Received: 24 September 2024 | Accepted: 8 November 2024 | Published online: 9 November 2024

DOI: 10.59797/ijsc.v52.i2.162

ORIGINAL ARTICLE

Indian Journal of Soil Conservation

Evaluating ecologically important bamboo species for the pulp and paper industry

S.K. Sharma[1,*] | S.K. Chechi[1] | S. Chambyal[1] | V.K. Sharma[1] | G. Kumar[1] | K. Sharma[1] | B.K. Nayak[1] | Varun Attri[2]

[1]Kuantum Papers Limited, Saila Khurd, Hoshiarpur, Punjab.

[2]Regional Research Station (PAU), Ballowal Saunkhri, Balachaur, SBS Nagar, Punjab.

Corresponding Author :

E-mail: sudhirksharma@kuantumpapers.com

Handling Editor :

Dr Rajesh Kaushal

Key words:

Bamboo

Green gold

Physical strength properties

Pulp and paper industry

Tear factor

ABSTRACT

Bamboo is used worldwide to rehabilitate degraded lands because of its fast growth, effective rooting system, and ability to prevent soil erosion. The pulp and paper industry has been experiencing an acute shortage of raw materials for the last two years. In such a scenario, bamboo could significantly bridge the supply gap, thereby relieving the paper industry. Keeping the above in view, Kuantum Papers Limited, Punjab, has recently focused on using bamboo in its production system to cater to its needs. The mill's current share of bamboo in its total furnishing is around 10-15%, around 85 tons per day. The present study, therefore, focused on evaluating ecologically important bamboo species viz., *Bambusa balcooa, Bambusa vulgaris, Bambusa tulda, Dendrocalamus hamiltonii, Dendrocalamus strictus,* and *Melocana baccifera* in terms of their suitability to meet industry demands for strength, fiber quality, and yield for pulp production. These species were procured from different parts of the country. Results revealed that the properties of the species vary to some extent even after keeping all the conditions constant, like cooking temperature, time, and steaming temperature. The brightness of unbleached pulp for *B. tulda* was highest (23.7), and for *B. balcooa* was lowest (19.2). The screen pulp yield was highest in *M. baccifera* (51.4%) and lowest in *D. hamiltonii* (44.9%). The highest viscosity in unbleached pulp was observed in *B. Tulda* (27.9 cP) and lowest in *M. baccifera* (26.7 cP). The physical strength properties also vary from species to species. Burst Factor (BF) was highest in *D. hamiltonii* (52.77) and lowest in M. *baccifera* (35.67). The breaking length was highest in *D. hamiltonii* (6780 m) and lowest in *M. baccifera* (4900 m), whereas the tear factor was highest in *B. tulda* (105) and lowest in *B. balcooa* (79). The comparison between these varieties highlights the importance of understanding regional variation to optimize their utilization. Based on the study, specific recommendations can be made for cultivating bamboo on degraded lands to optimize environmental rehabilitation and industrial yield.

HIGHLIGHTS

- Bamboo is used worldwide for the rehabilitation of degraded lands.
- *M. baccifera* provided the highest screened pulp yield with the lowest breaking length and burst factor.
- *D. hamiltonii* and *B. tulda* are best suited for high-strength paper applications.
- *B. vulgaris* shows versatility, offering moderate to high strength and yield, making it an adaptable choice for various paper types.

1 | INTRODUCTION

Bamboo, commonly known as "Green gold" and "Poor man timber," is a widely used raw material in manufacturing industries due to its wide range of exploitable characteristics like fast growth and high fiber characteristics (Raikundlia and Sawlikar, 2022). In India, bamboo is grown on 15.69 M ha of land, It can grow from the seaside to an altitude range of 4000 m and tolerate a temperature range from 20^0-45^0C (Sharma *et al.,* 2009). The altitude range between 770-1080 m is the most suitable condition for its occurrence (Tewari *et* *al.,* 2019). It belongs to the subfamily Bambusoideae under the Poaceae family (Kaushal *et al.,* 2021). About 25% of bamboo species occurring worldwide are found in India (Chaudhary *et al.,* 2024). Bamboo has multiple other commercial and environmental significance. Its high demand in industry has created much attention among farmers and commercial growers, providing them a good source of income and employment opportunities to locals. It emerges as an essential raw material for pulping and papermaking to mitigate the shortage of wood resources, a major concern of pulp and paper industries (Chen Z *et al.,* 2018). It has high ash, low lignin, and excellent cellulose content, which helps to make excellent pulp yield (Shamsuri, 2021). Despite bamboo's numerous commercial and environmental benefits, it has not yet achieved the same level of acceptance among farmers as more commonly cultivated species like Eucalyptus, Poplar, and Shisham (Shrivastav and Tomar, 2020). Despite India being abundant in natural bamboo resources, it is a net importer of bamboo. Globally, the market for sustainable products has been on the rise, as there has been an increasing awareness about sustainable consumption. Although the demand for bamboo has been high since post covid, industries like pulp and paper that use it as raw material are facing challenges in procuring it, especially the industries located in the Northern part of India. The global demand for paper, which was 242.79 Mt in 1990, increased to 402 Mt in 2011, and the industrial demand for raw materials was 153 M cu m, against which internal market supply was only 60 M cu m. In contrast, the global consumption of paper and paperboard totaled 417 Mt in 2021. Consumption is projected to continue rising over the coming decade to reach 476 Mt by 2032; therefore, there is a need to promote species like bamboo that proliferate and have short rotation periods (Sharma *et al.,* 2024).

Bamboo's dense root systems stabilize soil and mitigate erosion, making it a valuable asset in restoring degraded lands (Kaushal *et al.,* 2020). Bamboo offers strength properties to the paper and makes it better than the one made without adding bamboo; it has a long fiber length, making it suitable for pulping (Netto *et al.,* 2024). It has lower ecological footprints, and its ability to use various paper-making processes underscores its suitability as a viable alternative to conventional pulp sources. While research on the role of bamboo in rehabilitating degraded lands is well-documented, studies specifically addressing bamboo's pulp quality parameters are limited. Recognizing this gap, our study focuses on screening ecologically important bamboo species such as, *Bambusa balcooa, Bambusa vulgaris, Bambusa tulda*, *Dendrocalamus hamiltonii*, *Dendrocalamus strictus,* and *Melocana baccifera* to evaluate their suitability to meet industry demands for strength, fiber quality and yield for pulp production. This dual focus will contribute valuable insights into species-specific pulp qualities and support sustainable resource management by highlighting bamboo's potential as a raw material that aligns with environmental restoration objectives.

2 | MATERIALS AND METHODS

The study focused on evaluating the physical and chemical properties of different bamboo species, *viz., Bambusa balcooa, Bambusa vulgaris, Bambusa tulda*, *Dendrocalamus hamiltonii*, *Dendrocalamus strictus,* and *Melocana baccifera*. The bamboo species used for the study studies were procured from different sources from Nagaland (*M. baccifera, D. strictus* and *B. tulda)*, Assam (*B. balcooa*), Himachal Pradesh (*D. hamiltonii*) and Uttarakhand (*B. vulgaris*). The details of the collected bamboo samples, along with climatic and soil conditions, are given in Table 1.

The physical and chemical tests on collected samples were done in the quality control laboratory (DSIR Approved) of Kuantum Papers Limited, Saila Khurd, Hoshiarpur, Punjab. Before converting the raw material into chips form, the material was checked for its suitability for pulping. Raw materials' quality directly affects the final product's quality and physical appearance. Equal amount of chips after proper chipping was taken taken and cooked in the sodium hydroxide solution as per the details given in (Table 2).

The pulping of different species of bamboo collected was carried out using Autoclave bomb digester followed by bleaching in ODoEopD1P sequence. The observations at

TABLE 1 Climatic and soil conditions of the different locations

Species	Location	Altitude (above MSL)	Average rainfall (mm)	Temperature Range (°C)	Soil
Melocana baccifera	Farmer Field, Mariani (Nagaland)	1025 m	1800 - 2500	21-40	Fine clay, clay loamy, and the fine loamy clay
Dendrocalamus strictus	Farmer Field, Mariani, (Nagaland)	1025 m	1800-2500	21-40	Fine clay, clay loamy, and the fine loamy clay
Bambusa tulda	Farmer Field, Mariani, (Nagaland)	1025 m	1800-2500	21-40	Fine clay, clay loamy, and the fine loamy clay
Bambusa balcooa	Farmer Field, Pathsala (Assam)	1960 m	1660-1830	20-30	Sand (coarse to fine) and clay
Dendrocalamus hamiltonii	Farmer Field, Arla, Palampur (HP)	1254 m	2909-3800	16-22	Loam to clayey-loam
Bambusa vulgaris	FRI Nursery, Dehradun (Uttarakhand)	640 m	2051-2200	0-33.8	Sandy loam to sandy clay loam

each stage were carried out using standard methods, as mentioned below:

1. Optical Properties *i.e.* Brightness Measured as per TAPPI (Technical Association of the Pulp and Paper Industry) Test Method (T-218) using Instrument Konica Minolta.
2. Viscosity of pulp measured using TAPPI Test Method (T-230), Capillary viscometer Method.
3. Screened Yield and Black Liquor characteristics were measured using the CPPRI Laboratory Manual of Testing Procedures 2001.
4. Physical Strength properties, i.e., Tear, Tensile, and Bursting Strength, measured using TAPPI Methods.
5. Freeness of pulp measured using Degree SR, Schopper Reigler (ISO-5267).

3 | RESULT AND DISCUSSION

The results for all the tested species are summarized in Table 3-6. The properties of these samples were observed and analyzed from the initial stage to the final stage. *B. tulda* exhibited the highest brightness at 23.70±0.52%, followed closely by *D. strictus* at 23.30±0.99%, with *B. balcooa* having the lowest brightness at 18.20±0.78%. The screen pulp yield was highest in *M. baccifera, which* achieved the highest yield at 51.40±0.40%, while *D. hamiltonii* had the lowest at 44.90 ±1.94%. Viscosity values for unbleached pulp were fairly consistent across species, ranging from 26.70±0.01 cP for *M. baccifera* to 27.90±0.02 cP for *B. tulda* (Table 3).

The characteristics of black liquor extracted from different bamboo species revealed differences in chemical parameters, including pH, chloride content, organic and inorganic composition, and silica content (Table 4). The pH levels range from 11.90±0.51 in *B. tulda* to 12.4±0.20 in *D. hamiltonii*, indicating slightly alkaline properties across all species. Chloride content as Cl varies, with *B. balcooa* showing the highest level at 3.40±0.11%, while *M. baccifera* has the lowest at 2.45±0.01%. Regarding organic and inorganic content, *B. balcooa* displays the highest organic content at 65.84±1.10 %, while the lowest is *B. tulda* with a value of 59.07±0.95. Conversely, *M. baccifera* has the highest inorganic content (40.03±0.62%), whereas the lowest is B. balcooa, with a value of 34.16±2.97%. Silica content is highest in *D. hamiltonii* at 0.90±0.04% and lowest in *B. vulgaris* at 0.36±0.09% (Table 4).

At the refining stage, the characteristics of six bamboo species revealed key differences in terms of Schopper degree (°SR), BF (burst factor), breaking length, and tear factor (Table 5). All species exhibited similar Degree SR values, with *B. balcooa*, *D. hamiltonii*, and *B. vulgaris* slightly higher at 31, compared to 30 for the other species. The BF (Burst Factor) values ranged from 35.67±1.78 for *M. baccifera* to 52.77±1.70 for *D. hamiltonii*, indicating superior strength of *D. hamiltonii* under pressure. *D. hamiltonii*

TABLE 2 Pulping parameters and cooking chemicals for treating different bamboo species

Parameters		Unit
Pulping parameters	Raw Material O.D.	500 gm
Cooking chemical (White Liquor)	Active alkali as NaOH	21%
	Steaming Time	120 min
	Cooking Temp	165°C
	Cooking Time at 165°C	120 min

TABLE 3 Characteristics of unbleached pulp of different bamboo species

Bamboo species	Brightness (%)	Screened Pulp Yield (%)	Viscosity (cp)
Melocana baccifera	20.70±0.25[b]	51.40±0.40[a]	26.70±0.01[e]
Dendrocalamus strictus	23.30±0.99[a]	50.20±0.57[ab]	27.80±0.01[b]
Bambusa tulda	23.70±0.52[a]	48.20±0.26[bc]	27.90±0.02[a]
Bambusa balcooa	18.20±0.78[c]	46.40±0.53[cd]	26.80±0.06[d]
Dendrocalamus hamiltonii	19.90±0.50[bc]	44.90±1.94[d]	26.90±0.02[c]
Bambusa vulgaris	19.10±0.36[bc]	46.30±0.46[cd]	27.80±0.02[b]
CD (0.05)	1.93	2.79	0.09

TABLE 4 Characteristics of black liquor extracted from different bamboo species

Bamboo species	pH	Chlorides component (%)	Organic composition (%)	Inorganic composition (%)	Silica content (%)
Melocana baccifera	12.00±0.05[a]	2.45±0.01[c]	59.97±0.62[c]	40.03±0.62[ab]	0.62±0.06[b]
Dendrocalamus strictus	12.10±0.10[a]	2.74±0.01[b]	61.06±0.98[bc]	38.94±1.13[abc]	0.56±0.03[b]
Bambusa tulda	11.90±0.51[a]	2.82±0.01[b]	59.07±0.95[c]	40.93±0.94[a]	0.65±0.03[b]
Bambusa balcooa	12.20±0.23[a]	3.40±0.11[a]	65.84±1.10[a]	34.16±2.97[c]	0.81±0.02[a]
Dendrocalamus hamiltonii	12.40±0.20[a]	2.55±0.03[c]	64.71±1.15[ab]	35.29±1.04[bc]	0.90±0.04[a]
Bambusa vulgaris	12.20±0.25[a]	2.83±0.05[b]	62.67±2.05[ab]	37.33±1.07[abc]	0.36±0.09[c]
CD(0.05)	NS	0.17	3.81	4.69	0.15

TABLE 5 Characteristics of different varieties of bamboo at the Refining Stage

Bamboo species	Schopper degree (°SR)	Burst Factor (BF)	Breaking Length (m)	Tear Factor
Melocana baccifera	30.00±0.58[a]	35.67±1.78[c]	4900.00±100.00[c]	85.00±7.64[bc]
Dendrocalamus strictus	30.00±1.00[a]	45.75±1.96[b]	6007.00±314.93[b]	100.00±6.35[ab]
Bambusa tulda	30.00±0.57[a]	37.75±0.42[c]	5100.00±104.01[c]	105.00±2.65[a]
Bambusa balcooa	31.00±0.57[a]	48.86±1.05[ab]	6417.00±84.50[ab]	79.00±2.08[c]
Dendrocalamus hamiltonii	31.00±1.16[a]	52.77±1.70[a]	6780.00±72.34[a]	101.00±3.22[a]
Bambusa vulgaris	31.00±1.73[a]	45.80±1.67[b]	6098.00±154.07[b]	104±5.13[a]
CD(0.05)	NS	4.75	502.55	15.40

TABLE 6 Characteristics of different varieties of bamboo at P Stage

Bamboo species	Brightness (%)	Viscosity (cP)	Bleach Pulp Yield (%)
Melocana baccifera	85.50±0.38[b]	7.32±0.04[c]	49.16±0.38[a]
Dendrocalamus strictus	86.40±0.47[ab]	7.62±0.08[c]	47.75±0.24[a]
Bambusa tulda	86.70±0.42[ab]	7.03±0.09[c]	45.60±0.35[b]
Bambusa balcooa	87.50±0.4[a]	8.72±0.04[b]	43.30±0.75[c]
Dendrocalamus hamiltonii	86.50±0.40[ab]	9.24±0.03[b]	42.50±0.68[c]
Bambusa vulgaris	87.20±0.18[a]	12.3±0.60[a]	43.30±0.32[c]
CD(0.05)	1.21	0.79	1.53

showed the highest breaking length at 6780±73.24 m, indicating better fiber strength, followed by *B. balcooa* at 6417±84.50 m. Comparison of tear factor indicates that *B. tulda* had the highest tear factor of 105±2.65, followed closely by *B. vulgaris* (104±5.13) and *D. hamiltonii* (101± 3.22). The lowest tear factor of 79±2.08 was recorded in *B. balcooa,* indicating comparatively lower resistance to tearing. Overall, *D. hamiltonii* stands out for its superior BF, breaking length, and tear factor, making it particularly robust at the refining stage (Table 5).

The bamboo species display brightness, viscosity, and bleach pulp yield differences at the P stage. *B. balcooa* and *B. vulgaris* showed the highest brightness levels at 87.50± 0.40% and 87.20±0.18%, respectively. In contrast, *M. baccifera* showed a slightly lower brightness of 85.50± 0.38% (Table 6). Viscosity measurements vary significantly, with *B. vulgaris* showing the highest viscosity at 12.30±0.60 cP, followed by *D. hamiltonii* at 9.24±0.03 cP. In contrast, *B. tulda* has the lowest viscosity at 7.03±0.09 cP, indicating potential differences in fiber strength and flexibility between species. *M. baccifera* had the highest bleach pulp yield of 49.16±0.38%, while *D. hamiltonii* had the lowest yield at 42.50±0.68 %. Overall*, M. baccifera is the* optimal species for higher pulp yield, and *B. vulgaris* and *D. hamiltonii* for strong fiber characteristics through higher viscosity values.

Overall, the results revealed that *M. baccifera* provided the highest screened pulp yield (51.4%), but its strength properties were lower, with the lowest breaking length (4900 m) and burst factor among the species. This yield advantage makes it ideal for cost-effective, high-volume paper production where strength requirements may be more moderate. *D. strictus* had a high tear factor (100) and a moderate screened yield (50.2%), making it a balanced option for paper requiring strength and durability. *B. tulda* recorded the highest tear factor (105) and brightness in unbleached pulp (23.7), making it ideal for high-strength applications and quality paper that requires a brighter base. *B. balcooa* had the lowest tear factor (79) and lower brightness (19.2) and thus remains useful due to its moderate strength properties, which may suit cost-effective production for general-purpose paper. *D. hamiltonii* exhibited the highest burst factor (52.77) and breaking length (6780 m), highlighting its potential for high-strength applications, although it had the lowest screened yield (44.9%). *B. vulgaris* showed strong physical properties with a high tear factor (104) and moderate pulp yield, comparable to *D. strictus*, and thus is essential for its adaptability across applications, blending strength and yield effectively. Bamboo is a sustainable alternative for pulp and paper production, adding to the existing body of research that underscores bamboo's rapid growth and wide availability (Hidayati *et al.,* 2019). Similar studies confirm the commercial potential of bamboo, analyzing fiber dimensions and chemical and pulping properties across different species and countries. However, a comprehensive assessment across lesser-studied bamboo species is still needed to understand their suitability for papermaking fully. Results conform with the findings of Chaurasia *et al.* (2016) on *Melocanna baccifera* and Junior *et al.* (2019) on *Bambusa vulgaris*, who revealed that bamboo exhibits promising properties similar to traditional wood fibers.

The chemical composition of bamboo poses unique challenges and advantages for the pulping process. As Chen *et al.* (2019) noted, high ash and silica content can lead to equipment wear and increased recovery costs. Bamboo's high lignin levels (27-29%) require longer cooking times and more chemicals for effective delignification (Mansouri *et al.,* 2012; Rowell *et al.,* 2012). The high extractives content, such as organic and inorganic in bamboo, also reflects the presence of low molecular weight carbohydrates and other constituents, affecting the efficiency of the pulping process (González *et al.,* 2013). In mechanical testing, bamboo fibers generally showed slower tensile strength development than softwood pulps, likely due to bamboo's thicker-walled fibers that resist internal fibrillation (Khantayanuwong *et al.,* 2021). However, the tear strength of bamboo pulp was found to increase with the initial beating time, indicating the potential for durable paper products (Scott and Abbott, 1995). Further research has shown that bamboo's age and culm section influence its pulping properties. Suhaimi *et al.* (2022) and Yoon *et al.* (2006) demonstrated that younger bamboo yields more pulp, and the cellulose content is highest in the top section of older culms, enhancing its potential for pulp production. Silica, while problematic for equipment, remains underexplored in mitigation, suggesting a future research avenue (Liese and Tang, 2015). Chemical pre-treatments, such as sodium hydroxide soaking, have improved pulp yield, SR degree (freeness), and brightness (Ainun *et al.,* 2018). Such advancements may reduce dependency on harsh bleaching processes, making bamboo a more viable alternative to wood in papermaking. The findings collectively indicate that optimized handling of bamboo's unique properties holds significant potential as a sustainable raw material for the paper industry. This diversity in properties across species allows the pulp and paper industry to tailor bamboo use to specific product needs, supporting specialized, high-strength papers and more general-purpose paper production while emphasizing sustainability.

5 | CONCLUSIONS

Integrating bamboo into the paper industry can lead to both environmental sustainability and the industry's long-term viability. From a technical perspective, bamboo fibers possess several properties that make them highly suitable for paper production. Bamboo for paper making generally employs lower chemicals during the pulping process due to low lignin content than the woody raw material. This helps reduce production costs and maximize production efficiency. Data from various bamboo species illustrate the potential of bamboo as a versatile resource for the pulp and paper industry, each species bringing unique qualities suited to different paper applications. *D. hamiltonii* and *B. tulda* are best suited for high-strength paper applications, while *M. baccifera* excels in pulp yield, making it more suitable for high-volume production. *B. vulgaris* shows versatility, offering moderate to high strength and yield, making it an adaptable choice for various paper types. Overall, it can be concluded that integrating bamboo into the pulp and paper supply chain creates a model of sustainable resource management that benefits the industry, environment, and society. As industries and governments prioritize sustainability, the role of bamboo in paper production will likely widen, contributing to a greener and more resilient future for the planet.

ACKNOWLEDGEMENTS

We are thankful to all the management of Kuantum Papers Limited. We would also like to express our warm regards to the Process Quality Control Department for their support in testing and data compilation.

DATA AVAILABILITY STATEMENT

The data generated and analyzed during the current study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors have declared that there is no conflict of interest.

AUTHOR'S CONTRIBUTION

SKS carried out the research over the period and recorded data, whereas SKC and VKS arranged testing and analyzed the data. SC proofread the compiled documents and made corrections. KS laid out the research and analysis methods for this research, constantly proofreading and making additions and deductions. VA analyzed and compiled the data statistically. GK and BKN supervised the field research work.

REFERENCES

Ainun, Z.M.A., Muhammad, K.I., Rasmina, H., Hazwani, H.A., Sharmiza, A., Naziratulasikin, A.K. and Latifah, J. 2018. Effect of chemical pretreatment on pulp and paper characteristics of *bamboo gigantochloa scorthechinii* kraft fibers. *The Wood and Biofiber International Conference (WOBIC 2017) IOP Publishing, IOP Conf. Series: Materials Science and Engineering, 368*, 012044. https://doi.org/10.1088/1757-899X/368/1/012044.

Chaudhary, U., Malik, S., Rana V. and Joshi G. 2024. Bamboo in pulp, paper and allied industries. *Advances in Bamboo Science,* 3: 1-16.

Chaurasia, S.K., Singh, S.P. and Naithani, S. 2016b. A study on fiber characteristics of *Melocanna baccifera* (Roxb.) Kurz for the suitability of pulp and paper production. *Indian Journal of Forestry*, 39: 27-30. https://doi.org/10.54207/bsmps1000-2016-QH1DL3.

Chen, Z., Zhang, H., He, Z. and Zhang, L. 2018. Bamboo is an emerging resource for worldwide pulping and papermaking. *Bio Resources* 14(1): 3-5.

Chen, Z., Zhang, H., He, Z., Zhang, L. and Yue, X. 2019. Bamboo as an emerging resource for worldwide pulping and papermaking. *Bio Resources*, 14: 3-5.

González, I., Alcalá, M., Arbat, G., Vilaseca, F. and Mutjè, P. 2013. Suitability of rapeseed chemi thermomechanical pulp as raw material in paper making. *Bio Resources*, 8(2): 1697-1708. doi:10.15376/biores.8.2.1697-1708.

Gülsoy, S.K. and Şimşir, S. 2018. Chemical composition, fiber morphology, and kraft pulping of bracken stalks (*Pteridium aquilinum* (L.) Kuhn). *Drvna industrija*, 69(1): 23-33. doi:10.5552/drind.2018.1725.

Hidayati, S., Suroso, E., Satyajaya, W. and Iryani, D.A. 2019. Chemistry and structure characterization of bamboo pulp with formacell pulping. *IOP Conf. Ser.: Mater. Sci. Eng.*, 532: 012024. https://doi.org/10.1088/1757-899X/532/1/012024.

Hossain, M.J., Ghosh, R.K., Das, A.K., Maryana, R., Nath, S.C., Islam, M.R. and Sarker, S.C. 2022. Effect of age and height on the chemical properties of Muli bamboo (*Melocanna baccifera*). *ACS Omega*, 7(43): 39370-39374. https://doi.org/10.1021/acsomega.2c05684.

Júnior, E.A.B., Lengowski, E.C., de Andrade, A.S., Venson, I., Klock, U., da Silva Júnior, F.G., Gonçalez, J.C. and de Muñiz, G.I.B. 2019. Bamboo kraft pulping. *Advances in Forestry Science*, 6, 791-796. https://doi.org/10.34062/afs.v6i4.8361.

Kamthai, S. and Puthson, P. 2005. Effect of beating revolution on sweet bamboo (*Dendrocalamus asper* Backer) kraft pulp properties. *CMU Journal*, 4(2): 137-47.

Kaushal, R., Singh, I., Thapliyal, S.D., Gupta, A.K., Mandal, D., Tomar, J.M.S., Kumar, A., Alam, N.M., Kadam, D., Singh, D.V., Mehta, H., Dogra, P., Ojasvi, P.R., Reza, S. and Durai, J. 2024. Rooting behavior and soil properties in different bamboo species of Western Himalayan Foothills, India, *Scientific Reports*, 10: 4966.

Khantayanuwong, S., Boonpitaksakul, W., Chitbanyong, K., Pisutpiched, S. and Puangsin, B. 2021. Physical properties of handsheets derived from coi (*Streblus asper* Lour.) pulp fiber as papermaking material traced from ancient times. *Bio Resources*, 16(3): 6201-11. doi:10.15376/biores.16.3.6201-6211.

Liese, W. and Tang, T.K.H. 2015. Properties of the bamboo culm. In *Bamboo: The Plant and Its Uses*, Springer, Cham, pp 227-256. https://doi.org/10.1007/978-3-319-14133-6.

Mansouri, S., Khiari, R., Bendouissa, N., Saadallah, S., Mhenni, F. and Mauret, E. 2012. Chemical composition and pulp characterization of Tunisian vine stems. *Industrial Crops and Products*, 36(1): 22-27. doi:10.1016/j.indcrop.2011.07.036.

Moradbak, A., Tahir, P., Mohamed, A. and Halis, R. 2016. Alkaline sulfite anthraquinone and methanol pulping of bamboo (*Gigantochloa scortechinii*). *Bio Resources*, 11(1): 235-48. doi:10.15376/biores.11.1.235-248.

Netto, L.G., Agostinho, F., Almeida, C., Liu, G. and Giannetti, B.F. 2024. Environmental performance of bamboo-based office paper production: a comparative study with eucalyptus. *Industrial Crops and Products.* 211: 118234.

Nitisoravut, N. and Malinen, R.O. 2007. Fiber morphology and paper making properties of selected Thai bamboos. *Appita Annual Conference*, 1: 83-89.

Panda, M.R. and Dey, A.N. 2024. Effect of number of nodes on the offset on multiplication and growth performance of *Bambusa nutans* wall. *Ex. Munro.* and *Bambusa balcooa* Roxb. *Indian Forester*. 150(7): 640-647.

Przybysz, K., Małachowska, E., Martyniak, D., Boruszewski, P., Iłowska, J., Kalinowska, H. and Przybysz, P. 2018. Yield of pulp, dimensional properties of fibers, and properties of paper produced from fast-growing trees and grasses. *Bio Resources*, 13(1): 1372-1387.

Raikundliya, S.J. and Sawlikar R. 2022. The role of bamboo in economic development of folks of Chandrapur district (MS). *Journal of Soils and Crops,* 32(2): 404-407.

Rowell, R.M., Pettersen, R., Han, J.S., Rowell, J.S. and Tshabalala, M.A. 2012. Cell wall chemistry. In: R.M. Rowell (Ed.), *Handbook of wood chemistry and wood composites.* Boca Raton, FL, USA: CRC Press. pp 35-47.

Scott, W.E. and Abbott, J.C. 1995. *Properties of Paper: An Introduction* (2nd ed.). Tappi Press, 78.

Shamsuri, M.A. 2021. Review on The paper making process from bamboo as a paper product (Nor Mazlana Main, Trans.). *Progress in Engineering Application and Technology,* 2(1): 965-971.

Sharma, S.K., Chambyal, S., Kumar, G. and Kumar, K. 2024. Suitability of Casuarina clone (CH-1) in Punjab: A path breaking solution for paper industries for their fiber demand and security. *Forestry Research and Engineering: International Journal,* 6(1): 206-209.

Sharma, A.K., Dutt, D., Upadhyaya, J.S. and Roy, T.K. 2011. Anatomical, morphological, and chemical characterization of *Bambusa tulda*, *Dendrocalamus hamiltonii*, *Bambusa balcooa*, *Malocana baccifera*, *Bambusa arundinacea*, and *Eucalyptus tereticornis*. *Bio Resources*, 6(4): 5062-5073. https://doi.org/10.15376/biores.6.4.5062-5073.

Sharma, S.K., Choube, L.M., Chauhan, S., Sharma, S.K., Shivani, Arya, S., Kaur, B. and Arya, I.D. 2009. Bamboo: As a vital resource of long fiber pulp and paper industry in India. *Advances in Bamboo Plantation, Management and Utilization*, 231-239.

Sivastav, A. and Tomar, A. 2020. Commercial eucalyptus and poplar plantation - New approaches in eastern UP. *International Journal of Environmental and Agriculture Research,* 6(8): 1-5.

Suhaimi, N.M., Hassan, N.H.M., Ibrahim, R. and Jasmani, L. 2022. Pulping yield and mechanical properties of unbeaten bamboo paper. *Pertanika Journal of Science and Technology*, 30(2): 1397-1408. https://doi.org/10.47836/pjst.30.2.30.

Tewari, S.K., Negi, H. and Kaushal, R. 2019. Status of Bamboo in India. *International Journal of Economic Plants,* 6(1): 30-39.

Tripathi, S.K., Mishra, O.P., Bhardwaj, N.K. and Varadhan, R. 2018. Pulp and papermaking properties of bamboo species *Melocanna baccifera*. *Cellulose Chemistry and Technology*, 52: 81-88.

How to cite this article: Sharma, S.K., Chechi, S.K., Chambyal, S., Sharma, V.K., Kumar, G., Sharma, K., Nayak, B.K., Attri, V. 2024. Evaluating ecologically important bamboo species for the pulp and paper industry. *Indian J. Soil Cons.,* **52** (Global Soils Conference - 2024 Special Issue): S85-S90.