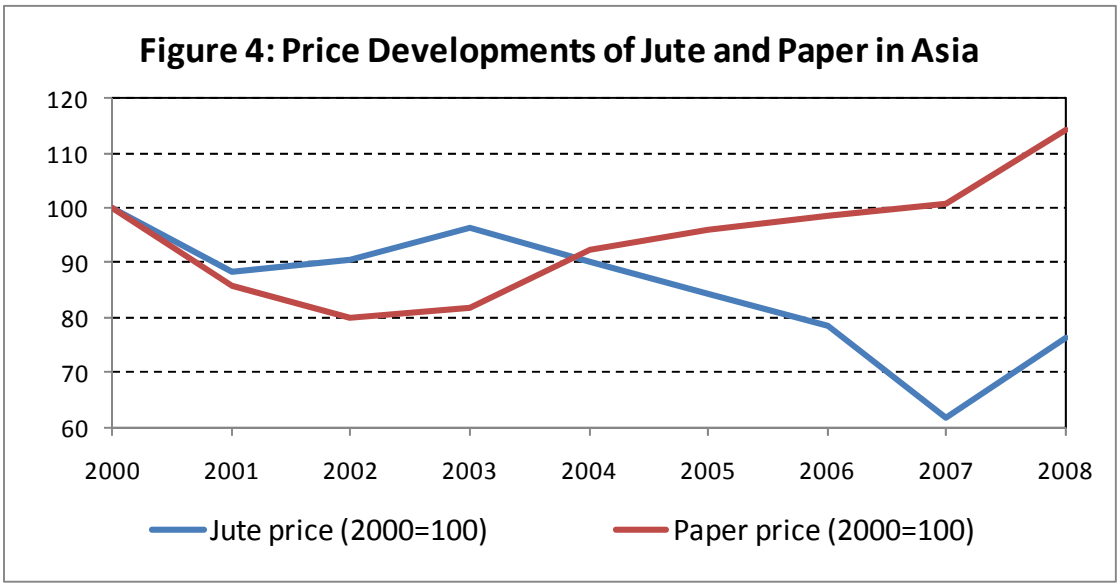
V. Concluding Remarks

Availability and suitability do not necessarily guarantee the economic viability of nonwoods for papermaking in Bangladesh. For example, there was one bagasse-based pulp mill in Bangladesh, which was however shutdown recently due to the cheaper supply of other fibrous raw materials. One next step would be to compare the domestic market value of nonwoods with the price of imported raw materials (both woods and nonwoods) as well as imported pulp. Hence, Bangladesh's comparative as well as competitive advantages will need to be analyzed. Furthermore, given that land is scarce in Bangladesh, issues related to alternative uses of land and their distributional implications will need to be taken into considerations. For example, growing jute (for paper) instead of rice (for food) would have negative implications on already high food prices, benefitting food producers but hurting food consumers. The sections above have provided some indications. The burning of corn stalks on the field shows that some agricultural waste is currently not valued in Bangladesh. On the other hand, while bagasse is physically available and chemically suitable, its current use for energy

[11] ECF bleaching — based on chlorine dioxide — is the superior technology choice for sustainable pulp and paper manufacturing, consistent with U.S. Environmental Protection Agency (EPA) and European Community guidelines and regulations, intended to ensure compliance with the International Stockholm Convention on Persistent Organic Pollutants.

generation within the sugar mills make it less likely to be economically feasible for papermaking, unless cheaper energy sources can be found for the sugar mills.

Indeed, the recent developments in the production of biofuels may imply competitive usages of some agricultural waste that is currently not valued. Looking at current trends of paper and jute prices in Asia from 2000 to 2008 (shown in Figure 4), the price (and hence, demand) for jute remains low, while the price (and demand) for paper is increasing in Asia. Based on these price trends it would also make economic sense to give jute a larger role in papermaking.



Source: Calculations by authors based on FAOSTAT, updated by Paperloop and WorldJute.com

Furthermore, given that economic prices may—due to externalities—not reflect the true values of goods to society, other considerations will need to be taken into account. For example, the wood that comes from cutting down forests in countries that have huge reserves of forests may be priced cheaper in market values than some nonwood fibers available in Bangladesh, but would obviously not make sense when taking environmental aspects into account. Indeed, as the Paper Task Force (1996, p. 15) has pointed out: "Non-wood plants may provide an additional source of fiber to papermakers, and thus, reduce the harvesting of trees from natural forests or the conversion of natural forests into tree plantations."

Little information is available to compare the environmental releases associated with nonwood and wood pulping. Many existing nonwood pulping operations, both in the developing world (for commercial paper applications) and the developed world (for specialty paper applications), are technologically outdated. Because of their small scale, most of these mills use chemical pulping processes without chemical recovery, a practice, which is both economically and environmentally inefficient. Therefore, black liquor is either treated before discharge or transported to wood-based pulp mills for recovery.

Based on their fiber properties, using nonwood fibers instead of wood chips may offer opportunities to reduce the magnitude of environmental releases generated by the pulping process. There also is some common misconception with regards to environmental standards of Bangladeshi paper mills. As Hartman, Huq and Wheeler (1997, p. 26) have stated: "Clean production [of paper] is not uncommon, even in very poor countries such as Bangladesh."

Another question that has been raised is on the technical feasibility of nonwood pulp recyclability. In general, nonwood fibers are as recyclable as wood fibers (see Garg and Singh, 2004). The strength of pulp made from recovered fibers determines its usefulness. Fiber length as well as fiber bonding ability determines pulp strength. Recovered fibers on average are shorter than virgin fibers and lose strength with each reuse cycle (Jahan, 2003a). For nonwood fibers that are generally shorter than wood fibers (such as wheat straw), issues such as slow drainage and low strength are a problem both in virgin production and recovered fiber paper production. On the other hand, nonwood fibers with greater fiber length can be used to compensate for losses in pulp strength from recycling. Depending on the strength of the nonwood fiber, more or less virgin pulp has to be added to the deinked pulp to produce high quality recycled paper.

Finally, in addition to physical, chemical, economic and environmental issues, we also need to take institutional issues into account. For example, though jute has been successfully tried as a raw material for pulp and paper in Bangladesh, China, India, Thailand and the United States, the global paper industry has been reacting very slowly in adopting it as a new pulping resource. Hence, there is an additional role for policy to encourage through price and non-price instruments the overall most beneficial way of papermaking in Bangladesh.

Based on current information, there is a good possibility in Bangladesh to set up integrated pulp mills based on nonwood fibers (with separate fiber lines for different fibers), which will contribute to a friendly environment as well as provide jobs and incomes in Bangladesh. Hence, substituting wood with some nonwood fibers in papermaking could imply a win-win solution for Bangladesh.

References

Akhtaruzzaman, A. F. M. and M. Shafi (1995) "Pulping of Jute", *Tappi*, Vol. 78, No. 2 (February), pp. 106-109.

Ashori, Alireza (2006) "Nonwood Fibers—A Potential Source of Raw Material in Papermaking", *Polymer-Plastics Technology and Engineering*, Vol. 45, No. 10 (October), pp. 1133-1136.

Atchison, Joseph E. (1995) "Twenty-Five Years of Global Progress in Non-Wood Plant Fibre Pulping -- Historical Highlights, Present Status and Future Prospects", in: *Tappi Proceedings of the 1995 Pulping Conference* (Atlanta, GA, USA: Tappi Press), Book 1, pp. 91-101; Summary available at: http://www.tappi.org/s_tappi/doc_bookstore.asp?CID=5488&DID=522120.

Atchison, Joseph E. (1998) "Progress in the Global Use of Non-wood Plant Fibers and Prospects for Their Greater Use in the Future", *Inpaper International*, Vol. 2 (April-June), No. 4, pp. 21-30.

Covey, Geoff; Tom Rainey; and Dennis Shore (2006) "The Potential for Bagasse Pulping in Australia", *Appita Journal*, Vol. 59, No. 1 (January), pp. 17-22.

De Jong, Stuart and John Begg (1999) *Market Opportunities for Non-Wood Fibre Crops* (Kingston, Australia: Rural Industries Research and Development Corporation (RIRDC), RIRDC Publication No 99/160, November); available at: http://www.rirdc.gov.au/reports/NPP/99-160.pdf.

Food and Agricultural Organization (FAO) (2002) *Pulp and Paper Capacities Survey 1996-2001* (Rome, Italy: Food and Agricultural Organization (FAO)); available at: http://www.fao.org/docrep/w5622t/w5622t0b.

Garg, Mayank and Surendra P. Singh (2004) "Recycling Potential of Bagasse and Wheat Straw Pulps", *Tappi Journal*, Vol. 3, No. 9, pp. 25-31.

Garg, Mayank; Amit K. Gautam; and Surendra P. Singh (2008) "Wheat Straw Pulp as Reinforcing Aid for Recycled Softwood Pulp", *IPPTA Journal*, Vol. 20, No. 2 (April-June), pp. 113-117; available at: http://www.ipptaonline.org/April-June%202008/2008_Issue_2_IPPTA_Article_9.pdf.

Gupta, H. K.; P. Shivhare; T. K. Roy; and V. K. Mohindru (1998) "Whole Jute: A Promising Raw Material for the Production of Pulps for Different Grades of Paper and Newsprint", Paper presented at the Proceedings of the 1998 TAPPI Pulping Conference, held at Montreal, Canada.

Gupta, Ramesh Chandra (1999) "A Report on the Bangladesh Pulp and Paper Industry", *Tappi Journal*, Vol. 82, No. 3, pp. 93-95

Han, James S. (1998) "Properties of Nonwood Fibers", in: *Proceedings of the 1998 Annual Meeting of the Korean Society of Wood Science and Technology* (Seoul, Korea: Korean Society of Wood Science and Technology); available at: http://www.fpl.fs.fed.us/documnts/pdf1998/han98a.pdf.

Hartman, Raymond S.; Mainul Huq; and David Wheeler (1997) "Why Paper Mills Clean Up – Determinants of Pollution Abatement in Four Asian Countries", Washington, DC: World Bank, *Policy Research Working Paper*, No. 1710 (January).

Hurter, A. M. and Robert W. Hurter (2003) *Chemical Properties of Dissolving Pulps from Nonwood Fibers* (Ottawa, Ontario, Canada: HurterConsult Inc.).

Hurter, Robert W. (2001) *Nonwood Plant Fiber Uses in Papermaking* (Ottawa, Ontario, Canada: HurterConsult Inc.); available at: www.hurterconsult.com/nonwood_uses.htm.

Islam, M. Khalidul and M. Sarwar Jahan (2001) "Blending of Nonwood Fiber Pulp for Making Paper", *IPPTA Journal*, Vol. 13, No. 2, pp. 7-12.

Jahan, M. Sarwar (1999) *Studies on the Pulping of Jute Based Raw Materials Using Various Additives and Their Characteristics* (Rajshahi: Rajshahi University, Ph.D. Dissertation).

Jahan, M. Sarwar (2003a) “Changes of Paper Properties of Non-wood Pulp on Recycling”, *Tappi Journal*, Vol. 2, No. 7, pp. 9-12.

Jahan, M. Sarwar (2003b) “Future Fibers for Pulp Mills in Bangladesh”, Paper submitted to the XII World Forestry Congress, Québec City, Canada (21-28 September); draft available at: http://www.fao.org/docrep/article/wfc/xii/0335-a2.htm.

Jahan, M. Sarwar (2006) “Formic Acid Pulping of Bagasse”, *Bangladesh Journal of Scientific and Industrial Research*, Vol. 41, No. 3-4, pp. 245-250.

Jahan, M. Sarwar; A. Al-Maruf; and M. A. Quaiyyum (2007) “Some Comparative Studies of Pulping of Jute Fiber, Jute Cutting and Jute Caddis”, *Bangladesh Journal of Scientific and Industrial Research*, Vol. 42, No. 4, pp. 425-434; available at: http://www.banglajol.info/index.php/BJSIR/article/viewFile/750/791.

Jahan, M. Sarwar; D. A. Nasima Chowdhury; and M. Khalidul Islam (2005) “Alkaline Sulphite Anthraquinone Methanol (ASAM) Pulping of Jute”, *IPPTA Journal*, Vol. 17, No. 3, pp. 37-43.

Jahan, M. Sarwar; D. A. Nasima Chowdhury; and M. Khalidul Islam (2006a) “NS-AQ Pulping of Kash (*Saccharum spontaneum*)”, *IPPTA Journal*, Vol. 18, No. 1, pp. 69-74.

Jahan, M. Sarwar; D. A. Nasima Chowdhury; and M. Khalidul Islam (2006b) “Characterization and Evaluation of Golpata Fronds as Pulping Raw Materials”, *Bioresource Technology*, Vol. 97, No. 3 (February), pp. 401-406.

Jahan, M. Sarwar; D. A. Nasima Chowdhury; and M. Khalidul Islam (2007) “Pulping of Dhaincha (*Sesbania aculeata*)”, *Cellulose Chemistry and Technology*, Vol. 41, No. 7/8, pp. 413-421.

Jahan, M. Sarwar; D. A. Nasima Chowdhury; M. Khalidul Islam; and F. N. Ahmed (2006) “Elemental Chlorine Free and Total Chlorine Free Bleaching of Soda-AQ Cotton Stalks Pulps”, *Journal of the Asiatic Society of Bangladesh, Science*, Vol. 32, No. 2, pp. 179-186.

Jahan, M. Sarwar; D. A. Nasima Chowdhury; M. Khalidul Islam; and M. Shahidul Islam (2007), “Organic Acid Pulping of Jute and Its Mechanism”, *Cellulose Chemistry and Technology*, Vol. 41, No. 2-3, pp. 137-147.

Jahan, M. Sarwar; D. A. Nasima Chowdhury; M. Khalidul Islam; and A. J. M. Moynul Hasan (2004) “Kraft Pulping of Bangladeshi Cotton Stalks”, *Bangladesh Journal of Scientific and Industrial Research*, Vol. 39, No. 3-4, pp. 139-146.

Jahan, M. Sarwar; D. A. Nasima Chowdhury; M. A. N. Russel; S. A. N. Shamim; Sung Phil Mun; and M. A. Quaiyyum (2006) “Alkaline Sulfite-Anthraquinone-Methanol (ASAM) Pulping of Corn Stalks”, *Cellulose Chemistry and Technology*, Vol. 40, No.7, pp. 531-536.

Jahan, M. Sarwar and F. I. Farouqui (2001) “Studies on the Blending of Cotton Stalk Plant Pulp with Jute Pulp for Paper Making”, *Journal of the Bangladesh Chemical Society*, Vol. 14, No. 1, pp. 1-7.

Jahan, M. Sarwar and F. I. Farouqui (2005) "Pulping of Retted Jute Fiber (*C. capsularies*) by Soda-additive Processes, *Cellulose Chemistry and Technology*, Vol. 39, No. 3-4, pp. 225-236.

Jahan, M. Sarwar; M. Khalidul Islam; A. J. M. Moynul Hasan; and D. A. Nasima Chowdhury (2002) "Investigation on Soda and Soda-Anthraquinone (AQ) Pulping of *Saccharum spontaneum*", *Tappa Journal* (May) pp. 21-25; available at: www.tappsa.co.za/archive/Journal_papers/Investigation_on_soda/investigation_on_soda.html.

Jahan, M. Sarwar; G. H. Kanna; Sung Phil Mun; and D. A. Nasima Chowdhury (2008) "Variations in Chemical Characteristics and Pulpability within Jute Plant (*Chorcorus capsularis*)", *Industrial Crops and Products*, Vol. 28, No. 2, pp. 199-205.

Jahan, M. Sarwar; Sung Phil Mun; and Mamunur Rashid (2004) "Fiber Dimensions and Chemical Properties of Various Nonwood Materials and Their Suitability for Paper Production", *Korea Tappi Journal*, Vol. 36, No. 5, pp. 29-35.

Jahan, M. Sarwar; Zhong Zheng Lee; and Yongcan Jin (2005) "Organic Acid Pulping of Rice Straw, Part-II: Bleaching and Beating", *Cellulose Chemistry and Technology*, Vol. 39, No. 1-2, pp. 85-94.

Jahan, M. Sarwar; Zhong Zheng Lee; and Yongcan Jin (2006) "Organic Acid Pulping of Rice Straw, Part-I: Cooking", *Turkish Journal of Agricultural Forestry*, Vol. 30, No. 3, pp. 231-239.

Jahan, M. Sarwar; M. A. Quaiyyum; M. Khalidul Islam; and M. Shafique (2001) "Utilization of Bangladeshi Cotton Plant Stalk as Pulping Raw Materials", B*angladesh Journal of Science and Technology*, Vol. 3, No. 1, pp. 41-48.

Jahan, M. Sarwar; Sabina Rawsan; D. A. Nasima Chowdhury; and A. Al-Maruf (2008) "Alternative Pulping Process for Producing Dissolving Pulp from Jute", *BioResources*, Vol. 3, No. 4, 1359-1370.

Kulkarni, A. G. (1999) "Jute for High-Value Pulp: Laboratory and Pilot Plant Studies", Paper presented at the Workshop on Prospects for the Pulp and Paper Industry in China (April).

Lora, Jairo H. (2002) "Characteristics, Industrial Sources, and Utilization of Lignins from Nonwood Plants" in: Thomas Q. Hu (ed.) *Chemical Modification, Properties, and Usage of Lignin* (New York: Kluwer Academic/Plenum Publishers), pp. 267-281.

Lutfar, Latifa Binte and Md. Siddiqur Rahman (2008) "Technologies for Creating Improved Value-added Jute Products with Emphasis on Pulp and Paper", Presentation made at the International Symposium on "Jute and Allied Fibres Production, Utilisation and Marketing", held at the Bhasha Bhavan, National Library in Kolkata, India (9-12. January); available at: http://www.jute.org/news.htm.

Mohiuddin, G. (2004) "Utilising Whole Jute Plant as Raw Material for Pulp and Paper", *The Daily Star* (of April 5, section on Point-Counterpoint); available at: http://www.thedailystar.net/2004/04/05/d404051502116.htm.

Montane, D.; X. Farriol; J. Salvado, P. Jollez; and E. Chornet (1998) "Fractionation of Wheat Straw by Steam Explosion Pretreatment and Alkali Delignification. Cellulose Pulp and By-products from Hemicellulose and Lignin", *Journal of Wood Chemistry and Technology*, Vol. 18, pp. 171-191.

Nahar N. (1987) *Studies on the Carbohydrates on Jute and Pigeon Pea* (Uppsala, Sweden: Swedish University of Agricultural Science, Ph.D. Dissertation).

Organisation for Economic Co-operation and Development (OECD) (2008) *OECD Environmental Outlook 2030* (Paris, France: OECD).

Pande, H. (1998) "Non-wood Fibre and Global Fibre Supply", *Unasylva -- An International Journal of the Forestry and Food Industries*, No. 193; available at: http://www.fao.org/docrep/W7990E/w7990e00.HTM.

Panwar M. P.; A. K. Upadhyay; P. N. Sharma; and Himanshu Marwal (2008) "Raw Material Preparation & Cooking For Agro-Based Paper Manufacturing", *IPPTA Journal*, Vol. 20, No. 3 (July-September), pp. 173-177; available at: http://www.ipptaonline.org/July-Sept%202008/2008_Issue_3_IPPTA_Article_19.pdf.

Paper Task Force (1996) *Non-Wood Plant Fibers as Alternative Fiber Sources for Papermaking (White Paper 13)* (Washington, DC: Environmental Defense Fund, July); available at: http://www.edf.org/documents/1634_WP13.pdf.

Reddy, Narendra and Yiqi Yang (2005) "Biofibers from Agricultural Byproducts for Industrial Applications", *Trends in Biotechnology*, Vol. 23, No. 1 (January), pp. 22-27.

Saijonkari-Pahkala, Katri (2001) *Nonwood Plants as Raw Material for Pulp and Paper* (Ruukki, Finland: MTT Agrifood Research, Academic Dissertation); available at: http://ethesis.helsinki.fi/julkaisut/maa/sbiol/vk/saijonkari-pahkala/nonwoodp.pdf.

Saha, Narayan; Isao Kawata; and Yasushi Furukawa (1997) "Alternative Fiber Resources for Pulp and paper Industry of Bangladesh: Why and What?", *Journal of Forest Research*, Vol. 2, No. 3 (August), pp. 165-170.

Tajvidi, Mehdi; Saeed Kazemi Najafi; Mohammad Mehdi Shekaraby; and Nazanin Motiee (2006) "Effect of Chemical Reagents on the Mechanical Properties of Natural Fiber Polypropylene Composites", *Polymer Composites*, Vol. 27, No. 5, pp. 563-569.

Tyagi, C. H. and Dharm Dutt (2007) "Studies on Pulp and Paper Making Characteristics of *Saccharum spontaneum*", *IPPTA Journal*, Vol. 19, No. 2 (April-June), pp. 109-114.

Vederah, Rajiv R. (2006) "The Role of India", Presentation made at the 47th Session of the FAO Advisory Committee on Paper and Wood Products in Rome (6. June); published in: Food and Agricultural Organisation (FAO) (ed.) *Proceedings -- FAO Advisory Committee on Paper and Wood Products – Forty-seventh session* (Rome, Italy: Food and Agricultural Organisation (FAO)); available at: http://www.fao.org/docrep/009/j8386e/j8386e07.htm.