

BAMBOO FOR PULP AND PAPER

A State of the Art Review

With Annotated Bibliography

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March 2003

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This report forms part of the Consultancy project “Preparation of State of the Art Reviews (STARs) along with Annotated Bibliographies on selected topics of Bamboos and Rattans”.

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OTHER STARs

1. *Dendrocalamus strictus*
2. *Bambusa bambos*
3. Management of Natural Sympodial Bamboo Stands and Plantations.
4. Collection, Conservation, Evaluation and Utilization of Rattan Germplasm.
5. Bamboos in Agroforestry Systems.

This work was carried out with the financial support from the International Network for Bamboo and Rattan (INBAR)

PREFACE

Bamboo is regarded as a major resource that meets the need of common people and also as a poverty alleviator due to its multi purpose uses. As a result of this, bamboo resources are of great importance in the rural socio-economy of several tropical countries. As pulp and paper being the major commercial bamboo consuming sector, it is very necessary to have an updated information on the state of art related to its pulping processes and technologies for the optimal utilization of this valuable resource. It is in this context, for the proper management and utilization of bamboo for paper and pulp, the International Network for Bamboo and Rattan (INBAR) assigned KFRI to prepare a State of the Art Review (STAR) on Bamboos for Pulp and Paper.

The report consists of three parts. In Part I, a brief highlights of pulp and paper making principles are dealt with, which is very essential to follow the Part II, Bamboo for Pulp and Paper. An annotated bibliography, arranged alphabetically by Author's name is given in Part III.

I sincerely thank INBAR for providing financial support for preparing the report. Dr. T.K. Dhamodaran, Scientist (Wood Science), Dr. R. Gnanaharan, Research Coordinator and Shri. K. Sankara Pillai, Librarian, KFRI, authors of this report deserve special mention for preparing an excellent report.

I hope this report will equally be useful to researchers, wood, pulp and paper technologists and pulp industry and all concerned with the promotion of sustainable utilization of bamboo for pulp and paper.

Peechi
March 2003

J.K.Sharma Ph.D
Director

ACKNOWLEDGEMENTS

Our sincere thanks are due to International Network for Bamboo and Rattan (INBAR) for providing financial assistance, without which the work could not have been materialised. Thanks are due to Dr. J.K. Sharma, Director, Kerala Forest Research Institute, for his keen interest and encouragements shown in the study. We also thank Mr. K.H. Hussain, Mrs. N. Sarojam and Mr. K.F. George for their help in the bibliographic compilation. Thanks are due to Mr. B. Jithesh, Technical Assistant, Library and Mrs. Sheeba Sabu, Technical Assistant, Wood Science Division of KFRI for DTP work and Mr. P.K. Thulasidas, Wood Science Division of KFRI for Technical assistance. Thanks are due to Dr. K.M.Bhat and Dr. C. Mohanan, Scientists of KFRI for editorial scrutiny.

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PART II. BAMBOO FOR PULP AND PAPER

5. BAMBOOS : DISTRIBUTION, UTILIZATION, STORAGE AND ECONOMICS

5.1. About bamboos

Bamboo grows in India, Burma, Thailand, Indonesia, China, Japan, the Philippines, Australia, South Africa, South America and southern North America. It is a grass of several genera and species. Bamboo provides the highest biomass per unit area. There are two types of bamboos: sympodial or clump forming, as in *Bambusa*; monopodial or single clump distributed laterally, as in *Melocanna*. Bamboo grows as high as 40 m with diameter up to 30 cm. The growth rate is tremendous; in 1-2 months of the first year full length is achieved (growth rate is about 15 to 120 cm per day in some species!) (Martin 1996)^{107a} and culm maturation through lignification takes place during the next two to three years.

Bamboo clumps die off after flowering, which occurs from cycles varying between 50 and 60 years depending on the species. Estimates of total global revenue generated from bamboo and its products – including the value of bamboo used by traditional communities and employment generated by them – range between US \$ 4.5 and 7.0 billion.

5.2. Distribution of bamboos

Sharma (1982)¹²¹ describes the distribution of bamboos in countries like China, Japan, Korea, besides that of South and Southeast Asia. A total of 1250 species of bamboos from 75 genera are reported from these countries. Occurrence of more than 50 species of bamboos is reported from Vietnam (Anonymous 1971). Recently, Ohrnberger (1999)¹¹⁴ has brought out information on bamboos of the world and their distribution.

Gamble (1896)⁹⁴ is one of the oldest records available on bamboos of India. Singh and Guha (1981)⁴²⁹ reviewed the various bamboos occurring in India, including their pulping, bleaching, beating properties and the properties of paper made from these. The upgraded list of distribution of bamboos in India is provided by ICFRE (1991)¹⁰⁰ and Moulik (1997)¹¹¹. A compendium of 128 species of bamboos from 18 genera occurring in India have been brought out by Seethalakshmi and Kumar (1998)¹¹⁸. The two most widely distributed genera in India are *Bambusa* and *Dendrocalamus*.

5.3. History of pulp production from bamboos

Bamboo, “the green gold of the forest”, around 10 million tonnes of which are produced annually in the world, is not expensive, long-fibered, easy to transport and therefore is an important raw material for the pulp and paper industry. Sumg (1967)²⁰ described the pulp characteristics and technology for the manufacture of bamboo paper in the 17th century China. Bourdillon (1899)¹³⁸, and later Sindall (1909)¹⁹² and Vincent (1911)²⁰⁵ described the use of bamboo for pulp and paper. It was India that took the lead in using bamboo in mechanized paper production. In 1912, the Titaghur Paper Mill in India started utilizing bamboo as a raw material in a limited scale. In 1918, the India Paper and Pulp Company Limited., Naihat produced paper made completely from bamboo. The pulp industry accounts for about half of India’s bamboo consumption (mostly *Dendrocalamus strictus* and *Bambusa bambos*). India uses about 3 million tonnes of bamboo per year in pulp manufacture and China about 1 million tonnes. China is set to increase the use of bamboo for paper pulp manufacture to a target of 5 million tonnes per year. The use of bamboo for pulp is reported to have decreased in India due to lack of raw material (INBAR 1977)¹⁵⁸.

Pearson (1912)¹⁸⁶ and Raitt (1912)²³¹ provided the history of work carried out at the Forest Research Institute, Dehra Dun, India which pioneered and laid a strong foundation for utilizing bamboo for pulp and paper. The general conditions necessary for establishment of a paper mill, manufacturing cost, etc. were provided by them. Bhargava and Singh (1941¹³⁷ and 1942)²⁶ established the suitability of bamboo as a raw material in the kraft process which was a major milestone in the pulp industry in India. Since then, many periodic reviews of the work carried out at the Forest Research Institute, Dehra Dun, India have appeared (Bhargava 1946¹³⁶; Singh and Mukherjea 1965⁷⁹; Tewari 1993)¹²⁴. Tissot (1970)¹⁹⁸ reviewed the status of bamboo as a raw material in the Indian paper industry and the problems encountered in producing pulp and paper from bamboo (mainly *Dendrocalamus strictus*). In comparison to wood, bamboo can be pulped by the kraft and 2-stage alkali processes with less chemical and power (Stevens 1958⁸⁰; INBAR 1977)¹⁵⁸. Only minor differences are found between pulps of 21 Indian bamboo species. The bamboo fibres are shorter than that of conifers but longer than that of hardwoods and narrower than that of wood fibres used in paper making.

An yield of 8 tonnes per ha per year of dry matter (4.0 tonnes of cellulose) was reported (Anonymous, 1955) from the Congo grown small bamboo, *Oxytenanthera abyssinica*. Hodge (1957)⁹⁹ described the economic future of bamboos in America. The reported annual yield per ha of bamboo cellulosic material was six times greater than that of southern pine. Belvin (1957)²⁵ reported the potential of

bamboo plantations in the USA. Istas (1958)⁴⁴ reported that the short, fine and stiff fibred dwarf bamboos of Belgian Congo (*Sasa paniculata*, *S. variabilis*, *Arundinaria nitida* and *A. simonii*) were unsuitable for pulping whereas the larger species, *Bambusa vulgaris* (with average fibre length around 2.7 mm) from Congo gave promising results. Istas and Raekelboom (1962)¹⁶⁰ reported an yield of 50 tonnes per ha of *Bambusa vulgaris* from Congo which also provided best paper making pulps. They suggested a cutting cycle of 2 years. Mooney (1959)¹¹⁰ reported an yield of 5 tonnes air-dry culms per acre (12.5 tonnes/ ha) with a 4-year cutting cycle for *Oxytenanthera abyssinica*. Breitenbach (1961) described the status of bamboo as a source of cellulose in Ethiopia. An area of about 1 million ha was reported to be under the bamboo species, *Oxytenanthera abyssinica*. An area of 10,000 ha of bamboo plantation, managed on a 5-year coppice rotation, would keep a pulp mill supplied permanently with raw material. FPRDI (1962)¹⁴⁸ discussed the merits of bamboo as a raw material for pulp and paper making and outlined the commercial possibilities of certain economically and technically suitable Philippine species such as *Gigantochloa levis*, *G. aspera*, *Schizostachyum lumampao*, *Bambusa blumeana*, *Bambusa vulgaris* and *B. vulgaris* var. *striata*. Ono (1962)¹² reported the results of a survey of bamboo forests in Indonesia and Burma (Myanmar) and discussed the scientific techniques of bamboo pulping industry.

It was reported by Matsui (1963)¹⁷⁸ that about 70 per cent of the forest undergrowth in Japan was composed of *Sasa* bamboos. The larger species, *Sasa kurilensis*, was reported to provide an yield of 50-60 tonnes per ha when clear cut. Nelson (1966)⁶¹ reported that *Sinarundinaria murielae*, three *Phyllostachys* spp., two *Arundinaria* spp. and *Oxytenanthera abyssinica* were promising species for planting in the southeast and the Pacific coast of the USA. The prospects of bamboo for pulp and paper and board making in India were reported by Guha (1961a⁹⁶ & b)³⁹⁵. Factors which limit the actual selection of raw material for large scale paper manufacture were enumerated by him. Chandrasekharan (1968)⁴⁷⁶ reported that bamboo only was used commercially in India for dissolving grade pulp.

McGrovern (1967)¹⁸⁰ compared bamboo with southern hardwoods and southern pines in the USA with regard to yield (in India and Japan), density, chemical composition, fibre dimensions, conditions for kraft pulping and bleaching and pulp properties. Razzaque *et al.* (1981)²³³ suggested a 12 month cutting cycle for bamboos for pulping. Adkoli (1992)¹³¹ made an assessment of the availability of bamboo for the production of pulp and paper in India. Availability of wastelands for bamboo plantations, investments and efforts needed to raise such plantations were also discussed by him.. The three main species of bamboos, *Dendrocalamus strictus*, *Bambusa arundinacea* (*B. bambos*) and *Melocanna baccifera* are reported to constitute 83 per cent of the total growing stock. Nomura (1999)¹⁸³ described the role of bamboo in pulping in Myanmar.

El Bassam and Jakob (1996)¹⁴⁶ reported that generally bamboos produced about 7 tonnes dry matter/ha per year. Cellulose content of more than 40 per cent emphasizes the suitability of bamboo as a raw material for pulp and paper production. The pulp yield from bamboos varies from 40-50 per cent.

Even though China is number one in bamboo production in the world, information on the utilization of bamboo for pulping in China is scanty. There was a mass movement in China during 1958 for setting up small paper mills in order to solve the problem of shortage of paper and board in the country. As many as 4200 small plants exist in China, out of which 4000 mills produce less than 10,000 tonnes per annum (Rao 1989)¹⁷. The total bamboo and reed pulp production in China recorded in 1986 was 820,000 tonnes, which forms 9.2 per cent of the total pulp production in the country. Tang (1999)²¹ describes the current situation and future developments on the utilization of bamboos for pulp and paper in China.

5.4. Decay while storage and control measures

Bamboo for pulp and paper manufacture is usually stored outdoors for up to a year. Because of lack of any toxic constituents, bamboo forms a ready food source for a variety of organisms. The presence of large amounts of starch makes bamboo highly susceptible to attack by staining fungi and powder-post beetles (Beeson 1941⁵⁴¹; Gardner 1945⁵⁴⁶; Mathew and Nair 1990)¹⁵⁸. It was found that the lignin content of bamboo chips subjected to fungal attack did not vary appreciably from that of healthy bamboo. The bleached pulp from decayed bamboo was more yellower.

Strength properties of pulp from decayed chips were appreciably reduced and this was due to the perforations or bore holes and erosion marks in the cell-walls, as observed by anatomical studies of the fibres from healthy and fungal attacked bamboos (Guha *et al.* 1958)⁵⁴⁷. Decay, mainly attributable to white-rotters, results in loss of wood substance and pulp yield, reduced pulp strength and increased consumption of bleaching chemicals because of the high content of residual lignin in the pulp. Bamboo attacked by brown-rot fungi was unsuitable for pulping, as the pulp yield was very low compared to healthy bamboo and the permanganate number was so high that the pulp was unbleachable. Fungal attack increases pulping costs, owing to increased alkali demands (because of acidic nature of fungi) and higher bleach consumption (Singh 1977)⁵⁶⁶.

Sheets made from decayed and stained bamboo pulp from *Bambusa tulda* were found to have low strength. There was no appreciable difference in the yield of unbleached pulp from healthy bamboo and bamboo attacked by stain fungi, but the yield of unbleached pulp from bamboo attacked by decay fungi was low. The strength properties of pulp from bamboo attacked by decay fungi were lower than

those made from bamboo attacked by stain fungi; which in turn were slightly lower than those made from healthy bamboo (Guha *et al.* 1958⁵⁴⁷; Guha 1960¹⁵²; Bakshi *et al.* 1960)⁵³⁹. It is not advisable to store bamboos for long periods in warm and humid areas or under conditions favourable for decay. However, if bamboos have to be stored for long periods, storage should be under water or with suitable prophylactic treatment (which should not interfere with pulping) to prevent decay.

Different studies have been reported on flowered bamboo (Bhargava 1945¹³⁶; Bakshi *et al.* 1968⁵⁴⁰; Kala 1973²²¹; Dhoundiyal *et al.* 1973)¹⁴⁴. Flowered bamboo culms are more resistant to beetle attack, may be due to starch depletion. Flowered bamboo, if in sound condition, is equally good for pulping and bleaching.

When *Bambusa polymorpha* and *Cephalostachyum pergracile* were stored for 12 months in piles in the open or submerged in a natural pond, deterioration through stain and rot fungi was severe in the piles kept in the open but negligible in the bamboo kept under water. Neither duration nor method of storage had a great effect on chemical composition and sulphate pulp yields, but some strength properties of the pulp decreased about equally in both methods during storage. Brightness and response to bleaching were better in pulp from water-stored bamboo; this was also confirmed in a limited bleaching trial on mechanical pulp from *B. polymorpha* (Mai-Aung *et al.* 1969)⁵⁵⁷.

Purushotham (1970)⁵⁶¹ suggested measures for protection of bamboo against fungal and insect attack at felling and stacking sites. Prophylactic treatment of the raw material while storing outdoors reduced the wood substance loss by 28-30 per cent and pulp yield loss by about 30 per cent (Guha and Chandra 1979)⁵⁴². Kumar *et al.* (1980)⁵⁵⁵ reviewed the work done on storage losses and the adverse effect of inadequate protection on strength of paper sheets, bleach consumption and brightness and loss in digester capacity utilization. Possible ways of using effective chemicals for overcoming these problems were also described.

For long-term storage of bamboos in the open, it is recommended that the stacks are put-up on specially prepared ground (above a 10 cm layer of boiler ash and powdered lime sludge containing about 2% BHC) to prevent termite attack. The stacks should be profusely treated during different stages of stack forming and may be covered with treated bamboo mats or thatched grass (Kumar *et al.* 1994)⁵⁵⁴. Treatments must be done in such a way that chemical pollution of the environment is avoided. Stacking methods and treatments depend on the incidences of both fungal and insect attack. For reed bamboos, vertical stacking results in a small gain in pulp yield over horizontal stacking because the former suffers less fungal damage. Monthly treatment with borax – boric acid results in a substantial gain (Gnanaharan *et al.* 1982)⁵⁶⁰. A pest management strategy using minimal application of pesticide is recommended by Nair *et al.* (1983)⁵⁶⁰.

Prophylactic treatment with a mixture of sodium pentachlorophenate (NaPCP), boric acid and borax effected a saving of nearly 60 per cent in terms of pulp yield, in green material over a storage period of one year. Treatments should be repeated after 4-6 months, immediately after the monsoons (Kumar *et al.* 1985)⁵⁵³. Storing of bamboo (*Bambusa vulgaris*) for relatively long periods (4 months) should be avoided. Air-drying facilitates processing without reducing pulp quality quality (Vivone and Gomide 1985)⁴⁷⁴.

Maheshwari *et al.* (1988)¹⁷⁵ described the efficient management of bamboo storage for reducing the cost of paper production. They also described the aspects of optimum inventory of bamboo at different places of storage, proper selection of site for storage, layout of stacks in the yard in compliance with the insurance rules and easy approach for transport system, design of stacks, prevention of fire hazards, preservation of raw materials, etc.

Singh *et al.* (1988)²³⁷ described the problem of decay on storage and its effect on pulp properties. Fungal and borer attacks influence the pulp yield and cause appreciable decrease in strength properties of paper. Prophylactic treatment of bamboos with 2.5 per cent solution of boric acid, borax and sodium pentachlorophenate (1:1:0.5) can effect considerable savings in wood raw materials. Laboratory screening tests on fungicides/insecticides revealed several formulations suitable for field applications (Kumar and Dobriyal 1990)⁵⁵². While advanced fungal attack produces unbleachable pulps, borer attack in epidemic stages reduces the entire stack to powder causing 20-40 per cent volumetric loss. Termites also attack bamboo stacks, which in the absence of adequate protection can suffer losses up to a level of one metre from the ground during one year of storage. Protected bamboos remain sound during storage (Kumar *et al.* 1990)⁵⁵¹.

Apart from the chemical methods of protecting bamboos, some traditional (non-chemical) methods of preservation are also in practice, which include felling bamboos during low sugar content season (August and December - as the sugar content will be higher in spring than in winter); felling bamboos at maturity when sugar content is low (as the sugar content varies with age); post-harvest transpiration of bamboo culms (by keeping culms upright against trees for few days; parenchyma cells in plants continue to live for some time even after felling and during this period the stored food materials are utilized and thus the sugar/starch content in bamboos is lowered), and storing under water for a period of 4-12 weeks (which helps to reduce the starch/sugar content by leaching) (Kumar *et al.* 1994)⁵⁵⁴. It is reported that bamboos harvested during summer are more rapidly deteriorated than those harvested in the rainy season (Liese 1980)^{168a}. Kirkpatrick and Simmonds (1958)⁵⁴⁹ made an attempt to correlate the natural durability of bamboo with the time of harvesting based on the

phases of the moon. But this aspect was never proved beyond doubt and hence remains as a controversial subject.

5.5. Economics of bamboo plantation

Because of the high quality of pulp that can be obtained from bamboo and because of its availability in large quantity at a reasonable price, bamboo was used extensively as raw material in paper industry. In 1950, about 225,000 tonnes of bamboo was used in this industry in India (FRI 1951). The increasingly important role played by bamboo in the development of Indian pulp and paper industry is illustrated by Podder (1959)¹⁴. From a consumption of 5,830 tonnes in 1924 in India, it rose to 4,50,000 tonnes in 1959. According to the report of Government of India (GOI 1961), bamboo to the level of 70 per cent was used as raw material in pulp industry in 1958–‘59. In India, bamboo forests occupy about 10 million ha, roughly about 31 per cent of the total forest area of the country. Average yield of bamboo is 10-15 tonnes per ha per year. With a production of 3.23 million tonnes of bamboo a year, India is second only to China.

The economics of industrial plantations of *Bambusa bambos* (Syn. *B. bambos*), one of the prime/dominant bamboo species in India was described by Bhat (1970)⁸⁶. He determined the standing cost of production of raw material for pulping by raising *B. bambos* as an under-storey crop in the deciduous forests of India, taking into account the establishment and cultural costs. The average physiological life cycle of this bamboo is reported to be 42 years, of which 2 years are spent in nursery. The remaining 40 years can be fixed as the rotation for this species, and the regular cutting cycle begins at around 10 years from planting. Shanmughavel (1995)¹⁹⁰ discussed the and economic aspects (costs and returns from a 6-year-old plantation) of *Bambusa bambos* and suggested that this is an ideal species for commercial plantations.

Kandelaki (1976)¹⁰³ described the investigations in Soviet Georgia on the technical and economic feasibility of utilizing home-grown bamboos as raw material in the pulp and paper industry. Selective harvesting of a high yielding plantation of *Phyllostachys edulis* of 3-year- old culms yielded 52.73 tonnes per ha per year (as against 4.5 tonnes per ha per year for a fir plantation and 5.5 tonnes per ha per year for alder). The cost of 1 tonne of bamboo was calculated at 11.77 rubles against 44 rubles for conifer pulpwood grown in Georgia. The pay-back period for a *P. edulis* plantation was 7 years from establishment.

Specific techniques of economic analyses, *ie*, benefit–cost analysis, marginal analysis, budgeting and market research, were suggested by McCormac (1985)¹⁰⁸ viz-a-viz specific bamboo resources and development objectives. Wu and Xu (1987)²⁴⁰ described the world level economic benefit of paper

making with bamboo(Singh 1989) ⁷⁷ projected the estimated demand for paper and paperboard in India for 2000 and the requirement of bamboo. Xie *et al.* (1999) ²⁴² developed a stand model of pure and mixed plantation of Moso bamboo (*Phyllostachys pubescens*) for pulp. A model for calculating new culm yield of pure Moso bamboo stands was established based on the non-linear relationship between culm yield, and bamboo stand density and culm age components. The best high yield structure for pure Moso stands will have a stand density of 3000 culms per ha and will produce a culm yield of 31.1 tonnes per ha every two years. In mixed Moso and broad leaved tree stands, the most important structural factor influencing productivity was the bamboo and tree density ratio, and the second most important factor was the bamboo standing density. A bamboo standing density of 2100 culms per ha mixed stand will produce 22.8 tonnes per ha of culms every two years. Yang *et al.* (1999) ¹²⁹ determined the productivity of Moso bamboo stands by habitat and management, with significant differences found between different management regimes, site qualities or status of the original bamboo stand. Yuan *et al.* (1999) ¹³⁰ suggested a 3-use management system (bamboo shoots, young bamboo for pulping and mature bamboo for wood purpose) for Moso bamboos in China. The new management system was more successful than the usual management for 2-uses (shoot and wood). Detailed data on comparative yield and their economics were provided by them.