PROSPECT OF TREMA ORIENTALIS AS A PULPING RAW MATERIAL IN BANGLADESH

*M. Sarwar Jahan**

ABSTRACT

The pulp and paper industry in Bangladesh is looking for new raw materials with high productivity per hectare. Currently, bamboo and Gmelina arborea are the main pulping raw materials for the pulp and paper industry of the country. Trema orientalis is one of the fastest growing woods in the tropical region. This paper reviews the literature on the topic, in particular, related to the chemical, morphological and physical properties of T. orientalis and its suitability for pulping. In addition, the advantages and disadvantages of various pulping processes proposed in the literature were critically analyzed. It was concluded that T. orientalis is a potential pulp wood for the Bangladesh pulp and paper industry.

Keywords: *Trema orientalis; Physical, Chemical and Morphological properties; Pulping; Bleaching*

1. INTRODUCTION

A growing demand for paper, combined with a declining fiber supply from the forests in Bangladesh, is forcing the pulp and paper industry to find technically and economically viable fiber sources. Although various non-wood fibers may be helpful, wood pulp is still the industry's performance. Forestland in Bangladesh is only 10.2 %, while the population density is very high (FAO, 2009). The use of forestland for the paper industry is decreasing as compared to other land uses. So, it is hard to supply pulpwood from forest to keep the growth of paper industry in the country. In order to achieve this growth, plantation of fast growing species must be established to compensate for the decreasing supply from forests. Fast wood plantation can produce one-and-a-half to two times more wood per hectare per year, and reach maturity two to three times faster than longer-rotation softwood plantations (Cossalter and Smith, 2003). Higher yield of wood reduces the cost of raw material, thus less land is needed to produce the same amount of wood. Environmentalists are also keeping pressure on the industry for preserving forests. So it can be said that restricted access to the natural forest attracts short rotation wood as sources of fibers.

Acacias and Eucalyptus camadonesis are most promising fast growing wood in Bangladesh. The average diameter at barest height (DBH) and height of 4-year old acacia mangium were approximately 24.1 cm and 8 m, respectively (Ogata, et al., 2002). Eucalyptus amplifolia produced 12.8 m height and 17 cm DBH in 53 months (Rockwood, et al., 1995). It was observed in our earlier study that *T. orientalis* is one of the fastest growing trees (Jahan and Mun, 2003). The local name of *T. orientalis* in Bangladesh is Nalita. The fastest growth of *T. orientalis* occurs in warm and moist areas with consistent temperatures. *T. orientalis* is widely distributed through a range of altitudes in higher rainfall areas. It prefers sites on well-drained and exposed soils. *T. orientalis* is also a nitrogen-fixing tree. The average height and DBH of *T. orientalis* was 11.6 m and 21.3 cm at the age of 24 months (Jahan and Mun, 2003.) This species grows naturally in all parts of Bangladesh. Figure-1 shows the tree, brunch, stem and leaves of *T. orientalis* grown in Dhaka region. The picture of stem of three year old *T. orientalis*, indicated that *T. orientalis* is extremely fast growing (Figure-2). Therefore, it may be a suitable source of fiber supply for papermaking in near future (Jahan and

Figure-1: Photograph of *T. orientalis* stem, brunch, leaves and tree

Source: *Jahan and Mun, 2003*

Figure-2: Cross Section of *T. orientalis*

* Pulp and Paper Research Division, BCSIR Laboratories, Dhaka, Dr. Qudrat-i-Khuda Road, Dhaka 1205, Bangladesh.
E-mail: sarwar2065@yahoo.co.uk

Mun, 2004).

This review discusses the status and technology of *T. orientalis* pulping and bleaching. The possibilities of commercial production of pulp from this species have also been discussed.

2. PRESENT STATUS OF PULP AND PAPER INDUSTRY IN BANGLADESH

The present status of pulp and paper mills in Bangladesh was elaborately discussed by Quader (2011). Bangladesh Chemical Industries Corporation (BCIC) was a key player in the Bangladesh Pulp and Paper Industry. There were four pulp and paper mills under the umbrella of BCIC, namely: Karnaphuli Paper Mill (KPM), Khulna Newsprint Mill (KNM), North Bengal Paper Mill (NBPM) and Sylhet Pulp & Paper Mill (SPPM). Unfortunately, presently only KPM is in operation, producing quality paper, as well as packaging grade with yearly capacity of 30,000 MT. This mill was commissioned in 1953. One of the main reasons of closing the other three mills was due to the shortage of fiber supply. KNM, a newsprint mill was started in 1959 with an annual capacity of 50,000 MT. This mill used Gewa wood from the Sundarban. UN has declared Sundarban as the world heritage site. Therefore, the government authority stopped the supply of wood to the mills, consequently the mill was forced to shut down. NBPM, a bagasse based pulp mill, was commissioned in 1973 with the annual capacity of 15,000 MT of writing and printing paper. The sugar production in Bangladesh has remarkably decreased. As a result, the bagasse availability also decreased, which led to the closure of NBPM. SPPM, the only pulp mill based on reeds, began production in 1975 with an annual production capacity of 20,000 MT. In addition, BCIC has a joint ownership on the Magura Paper Mill, which produces packaging paper at around 15000 MT per year.

The BCIC's pulp and paper capacity accounted for around 90 % of the Bangladesh's total output some 25 years ago. But today BCIC is producing < 5 % of the total paper products in Bangladesh (Quader, 2011). The private investment in the Bangladesh Pulp and Paper Industry has been significant in the past years, and it dominates the industry, including: T.K. group (paper, board, tissue mill), Basundhar group (paper, tissue, newsprint), Creative paper mill, Capital paper mills, Hakkani paper mill, and Hossain pulp & paper mills.

The per capita paper and board consumption in Bangladesh is about 3.5~4 kg/year, which is much lower than that in a typical developed country (about 300 kg/year/person), and also substantially lower than the Asian average of around 30 kg/year/person. It is expected that the Bangladesh Pulp and Paper Industry could have a rapid increase in the near future.

All of the new mills are using waste paper and imported market pulps. In 2011, Bangladesh has imported about 160,000 MT market pulp at the cost of US$ 128 million, and also imported 424,000 MT paper and paper board (FAO-STAT, 2013). Therefore, it can be concluded that Bangladesh needs more pulp and paper mills to reduce the dependency on imported pulp, paper and paper products.

3. FOREST LAND IN BANGLADESH

The total forest land in Bangladesh is only 1.44 million ha, which accounts for about 11 % of total land area (FAO, 2011). For KPM, 38,000 ha forest land is allocated, where gmelina arborea is planted. This allocated land is controlled by the Bangladesh Forest Department. In addition to this allocated land, there is also a large size of allocated forest land for pulp wood production in Bandarban and Sylhet. The rotation time of G. arborea is 12 year. Unfortunately, this allocated land cannot meet the mill's raw material demand. In this context, there would be a potential to plant a fast-growth wood species, for example, *T. orientalis* that can increase the amount of wood per year per ha.

4. CHEMICAL, MORPHOLOGICAL AND PHYSICAL PROPERTIES OF *T. ORIENTALIS*

The anatomical, chemical, morphological and physical analysis have been reported by Jahan and Mun (2003) in relation to its age, sites and stem and branch (Jahan, et al., 2010). Shown in Table-1 are the chemical, morphological and physical properties of *T. orientalis* stem, which were compared with another potential hardwood in Bangladesh, the rubber wood. The $\propto$-cellulose content in *T. orientalis* was slightly higher than rubber wood (45.0 % vs 42.6 %) and also it is higher than that in typical softwood, but close to that in Eucalyptus (Sjostrom, 1993). The average Klason lignin content in *T. orientalis* was 24 %, which is very close to that from Ku, et al. (1987). The lignin content in *T. orientalis* is higher than that of acacia auriculiformis (Law, et al., 2000), acacia mangium (Santos, et al., 2008) and the Eucalyptus globules (Sjostrom, 1993). The pentosan content in *T. orientalis* is about 23.5 %, which is higher than that in rubber wood. It was found that the total lignin and holocellulose content in *T. orientalis* were increased

Table-1: Chemical, Physical and Morphological Properties of *T. orientalis*

	***T. orientalis* (Jahan, et al. 2010)**	**Rubber wood (Jahan, et al. 2011a)**
Extractives, %		
Acetone	0.89±0.02	0.64
Cold water	2.4±0.3	2.5
Hot water	4.9±0.3	7.9
1% alkali	21.4±0.9	17.1
Lignin, %		
Klason	24.1±1.1	24.1
Acid soluble	2.8±0.2	2.9
Pentosan, %	23.5±1.0	17.1
Holocellulose, %	78.5±1.8	73.8
α-cellulose, %	45.0±1.6	42.6
Ash, %	1.1±0.05	2.5
Density, g/cc	0.368±0.03	-
Fiber length, mm	1.34±0.2	0.96
Fiber diameter, µm	24.5±1.0	22.8

and ash and alcohol-benzene extract decreased from pith to bark (Jahan and Mun, 2003).

Extractives of a raw material are undesirable parts since it affects negatively in pulping and bleaching operations. In general, the extractive content (Table-1) in *T. orientalis* is reasonable, for example, lower than that of Acacia auriculiformis (Law, et al., 2000), and similar to other acacias (Malinen, et al., 2006). The relatively high 1 % alkali solubility in *T. orientalis* may be attributed to the higher amount of low molecular weight polysaccharides, which may result in lower pulp yield.

In the assessment of raw material quality for pulping, wood density is one of the most important parameters. The wood density can have a big impact on the total daily production of a mill (Goyal, et al., 1999). The wood density of *T. orientalis* was 0.368 g/cc (Jahan and Mun, 2003). Ku, et al. (1987) also observed similar wood density of *T. orientalis* from Taiwan. The wood density of *T. orientalis* was lower than the other hardwood species (Isabel, et al., 2001).

Fiber length influences the paper strength, particularly, tear and paper machine runability (Jackson, 1988; Watson and Dedswell, 1961). As shown in Table-1 the fiber length of *T. orientalis* was 1.34 mm, which was in the range of tropical hardwoods (0.7-1.5 mm) (Legg and Hart, 1959). Subramanyam (1987) studied 13 hardwood, including *T. orientalis* and *G. arborea* to evaluate their utility as pulping raw materials, and it was fund that *T. orientalis* was ranked the fifth and *G. arborea* was the last, among these species. It can be mentioned that *G. arborea* is presently being used by Karnaphhul Paper Mill in Bangladesh.

As shown in Figure-3, *T. orientalis* is a rather diffuse porous wood, which consists of fibers, vessels and parenchyma like other hardwoods (Jahan, et al., 2003). As observed in the study, the proportion of fibers and vessel increased with an increase of growth ring (from pith to bark).

5. PULPING OF *T. ORIENTALIS*

T. orientalis was studied for the first time by Shikata and Ogawa as the raw mater for pulping for producing rayon grade pulp using magnesium and calcium-based sulfite pulping processes. *T. orientalis* was readily digested by either process and yields a good quality pulp (Shikata and Ogawa, 1937). In 1953, Bhat and Jaspal (1953) studied this species for paper grade pulp and obtained bleached pulp yield of 46.0-49.8 % by the sulfate process, and the produced pulp could be used for the production of writing and printing papers when mixed with a long-fibered pulp, e.g. from Bamboo. Bhat and Singh (1954) found that *T. orientalis* is a promising raw material for the production of wrapping papers in high yields and of satisfactory

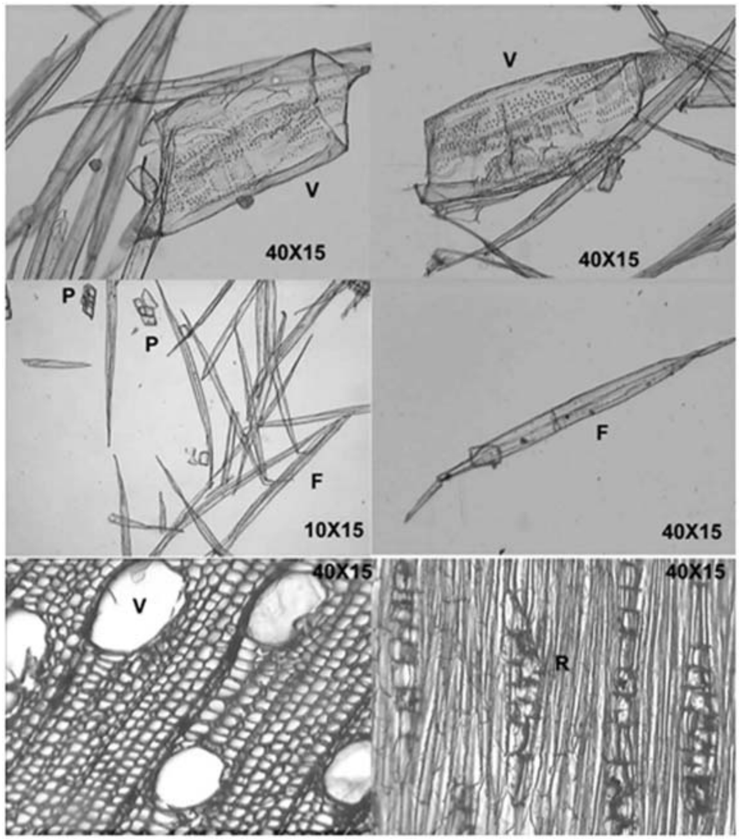

Figure-3: Micrograph of fibers, vessels and parenchyma cells of *T. orientalis* (Jahan and Mun, 2003)

strength. Bhat, et al. (1954) again studied both laboratory and pilot-plant experiments for the production of sulfate and soda pulps from *T. orientalis* and the resulting pulps had satisfactory strength properties, and it was recommended that the pulps should be mixed with a long-fibered pulp in the manufacture of wrapping papers. Hung (1956) studied to use *T. orientalis* for various pulping processes and the low-concentration NH_4HSO_3 process gave a particularly high yield (65%). Chung, et al. (1966) evaluated common Taiwan hardwoods, namely, Lagerstroemia subcostata, Schefflera octophylla, *T. orientalis,* Mallotus paniculatus, Alnus formosana, and Albizzia falcata as the raw materials for four semi-chemical pulping processes, namely, neutral Na-sulfite, cold soda, sulfate, and soda. These processes gave 64 % or higher pulp yield for paperboards and corrugating mediums. Cold soda pulp had the highest yield and lowest cost. It is recommended that the mixture of bleached long fiber pulps and cold soda pulp could be used in making printing papers or newsprint papers. The Na-sulfite pulp could be used in making printing papers. The sulfate and soda pulps could be used in making wrapping papers or bag papers when mixed with kraft pulps. Witayapanyanonta, et al. (1973) studied the kraft pulping of *T. orientalis* at constant 4:1 liquor to wood ratio, 25.5 % sulfidity, variable active alkali content and cooking time, producing screened pulp in 51.2-52.9 % yield, which was further bleached by the CEH sequence, with a yield of 93.3-93.9 %. The writing and book papers were made from these pulps complied fully with the specifications, except for a slight deficiency in pick resistance of book paper. The wrapping paper from the unbleached pulp was deficient in tearing resistance due to relatively short fibers.

For commercial exploration of *T. orientalis* as the raw material for the pulp and paper production, the age of tree on the wood composition, fiber characteristics, wood quality variation with location, anatomy, lignin structure, and the impacts of these factors on pulping would be critical. Extensive R&D program on the pulping of *T. orientalis* has been made, whereby Soda-AQ pulping of *T. orientalis* was evaluated with respect to tree age up to 3 years (Jahan and Mun, 2004). At the age of 3 years, *T. orientalis* produced 48.9 % screened

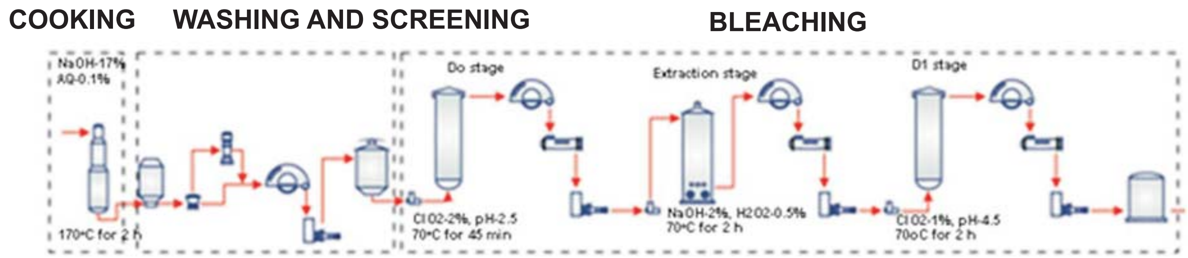

Figure-4: Flow diagram of *T. orientalis* pulping

pulp yield with kappa number 21 under the conditions of 17 % alkali charge, 120 min of cooking at 170°C. *T. orientalis* was also subjected to kraft pulping by varying active alkali and cooking time (Jahan, et al., 2008). Under conditions of 17 % alkali charge, 120 min of cooking at 170°C, the obtained screened pulp yield was 47.0 % with kappa number 20.1. The flow diagram and detail pulping and bleaching conditions of *T. orientalis* pulping in soda-AQ process is given in Figure-4. These results were very close to that of hardwood (Grace and Malcolm, 1993). Effect of different sites and trunk and branch on the pulping of *T. orientalis* was also evaluated and it was found trunk produced better pulp yield than branch (Jahan, et al., 2010). Sites also affect the pulp yield slightly. Different pulping process namely, soda, soda-anthraquinone (AQ), kraft, alkaline-sulfite-anthraquinone-methanol (ASAM), acetic acid and formic acid processes were also evaluated (Jahan, et al., 2007). A good pulp yield (46-52 %), strength and optical properties were obtained in all of these processes. The best pulp yield (51.7 %) and kappa number (13.4) were obtained in the ASAM process under the conditions of 17 % alkali charge at 180°C for 120 min of cooking. The digester pressure in the ASAM process is higher, and the recovery of methanol is another challenge. So the ASAM process is not realistic at this stage. Tear strength of *T. orientalis* pulp was comparatively lower. It was also observed that *T. orientalis* pulp fiber collapsed easily on bleaching, therefore, needs less refining energy to get maximum strength (Jahan and Min, 2004). Strength properties development of *T. orientalis* pulp stops only after ^{0}SR 30. Most of the literature suggested reinforcing softwood pulp for writing and printing grade paper pulp. However, in order to improve the tear strength of *T. orientalis* pulp, longer fiber jute pulp was reinforced (Jahan, et al., 2009). The f-cellulose content in formic acid pulp was greater than 94 %, which suggested further study for dissolving pulp in this process. Therefore, further study was carried out on *T. orientalis* for the production of dissolving pulp and it was found that a good quality dissolving pulp could be produced from *T. orientalis* (Jahan, et al., 2008a).

Recently, interest is growing on the conversion of biomass feed stock into fuel and chemicals, in addition to pulp (Saeed, et al., 2012; van Heiningen, 2006). A promising approach to configuring the forest product biorefinery is to fractionate and convert woody biomass into products, including pulp, extractives such as tall oil, as well as a number of minor products, while the unused biomass fractions, including lignin and hemicellulose solubilized during pulping, will be converted to liquid transportation fuels or other platform chemicals/ materials. In the forest biorefinery concept, pre-pulping extraction has been shown to make available hemicellulose components of the wood while preserving both the yield and quality of the pulp production (van Heiningen, 2006). Forest

Table-2: Comparison of *T. orientalis* and mixed hardwood pulps (Jahan and Mun, 2004; Jahan, et al., 2011a)

Wood species	Pulp yield (%)	Kappa number	^{0}SR	Tensile index (N.m/g)	Tear index (mN.m^2/g)	Burst index (kPa.m^2/g)
T. orientalis	50.0	21.0	30	58.8	7.6	4.8
Mixed hardwood	46.0	20.5	42	50.1	9.3	4.7

products companies may increase revenue by producing biofuels and chemicals in addition to pulp products in an Integrated Forest Biorefinery (IFBR). Therefore, a study was also carried out on the pre-extraction of *T. orientalis* prior to pulp (Jahan, et al., 2011). The pre-extracted liquor (PHL) contained sugars, lignin and acetic acid and these were increased with temperature and time. Pulping of pre-extracted mass was carried out in kraft process. Inferior pulp yield and paper making properties were obtained when pre-extraction was done at higher temperature and time. Pre-extraction at 150°C for one hour followed by kraft pulping showed comparable pulp yield, bleachability and papermaking properties with non-extracted *T. orientalis*, while pre-extracted liquor yielded 3.1 % acetic acid, 1.9 % lignin and 3.5 % hemicelluloses on wood. To implement biorefinery concept, dissolving pulp was also produced from *T. orientalis* (Jahan, et al., 2008a), pre-hydrolysis liquor can be used in producing biofuel, biochemical and biomaterials.

6. BLEACHING

Bleaching can be considered as a final delignification stage of pulp. Bleachability is dependent on the raw material and can be influenced by the conditions in the cooking process (Colodette, et al., 2002; Magnus, et al., 2005). Many attempts have been made to correlate the chemical structure of the residual lignin to the bleachability of the pulp (Tran, 2002; Kumer and Jameel, 1996; Moe, et al., 1998). It was observed that the active alkali and cooking time affect pulp bleachability of *T. orientalis* pulp (Jahan, et al., 2008). At the 19 % active alkali charge and 2.5 h of cooking, the brightness reached to 86.5 % at the Cl_2 consumption of 57.7 kg/MT pulp. In the pulp bleaching process, D_0, D_1 and E stages of bleaching was carried out at 70°C for 45 min, 120 min and 120 min, respectively (Figure-4). *T. orientalis* pulps obtained from the different processes (such as soda, soda-AQ, kraft and ASAM) were studied by D_0ED_1 and QPP bleaching sequences (Jahan, et al., 2007). The oxygen delignified *T. orientalis* pulps gave 76 to 86 % brightness in DED bleaching and 73 to 79 % brightness in QPP bleaching sequences. In the D_0ED_1 bleaching sequences, the brightness of kraft pulp reached to 86.4 % at the ClO_2 consumption of 40 kg/MT pulp (Jahan, et al., 2011). Bleachability of *T. orientalis* pulp also studied in respect to location and within tree (Jahan, et al., 2010). Pulp from Rajbari region showed better bleachability than that of Gaybandha and Dhaka region. Branch pulp responded slightly better bleachability than that of stem pulp. Kraft pulp showed better bleachability than soda-AQ pulp (Jahan, et al., 2010).

7. ECONOMIC EVALUATION OF T. ORIENTALIS PULPING

There was no comprehensive studies carried out on the economics of *T. orientalis* pulping. Kharnaphuli Paper Mills (KPM) is the only running pulp mill in Bangladesh, which uses *G. arborea* as raw material. In the KPM, the raw material cost is 50 % of total production cost. *T. orieatalis* produces 2.5 times wood than the *G. arborea*, which reduces the price of raw materials by at least 25 %. This means 12.5 % pulp production cost is reduced only from raw material. In the laboratory experiment, it was observed that 10 % less chlorine dioxide was required to bleach *T. orientalis* pulp in similar brightness level. Bleaching cost is 25 % of total pulp production cost in KPM. Therefore, total pulp cost is reduced by 6.25 % from pulp bleaching. From the above discussion, it is seen that pulp production cost can be reduced by 18.75 % if *G. arborea* is replaced with *T. orientalis* in KPM.

8. CONCLUDING REMARKS

Trema orientalis is one of the fastest growing species, with acceptable chemical compositions, morphological and anatomical properties to be used as the raw material for pulping. Suitable logging age of this species for pulping is 3 to 4 years, consequently exhibiting a low wood density.

The pulp yield from *T. orientalis* is comparable to that from other hardwood species. Both Soda-AQ and kraft processes are suitable for pulping of this species from the economic and technical points of views. Its bleachability is very good. The resulting pulp is easy to refine, with tensile acceptable for the writing and printing paper grade. Its tear index is slightly lower than the other hardwood species, which can be compensated for by reinforcing longer fiber pulp, such as jute fiber pulp. *T. orientalis* can also be used in the production of dissolving pulp grade. Pre-extraction of *T. orientalis* prior to pulping can extract acetic acid, lignin and hemicelluloses. Therefore, it can be concluded that *T. orientalis* is a potential raw material for the Bangladesh Pulp and Paper Industry, which may replace *G. arborea*.

REFERENCES

- Bhat, R. V., Jaspal, N. S., 1953. Indigenous cellulosic raw materials for the production of pulp, paper and board. Part XIII. Chemical pulps and writing and printing papers from Trema orientalis, Blume. *Indian Forester*, 79(2), pp. 69-76.

- Bhat, R. V., & Singh, M. M., 1954. Indigenous cellulosic raw materials for the production of pulp, paper, and board. XXII. Wrapping papers from Trema orientalis Indian Forest Bull., 186, p. 13.
- Bhat, R. V., Singh, M. M. 1954. Indigenous cellulosic raw materials for the production of pulp, paper and board. Part XXII. Wrapping papers from Trema orientalis Blume. *Indian Forester*, 80(8), pp. 453-465.
- Chung, C.S., Chieh, L.S., 1966. Comparisons of four semichemical processes on Taiwan hardwood pulping. *Taiwansheng Linye Shiyanso Baogao*. 135, p. 11.
- Colodette, J. L., et al., 2002. Influence of pulping conditions on eucalyptus kraft pulp yield, quality and bleachability. *Tappi.* J, 1(1), pp. 14-20.
- Cossalter, C., and Smith, P.C., 2003. Fast-Wood Forestry Myths and Realities. CIFOR, Jakarta, Indonesia. p. 50.
- FAO, 2009. State of the world's forest. Food and Agriculture Organization of the United Nations, Rome, Italy.
- FAO, 2011. State of World's Forest 112. Food and Agriculture Organization of the United Nations, Rome, Italy.
- FAOSTAT, 2013. Food and Agriculture Organization of the United Nations Rome, Italy.
- Goyal, G.C., et al., 1999. Variability in pulping and fiber characteristics of hybrid poplar trees due to their genetic makeup, environmental factors, and tree age. *Tappi J.*, 82, pp. 141-147.
- Grace, T.M., Malcolm, E.W., 1993. Pulp and paper manufacture. In: Kocurek, M.J. (Ed.), Alkaline Pulping, Vol. 5. TAPPI, CPPA.
- Hung, C. M., 1956. Experiments on the pulping of Trema orientalis Bull. *Taiwan Forestry Research Inst.* 46(5).
- Jahan, M.S., Mun S.P., 2003. Characterization of Nalita Wood (Trema orientalis) as a Source of Fiber for Papermaking (Part I): Anatomical, morphological and chemical properties. *Korean Tappi J.* 35 (5), pp. 72-79.
- Jahan, M.S., Mun, S.P., 2004. Effect of tree age on the soda-anthraquinone pulping of Nalita wood (Trema orientalis). *Korean J. Ind. Engg. Chem.* 10(5): pp. 766-771.
- Jahan, M. S., and Sung, P.M., 2005. "Effect of tree age on the cellulose structure of Nalita wood *(Trema orientalis)*." *Wood Science and Technology* 39(5) pp. 367-373.
- Jahan, M.S., Rubaiyat, A., and Sabina, R., 2007. "Evaluation of cooking processes for Trema orientalis pulping." *Journal of Scientific and Industrial Research* 66(10) pp. 853.
- Jahan, M.S., et a., 2008. Kraft pulping and bleaching of *Trema orientalis* (Nalita). *Cellulose Chem. Technol.* 42, pp. 223-228.
- Jahan, M. S., et al., 2008a. Process for the production of dissolving pulp from *Trema orientalis* (Nalita) by prehydrolysis kraft and soda-ethylenediamine (EDA) process. *BioRes.* 3(3): pp. 816-828.
- Jahan, M. S., Rawshan, S. 2009. Reinforcing potential of jute pulp with *trema orientalis* (Nalita) pulp. *BioRes.* 4(3) : pp. 921-931.
- Jahan, M.S., Chowdhury, D.A.N., Ni, Y. 2010. Effect of different locations on the morphological, chemical, pulping and papermaking properties of *Trema orientalis* (Nalita). *Bioresou. Technol.* 101(6), pp. 1892-1898.
- Jahan, M.S., et al., 2011. Effect of pre-extraction on the pulping and paper making properties of short rotation Trema orientalis. *Indian J. Ecol*.l 38, pp. 35-40.
- Jahan, M.S., et al., 2011a. Evaluation of rubber wood (Hevea brasiliensis) as a pulping and papermaking raw materials" *Nordic Pulp and Paper Research J.* 26(3), pp. 258-262.
- Jackson, F., 1988. Fiber length measurement and its application to paper machine operation *Appita J.* 41, pp. 212-216.
- Ku, Y. C., Chen, H.T., and Chen, Z.T., 1987. Wood fiber characteristics and pulping experiment of fast growing tree species (I): *Trema orientalis*, Albizzia falcataria and Cunninghamia lanceolata. *Taiwan J. of Forestry* 2(4), pp. 319-332.
- Kumer, R.K., Jameel, H., 1996. Bleachability difference between RDH and kraft-O2 pulps- role of phenoloic hydroxyl groups in the residual lignin. *International Pulp Bleaching Conference* pp. 147-162.
- Law, K.N., and Daum., R. W., 2000. CMP and CTMP of a fast-growing tropical wood: *Acacia maingium. Tappi J.* 83: pp. 1-7.
- Legg, G.W. and Hart, J. S., 1959. Alkaline pulping of poplar and birch-influence of sulfidity and effective alkali on the rate of pulping and pulp properties. *Pulp Paper Mag.* Can., 60(7): pp. T203-T215.
- Magnus B., Germgard., U & Basta, J., 2005. Effect of cooking conditions on ECF bleaching and brightness reversion of birch kraft pulp, *Tappi Journal,* 4(7), pp. 16-22.
- Malinen, R.O., Pisuttipiched, S., Kohelmainen, H., and Kusuma, F.N., 2006. Potential of Acacia

species as pulpwood *Appita J.* 59: pp. 190-196.

- Miranda, I., Almeida, M.H., and Pereira, H. 2001. Provenance and site variation of wood density in Eucalyptus globulus labill. At harvest age and its relation to non-destructive early assessment. *Forest Ecology and Management* 149: pp. 235-240.
- Moe, S.T., Ragauskas, A.J. & McDonough, T.J., 1998. Extended oxygen delignification of high yield kraft pulp. Correlation between residual lignin structures and bleachability by oxygen and chlorine dioxide. International Pulp bleaching Conference, Helsinki, Proceedings Book 1, pp. 33-39.
- Ogata, Y., et. al., 2002. Asynchronous wood formation in young Acacia mangium planted in Malaysia. *Journal of Wood Soc.* 48(2); p. 89.
- Quader, MMA, 2011. Paper sector in Bangladesh, Challenges and Scope of development. *J. Chem. Eng.* 26 (1), pp. 41-46.
- Rockwood, D.L., et al., 1995. Genetic variation in wood, pulping and paper properties of Eucalyptus amplifolia and E. grandis grown In Florida, USA, CRC for Temperate Hardwood Forestry- IUFRO, Hobert, p.53-59.
- Saeed, A., et al., 2012. Mass balances of components dissolved in the pre-hydrolysis liquor of kraft-based dissolving pulp production process from Canadian hardwoods. *Biomass Bioenergy.* 39, pp. 14-19.
- Santos, A., et al., 2008. Effect of Eucalyptus Globulus Wood Density on Papermaking Potential, *Tappi Journal* May, pp. 25-32.
- Shikata, M. and Ogawa, K., 1937. Tropical wood pulp and pulp cooking. I. Cooking of tropical hardwood. Seniso Kogyo 13, pp. 305-10.
- Sjostrom, E., Wood Chemistry. Fundamentals and Applications. Second edition ed. 1993, San Diego: Academic press. pp. 292.
- Subramanyam, S.V., 1987. Assessment of utility of some pulp wood species of Kerala State based on fibre quality. *Indian Forester* 113.6; pp. 427-433.
- Tran, A.V., 2002. Effect of cooking temperature on kraft pulping of hardwood. Tappi J. 1(4), pp. 13-19.
- Van Heiningen, A., 2006. Converting a Kraft pulp mill into an integrated forest biorefinery. *Pulp Paper Canada*, 107, pp. 38-43.
- Watson, A. J., and Dedswell, H.E., 1961. Influence of fibber morphology on paper properties, Part I Fibre length. Appita J. 14; pp. 168-178.
- Witayapanyanonta, Buncha; Tamolang, Francisco N., 1973. Pulp and papermaking qualities of anabiong Trema orientalis. *Araneta Research Journal* 20 (4); pp. 239-57.