Chemical Characterization of Tolla Bamboo (*Bambusa longispiculata*) of Different Ages and Heights

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Abstract

Bamboo is an abundant source of biomass that is underutilized despite having a chemical composition and fiber structure similar to wood. However, there is limited information about the chemical characterization of its culms for its utilization and processing. This paper investigated the main chemical compositions of 1, 2, 3, 4 and 5 years old *B. longispiculata* (Talla bamboo) at their three specific positions (top, medium and bottom). All the tests were conducted following the standard TAPPI (Technical Association of the Pulp and Paper Industry) methods. The water-soluble extract of the bamboo is in the range of 3.94-7.09%, 4.56-7.20% and 19.12-27.64% for cold water, hot water and caustic soda (1% NaOH) solubility respectively for 1-5 years old bamboo at their different ages and heights. The top culm position of 5 years old bamboo had the maximum holocellulose content (72.83%). The bottom part of 5 years old bamboo showed the highest (6.39%) benzene-ethanol extract. On an average 3 to 5 years old of bamboo showed the highest lignin content (30.86%) while the minimum lignin content (25.75%) was observed for the top culm position of one-year-old bamboo. Thus, the chemical characterization in the bamboo species will facilitate the alternative use of their processing and utilization-related industry.

সারসংক্ষেপ

কাঠের মতো রাসায়নিক বৈশিষ্ট্য এবং ফাইবার গঠন থাকা সত্ত্বেও বায়োমাসের উৎস হিসেবে বাঁশকে ব্যবহার করা হয় না। বয়স এবং উচ্চতার ভিত্তিতে বাঁশ সাধারণত বিভিন্ন ধরনের রাসায়নিক বৈশিষ্ট্য প্রদর্শন করে। এই গবেষণাপত্রে ১, ২, ৩, ৪, ও ৫ বছর বয়সি তল্লা বাঁশের (*Bambusa longispiculata*) বিভিন্ন উচ্চতায় (শীর্ষে, মাঝে এবং নিচে) আদর্শ TAPPI পদ্ধতিতে রাসায়নিক বৈশিষ্ট্য নির্ণয় করে এর উপযোগিতা নির্ধারণ করা হয়েছে। গবেষণা থেকে দেখা যাচ্ছে যে, ১–৫ বছরের বাঁশগুলোর বয়স ও উচ্চতার ভিন্নতা অনুসারে পানিতে দ্রবণীয় নির্যাস যথা– গরম পানি, ঠান্ডা পানি এবং কস্টিক সোডায় (NaOH) দ্রবণীয়তার হার ছিল যথাক্রমে ৩.৯৪–৭.০৯%, ৪.৫৬-৭.২০% এবং ১৯.১২–২৭.৬৪%। পাঁচ বছর বয়সি বাঁশের শীর্ষ অংশে সর্বোচ্চ হলোসেলুলোজ উপাদান (৭২.৮৩%) পরিলক্ষিত হয়েছে। পাঁচ বছর বয়সি বাঁশের নিচের অংশে সর্বোচ্চ (৬.৩৯%) বেনজিন-ইথানল নির্যাস দেখা গেছে। এছাড়াও তিন থেকে পাঁচ বছর বয়সি বাঁশে সর্বোচ্চ গড় লিগনিন উপাদান ছিল (৩০.৮৬%) যেখানে এক-বছর বয়সি বাঁশের সর্বনিম্ন লিগনিন উপাদান ছিল (২৫.৭৫%)। এই রাসায়নিক বৈশিষ্ট্যগুলো প্রান্তিক ব্যবহারকারীদের জন্য দিক-নির্দেশনা হিসাবে কাজ করতে পারে। পরিশেষে, কাঠের বিকল্প ব্যবহার হিসাবে তল্লা বাঁশের রাসায়নিক বৈশিষ্ট্য নির্ণয় এর ব্যবহার সহজতর করবে।

Key words: Age and height position, *Bambusa longispiculata*, Extractives, Holocellulose, Lignin, Pulp and paper.

Introduction

Over the past few decades, bamboo has received more attention as a renewable, cheap, fast-growing, and easily available material. It is also compatible with existing processing technologies (Tong *et al.* 2005). The overall demand for wood is rising as a result of the growing world economy and population, while the amount of wood supply is expected to decline due to the global biomass demand for green energy (Van der Lugt *et al.* 2008). Consequently, the search for alternative raw materials in place of wood has come into focus (Pannipa 2013). Research on bamboo has progressed rapidly due to its wide availability and material characteristics comparable to wood (Viel *et al.* 2018). Non-timber forest products mitigating the pressure on slow-growing forest resources and the growing demand for qualitative timber (van der Lugt *et al.* 2008). Recently, there are also growing interested in the utilization of bamboo for pulp production (Rasheed *et al.* 2020; Sridach 2010), nanofiber extraction (Visakh *et al.* 2012), composite materials (Amada and Untao 2001; Chiu and Young 2020; Jain *et al.* 1992; Muhammad *et al.* 2019; Tong *et al.* 2005; Viel *et al.* 2018), and biofuel production (Sun *et al.* 2014; Yang *et al.* 2019).

Bamboo is called "Wood of the poor" in India, "Friend of the people" in China, and simply "Brother" in Vietnam, for its many versatile essential uses (Khin *et al.* 2006). Bamboo is a naturally occurring giant grass that grows abundantly in most tropical countries (mainly Asia) except Europe and Antarctica (Lakkad and Patel 1980). *B. longispiculata* is an evergreen clumping bamboo, cultivated in the tropics which is used as an ornamental and construction materials. *B. longispiculata* is native to Bangladesh, India and Myanmar besides it can be normally be found along riverbanks, roadsides, and disturbed sites (Judziewicz *et al.* 2000; Clayton *et al.* 2019). It can grow up to a height of 15 m. Bamboos are usually monocarpic species, living for many years before flowering, then flowering and seeding profusely for 1-3 years before dying (Flora of China Editorial Committee 2019).

Compared to other lignocellulosic biomass, bamboo has unique characteristics in chemical composition. The most abundant organic polymer on the planet is cellulose, which accounts for 40 to 50 % of the mass in bamboo (Li *et al.* 2014; Zhang *et al.* 2018). Hence, the chemical characterization of bamboo is emergent in determining its suitability for various applications and treatments. The accurate compositional analysis enables the evaluation of potential conversion of yields and process economics (Sluiter *et al.* 2010). Since knowledge of bamboo's basic properties is extremely limited, understanding its physio-chemical properties is essential for the effective exploitation of bamboo. However, more research is required to determine its diversified applications.

The plant's characteristics depend on its age and height position (Majumdar *et al.* 2015). Bamboo's chemical composition changes according to species, environment, age, and location, as well as culm height (Liese and Weiner 1996). Such variation changes during the growth and maturation of bamboo (Xiaobo 2004). The understanding of the variation in the chemical composition of bamboo at their different age and height is important for their potential uses. Nevertheless, the chemical properties variation of *B. longispiculata* has not yet been reported yet. Hence, this study was conducted on a detailed analysis of chemical composition at their different ages and heights, to better understand the effect of these factors

on further uses and processing of the wood processing industry.

Materials and Methods

Raw materials

Healthy, straight and defect-free 1 to 5 years-old Bamboo *(B. longispiculata)* was collected from Keucia silviculture research station, Bangladesh Forest Research Institute (BFRI), Satkania, Chattogram (92°24' E and 93°15' E longitude and 24°22' N and 25°8' N latitude), Bangladesh in April, 2021. The area is marked by hot humid summer and dry cool winter. The mean maximum and minimum temperatures of the area are 30.2°C and 12.6°C respectively with a relative humidity of 79% and annual rainfall of 2919.1 mm. Reagent grade (≥95% purity) sodium hydroxide (NaOH), acetic acid (CH_3COOH), Sodium chlorite ($NaClO_2$) and sulfuric acid (H_2SO_4) were collected from Carolina Biological Supply Company, New York City, USA. Analytical grade (≥95% purity) benzene and ethanol were sourced from Merck KGA, Darmstadt, Germany.

Preparation of raw materials

For the present study, mature culms were randomly selected and felled. The average height of the bamboo was 65 feet. The preparation of raw materials was carried out based on the methods described elsewhere (Hossain *et. al.* 2022c). The bamboo culms were cut above 15 cm from ground level and then subdivided equally into the top, middle and basal portions according to their total length. The strips were not small enough to be placed in a Wiley Mill. So, at first, the bamboo was chipped into very small pieces by a Hammer mill and dried in the sun. Then the sawdust of bamboo species was ground to fine particles (size 40-60 mesh) with Wiley mill for chemical analysis. The material was then placed in a shaker with sieves to pass through a No. 40 mesh sieve yet retained on a No. 60 mesh. The fine particles were stored in an air-tight container labeled with appropriate code to permit a complete reaction of samples with the reagents used in the analysis as shown schematically in Fig. 1.

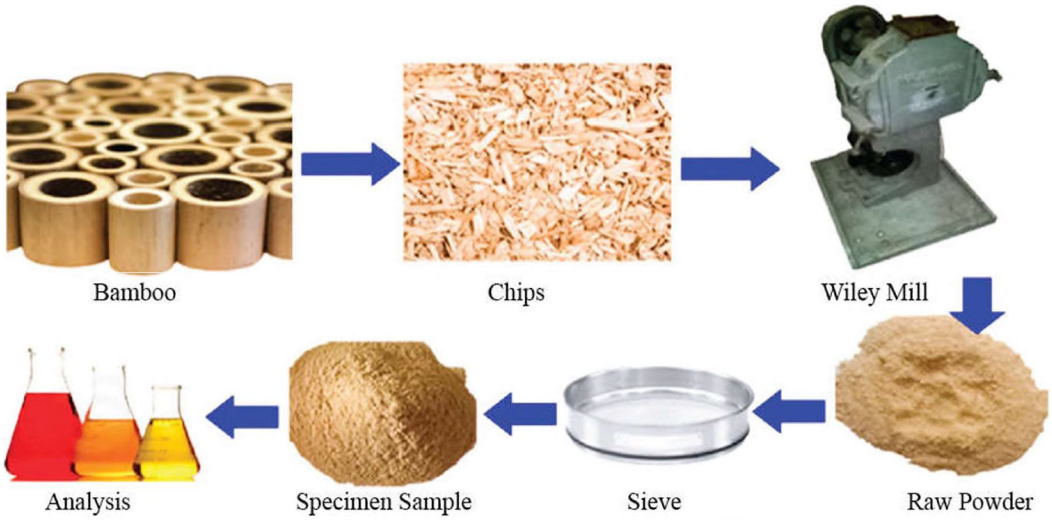

Figure 1. Preparation of bamboo powder sample for chemical analysis.

Experimental methods

Bamboo sample was analyzed at a minimum in triplicate, and the mean values were recorded. All the results were carried out on a percent basis. Chemical analysis was carried out based on the methods described elsewhere (Hossain *et al.* 2022 a, b). Proximate chemical analysis was conducted on air dry milled bamboo samples according to the following standard methods as shown in Table 1.

Table 1. Standard chemical methods followed for different experiments

Sl. No.	Name of the experiments	Name of the chemical methods
1	Moisture content	TAPPI T-264 cm-8
2	Cold water solubility	TAPPI T-207 cm-99
3	Hot water solubility	TAPPI T-207 cm-99
4	1% Sodium Hydroxide (NaOH) solubility	TAPPI T-212 om-02
5	Holocellulose	TAPPI T 249-75
6	Solvent extractives	TAPPI T 249-75
7	Total lignin content	TAPPI T-222 cm-02

Results

Solubility

Water solubility

The chemical composition of the culms is an important factor that influences the utilization and processing of bamboo. Fig. 2A & 2B were illustrated the effect of age and position on the cold and hot water solubility content of *B. longispiculata*. The hot water solubility was higher than the cold water solubility. The solubility of both types decreased with increasing age and height. The highest average cold water solubility was observed in the age graduation of *B. longispiculata viz.*, one (6.74%), two (5.30%), three (5.01%), four (4.80%), and five-year-old (4.23%). The bottom part of one-year-old bamboo showed the highest (7.20%) cold water solubility and the top portion of 5 years old bamboo showed the lowest (3.94%) value.

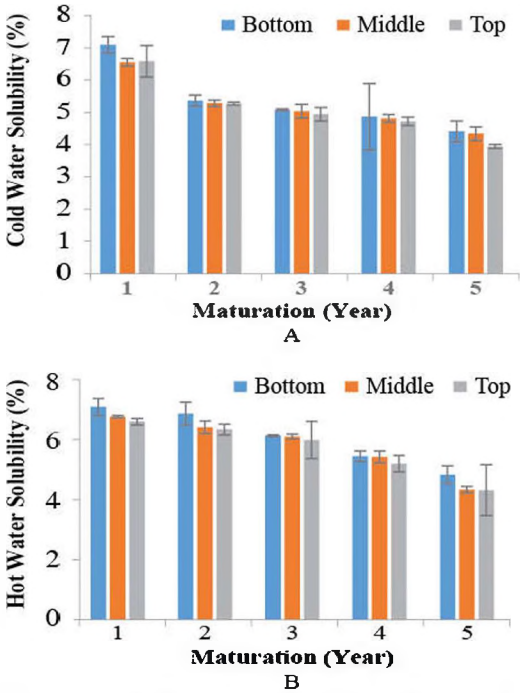

Figure 2. The effect of age and height position on cold (A) and hot (B) water solubility of *B. longispiculata*. The vertical bars represent the standard error.

On the other hand, the highest average hot water solubility values were observed in the age graduation of *B. longispiculata viz.,* 1 year (6.92%), 2 (6.64%), 3 (6.17%), 4 (5.44%), and 5 years old (4.56%). The bottom part of 1 year old bamboo showed the highest (7.20%) hot water solubility and the top portion of five-year-old bamboo showed the lowest (4.38%) values.

Caustic soda solubility

The caustic soda (1% NaOH) solubility of *B. longispiculata*, depending upon age and height is presented in Fig. 3. The caustic soda solubility was decreased with increasing age and height. The highest average values were observed in the age graduation of *B. longispiculata viz.,* 1 year (27.43%), 2 years (25.54%), 3 years (23.39%), 4 years (220.18%), 5 years old (19.31%). The bottom part of one year old bamboo showed the highest (27.64%) cold water solubility and the top portion of 5 years old bamboo showed the lowest (19.12%) value. The total average caustic soda (1% NaOH) solubility of *B. longispiculata* value was observed at 23.17%.

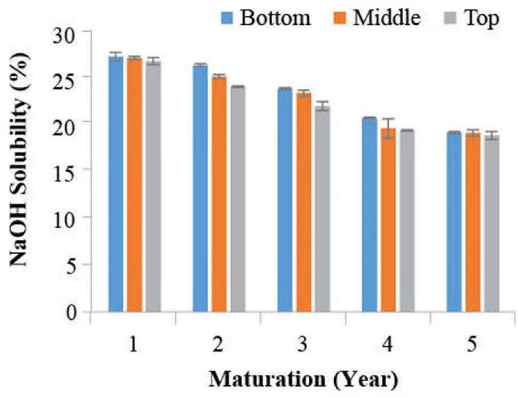

Figure 3. The effect of age and height position on caustic soda (NaOH) solubility of *B. longispiculata*. The vertical bars represent the standard error.

Extractive

From Fig. 4, the variation of extractive content was shown according to age and height position. The lowest extractive content was 0.62% for the top part of a 1 year old while the highest was 6.39% for the bottom part of a 5 years old *B. longispiculata*. The value was observed among the age graduation of *B. longispiculata viz.,* 1 (0.75%), 2 (2.53%), 3 (3.86%), 4 (5.68%), and 5 years old (6.15%). The extractive content was 3.79%. From the result, we observed that the results in different age groups were increased with the increase of age and height. It also observed significantly higher extractive content in 4 and 5 years old bamboo compared to one and 2 years old bamboo.

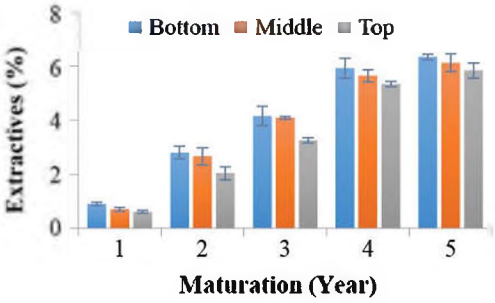

Figure 4. The effect of age and height position on extractives content of *B. longispiculata*. The vertical bars represent the standard error.

Holocellulose

The effect of age and height position on the holocellulose content of *B. longispiculata* was presented in Fig. 5. The bottom part of 1 year old bamboo showed the lowest (66.58%) and the top portion of 5 years old bamboo showed the highest (72.83%) holocellulose content. *B. longispiculata* showed different holocellulose content for 1 (67.04%), 2 (68.56%), 3 (70.12%), 4 (71.95%) and 5 (72.69%) years old bamboos. The average holocellulose content was recorded as 70.07%. The results showed a

general increasing trends for holocellulose contents with an increase in the age and height position of the bamboo.

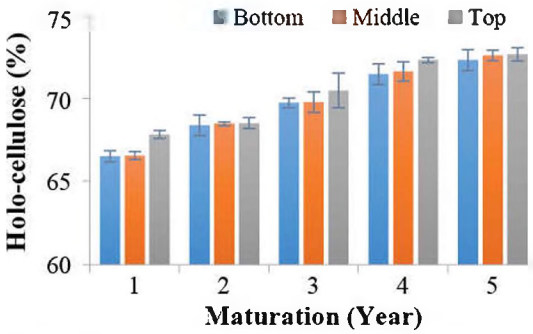

Figure 5. The effect of age and height position on holocellulose content of *B. longispiculata*. The vertical bars represent the standard error.

Lignin

Fig. 6 represented the effect of age and height position on the Klason lignin content of *B. longispiculata*. The bottom portion of 3 years old *B. longispiculata* showed the lowest lignin content (25.57%) and the top portion of 3 years old showed the highest lignin content (31.23%). The lowest average values were observed in the age graduation of *B. longispiculata viz.*, 1 year (26.60%), 2 years (29.51%), 3 years (30.05%), 4 years (31.31%), 5 years old (31. 20%). The total average lignin content was 29.74%.

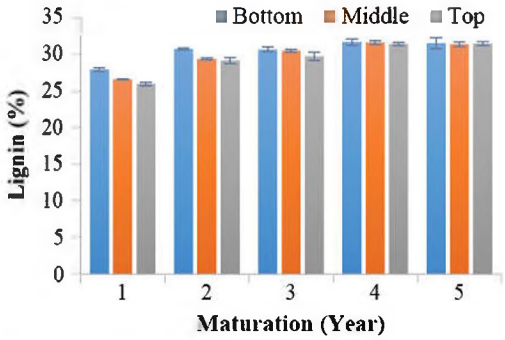

Figure 6. The effect of age and height position on total lignin content of *B. longispiculata*. The vertical bars represent the standard error.

Discussion

For a given bamboo species, the chemical composition cannot be defined precisely, and their composition varies with three parts (top, middle and bottom) and different ages. According to their varying chemical compositions, their utilization also varies.

The extractive contents, particularly cold and hot water soluble are important in the predetermination of water-soluble extractives. The cold water removes a part of extraneous components, such as inorganic compounds, tannins, gums, sugars, and coloring matter present in bamboo. On the other hand, the hot water treatment removed from the bamboo includes tannins, gums, sugars, coloring matter, and starches (TAPPI 2001). The water solubility test indicates the levels of these materials in the wood. The bottom position of all age classes gave the higher value of cold and hot water soluble compared to other portions. The tasted bamboo species did not contain a high concentration of hot water-soluble (10-15%) which may influence the susceptibility to insect and fungal attacks (Khin *et al.* 2006). The obtained result of hot water solubility is more comparable reported by Azeez *et al.* (2016) for *Bambusa vulgaris* These values fall within the acceptable range for paper production.

The alkali extractives (1% NaOH) are low molecular weight carbohydrates that consist of degraded cellulose and hemicellulose in bamboo. The content indicates the intensity of deterioration caused by fungi, heat, light and oxidation that is closely related to decay resistance (Junior and Moreschi 2003; Jiang *et al.* 2015). According to different height levels and ages, the value of alkali-soluble decreased with increasing height and age levels. Balaban and Ucar (2001) said this happens because the

bottom portion has a higher content of organic acid, polysaccharides, polyphenols, and tannin compared to other portions and ages. According to Jiang *et al.* (2015), 1% NaOH soluble extractive content of *B. vulgaris* was determined as 16.50% and according to Selvan *et al.* (2017) it was 33.13% for 5 years old and it was 18.19% for 1 year old which are comparatively similar with our result. Alkali charge must be kept low to preserve the cellulose content and enhance good pulp yield (Sadiku *et al.* 2016). *B. longispiculata* had shown a similar trend in this study. This might prevent the solubility of low molecular weight carbohydrates in a 1% NaOH solution.

It is important to consider that the amount and composition of extractives also depend on the species, part of the bamboo from which they were collected, time of year, and growth conditions, among other factors (Honorato-Salazar *et al.* 2015). In addition, the alcohol-benzene solubles in green bamboo (3.3%-3.9%) are higher than those in wood, such as poplar with a benzene-alcohol extractive content of 2.14% (Gong 2007). Li *et al.* (2007) in their studies reported that alcohol-toluene extractive content increased from the base to the top of the bamboo and showed a continuous increase with age. The presence of new cells may cause a lower amount of extractive content at the top. The higher extractive content is not beneficial to pulp and paper, and bioenergy production. It hinders the delignification and further processing. On the other hand, higher extractive content protects from biodegradation and it is beneficial to some bio-based composites. Therefore, 4 or 5 years old bamboo can be suitable for the biorefinery process. Further study can help to figure out its optimum utilization.

Holocellulose (alpha-cellulose and hemicelluloses) represents the total fraction of polysaccharides in bamboo. Height had a significant effect on holocellulose content. The top portion had a higher holocellulose content and the bottom portion had a lower holocellulose content. Hisham *et al.* (2006) reported that holocellulose content slightly increased beyond 3.5 years and the higher density of old bamboo was probably caused by greater content of lignin, ash, silica, and other extractive materials. The result compares favorably with those reported by Li *et al.* (2007) and Tsoumis (1991) for *Eucalyptus camadulensis* (55.6%), *E. hybrid* (67.80%), and generally for softwood (67%) and hardwood species (71.0 to 89.1%). This bamboo species showed holocellulose content (70.07%) in the range of wood species. 5 years old bamboo can be a potential source of raw material since it contains the highest amount of holocellulose and can be used for pulp and paper, bioenergy, and bio-based composite production.

The lignin present in bamboo is unique. The lignification process changes during the elongation of the culm; the full lignification of the bamboo culm is completed within one growing season, showing no further aging effect (Itoh and Shimaji 1981). Low quantities of lignin in lignocellulosic materials are desirable in the paper industry because they increase the pulp yield (Rowell 1984; MacLeod 2007). The lignin content in green bamboo showed much lower value than that of softwoods and hardwoods (Cai and Tao 2007; Gong 2007). The lignin values of 20-26% place bamboo at the high end of the normal range or 11-27% reported by Bagby *et al.* (1971) for non-woody biomass and closely resemble the ranges reported for softwoods (24-37%) and hardwoods (17-30%) (Fengel 1984; Dence 1992). The average lignin content

of *Yushania alpina, Phyllostachys edulis*, and *Bambusa oldhamii* at the ages of 1–3 years old are 25.27%, 20.35, and 20.9% respectively which are higher compared to the current results (Nahar and Hasan 2013). On the other hand, the high lignin content contributes to the high heating value of bamboo, and its structural rigidity makes it a valuable building material (Scurlock *et al*. 2000).

Conclusion

The study concentrated on a detailed analysis the chemical composition at different ages and heights of *B. longispiculata* to have a better understanding of the effect of these factors on the chemical composition of this bamboo species. The bottom portion of 5 years old bamboo showed the highest benzene-ethanol extractive; it may be advantageous for anti-decay and more suitable for structural application, furniture making and external uses. Based on the different height portions of bamboo, our result indicated a higher value at the bottom portion except for the holocellulose content. The higher lignin content is problematic for the delignification. It is troublesome for the application in pulp and paper, bioenergy, and bio-based composite. Therefore, less than 3 years old bamboo is beneficiary used in the biorefinery process. However, lignin is also a potential source of biorefinery. On the other hand, 5 years old bamboo contains the highest amount of holocellulose. Considering this, four or 5 years old bamboo is a promising source of raw materials in the biorefinery process. The variation of lignin content should be considered for the delignification. The proper ratio height position can solve the problem. Further study with cost-benefit analysis can mitigate all the issues with appropriate applications.

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