Radial variation of anatomical, morphological and chemical characteristics of Acacia auriculiformis in evaluating pulping raw material

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ORIGINAL RESEARCH

Radial variation of anatomical, morphological and chemical characteristics of *Acacia auriculiformis* in evaluating pulping raw material

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Abstract The Variations of anatomical, morphological and chemical characteristics with annual growth ring from first and second generation *Acacia auriculiformis* were investigated. The fiber length and wall thickness increased and proportion of ray cells decreased with increasing annual growth ring. First generation *A. auriculiformis* had higher proportion of fiber, longer fiber length than second generation *A. auriculiformis*. The average percentage of fibers, vessels and rays were 77.56%, 15.14% and 7.31% for first generation *A. auriculiformis* and 77.19%, 15.64% and 7.16%, for second generation *A. auriculiformis*, respectively. The holocellulose, α-cellulose and pentosan content increased and lignin and extractives content decreased with increasing annual growth ring. Holocellulose, α-cellulose, pentosan and lignin content in first generation *A. auriculiformis* were higher than second generation *A. auriculiformis*.

Keywords First and second generation · *Acacia auriculiformis* · Annual growth ring · Anatomical and morphological characteristics · Chemical characteristics

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Introduction

Acacia auriculiformis an exotic fast growing tree species was introduced in Bangladesh in 1960s as a shade tree in Tea estates known as Akashmoni. Forest management has been decentralized to improve forest resource conservation and to alleviate poverty and improve socioeconomic condition of rural people in developing countries. During the 1980s and onwards, many developing countries experienced various forms of decentralized forest governance with varying degrees of success and failures. The community-based forest management (CBFM) programs, popularly known as community forestry, social forestry, participatory forestry, joint forest management, etc., have been promoted in many countries as an innovative and potential approach to improved forest management and conservation strategies with a comprehensive blend of ecological and socioeconomic objectives (Nath et al. 2016). Social forestry in Bangladesh is about 11% of total forest land (Nath et al. 2016).

The government has introduced social forestry practices in 1981 by involving local landless and poor people. The participatory plantations were raised with exotics fast growing species such as *Acacias*, *Eucalyptus*, etc. In the social forestry programs, these exotics species provided return shortly. In 1983, the trial plantations of the Acacia were established and found that the *Acacia auriculiformis* and *Acacia mangium* were promising species in respect to survival and growth performance. *A. auriculiformis* was able to create vegetation cover in degraded forest areas easily. Bangladesh Forest Department allocated 46,000 ha forestland for social forestry program; acacia was planted in this forestland. It was also planted in agro-forestry program. Produced wood can be utilized in pulp mill as Bangladesh facing acute shortage of raw material.

Clear differences in morphological, chemical and anatomical characters were observed in the wood from first and second generation seeds (Haque et al. 2019; Honjo et al. 2005; Jusoh et al. 2013; Luangviriyasaeng and Pinyopusarerk 2002). Jusoh et al. (2013) found significantly lower wood density and shorter fiber length for second generation *A. mangium*. Luangviriyasaeng and Pinyopusarerk (2002) found that all families from the first generation seedling seed orchard grew significantly faster than local unimproved seed trees.

Similarly, radial and axial variations of morphological, chemical and/or anatomical characters were also observed (Chowdhury et al. 2009; Ibrahim 2017; Pereira 2007; Roque and Fo 2007). The basic density, fiber length, and fiber length increment increased up to about 80 mm radial distance from the pith and then were almost constant toward the bark (Chowdhury et al. 2009).The minimum and mean density, cell wall thickness, fiber width and lumen diameter decreased with the increase in growth rate (Roque and Fo 2007).

A tree improvement program for Acacias was started in 1981 by the Bangladesh Forest Department with the aim of improving the growth and stem of the species. Apparently the growth of Acacias from second generation seed was hindered. There is no study found on radial variation of chemical, anatomical and morphological properties of *A. auriculiformis* of second generation.

In this paper, the variation of chemical, anatomical and morphological properties of *A. auriculiformis* grown from first and second generation seed in social forestry plantation program in Bangladesh at the age of 10 years old was assessed.

Materials and methods

Material

The *A. auriculiformis* was collected from the Gazipur Forest Station at the age of 10 years old from the first and second generation. Three trees of each generation were selected for this experiment.

Anatomical, morphological and chemical properties

One radial increment from pith to bark was taken from each tree at BH. For chemical, anatomical and morphological analysis, sampling was carried out along the radius from pith to bark at annual growth ring of the total radius. At each annual growth ring, blocks of 1 cm length were taken. For anatomical analysis, transversal micro-sections from blocks of 30 μm thickness were obtained using a sliding microtome (MICROM, HM 325). Samples were stained with Safranin, dehydrated in alcohol and mounted in Canadian balsam on glass slides.

For SEM image analysis, the three samples were sectioned with sliding microtome as above and SEM image of cross section was recorded using a scanning electron microscope (Model EV018, Carl Zeiss AG, Germany). Fiber width, wall thickness, fiber lumen diameter were measured from the SEM image.

For the measurements of fiber length, sample was macerated in a solution containing 1:1 HNO_3 and $KClO_3$. A drop of macerated sample was taken on a slide. The fiber diameter and length was measured in image analyzer Euromex-Oxion using Image Focus Alpha software. For each sample, 100 measurements were done.

The chips from annual growth ring were ground in a Wiley mill and 40–60 mesh size was used for chemical analysis. The basic wood density of *A. auriculiformis* was determined according to PAPTAC Standard Methods (A. 8P Basic Density of Wood).

The extractive (T204 om88), Klason lignin (T211 om83) and ash content (T211 os76) were determined in accordance with Tappi Test Methods. Holocellulose was determined by treating extractive free wood meal with $NaClO_2$ solution. The pH of the solution was maintained at 4 by adding CH_3COOH–CH_3COONa buffer solution, and α-cellulose was determined by treating holocellulose with 17.5% NaOH.

Results and discussion

Chemical characteristics

Figures 1, 2, 3, 4 and 5 show the variation of chemical composition in respect to annual growth ring of first and

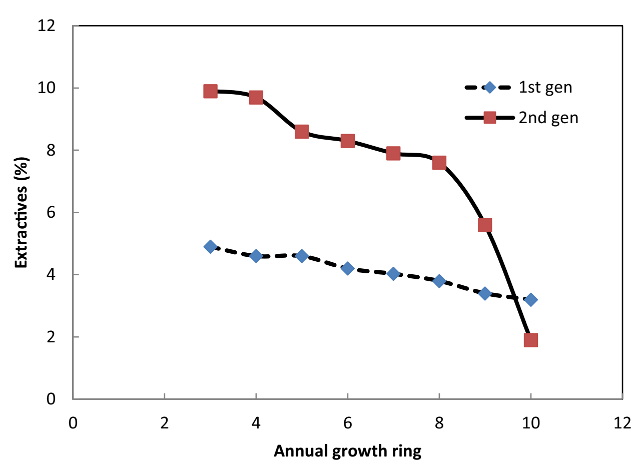

Fig. 1 Variation of extractive content with annual growth ring of *A. auriculiformis* from first and second generation seed

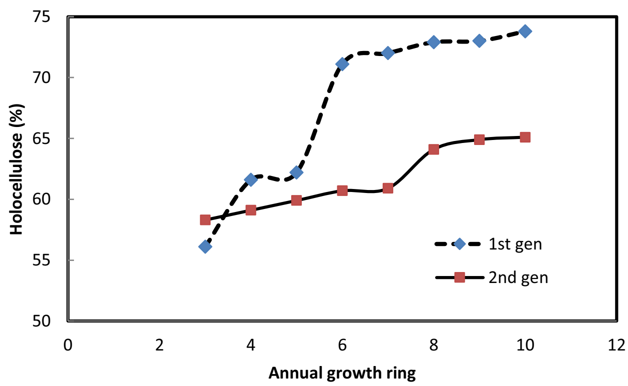

Fig. 2 Variation of holocellulose content with annual growth ring of *A. auriculiformis* from first and seecond generation seed

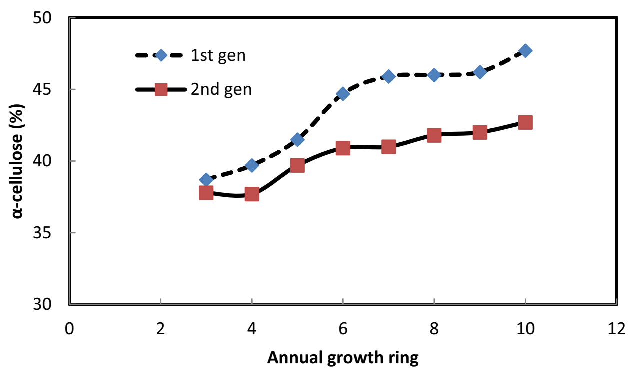

Fig. 3 Variation of α-cellulose content with annual growth ring of *A. auriculiformis* from first and second generation seed

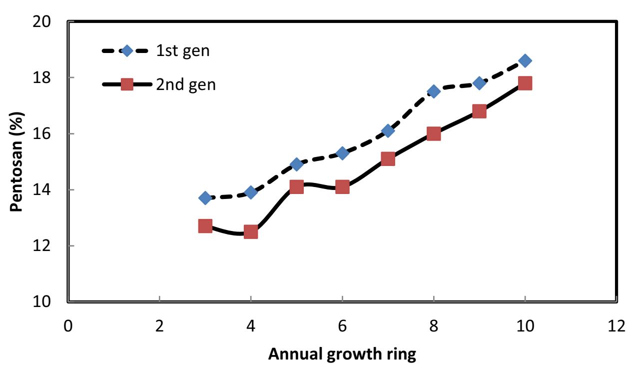

Fig. 4 Variation of pentosan content with annual growth ring of *A. auriculiformis* from first and second generation seed

second generation *A. auriculiformis*. Acetone extract content decreased with increasing growth ring. Acetone extract in second generation *A. auriculiformis* was higher than first generation. At the ring 1–3, extractive content was 9.9% for second generation and 4.9% for first generation, which decreased to 1.9% and 2.0% at the growth ring number 10, respectively (Fig. 1). Lourenço et al. (2008) also observed that heartwood had more extractives than sapwood ranging from 7.4% to 9.5% and from 4.0% to 4.2%, respectively,

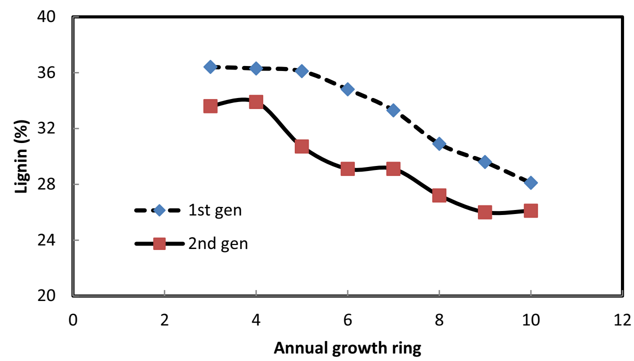

Fig. 5 Variation of lignin content with annual growth ring of.*A. auriculiformis* from first and second generation seed

for *Acacia melanoxylon*. Acetone soluble extractives were much higher than Eucalyptus species (Ribeiro et al. 2019). Holocellulose, α-cellulose and pentosan content increased with annual growth ring. Holocellulose, α-cellulose and pentosan content in first generation *A. auriculiformis* were higher than second generation (Figs. 2, 3 and 4). The α-cellulose is the most important component for pulping raw material. Higher α-cellulose content is related to pulp yield and papermaking properties. The α-cellulose content increased from 37.8% and 38.7% to 47.7% and 42.7% for first and second generation, respectively (Fig. 3). Pentosan is the main hemicelluloses component in hardwood species; it contributes fiber bonding in paper sheet and also increased in pulp yield. As seen in earlier study, pentosan content increased with the tree age (Haque et al. 2019). As shown in Fig. 4, the pentosan content in *A. auriculiformis* at annual growth ring 10 was 18.6% for first generation *A. auriculiformis*, which was 0.8% higher than that of second generation seed. Lignin is an undesirable component and is removed during pulping process. Figure 5 shows that the lignin content decreased with the annual growth ring. It decreased from 36.4% and 33.6% to 28.1% and 26.1% with the increase in growth ring from 1–3 to 10 for first and second generation, respectively. The lignin content in *A. auriculiformis* was higher than the lignin content in other hardwoods species in Bangladesh (Jahan et al. 2011; Mun et al. 2011). But the lignin content in *A. auriculiformis* obtained by Yamada et al. (1991) was similar in this study and higher than our previous study Jahan et al. (2008).

Anatomical characteristics

Table 1 shows the variation of anatomical properties with annual growth ring of first and second generation *A. auriculiformis*. The vessel proportion and number of vessel per sq mm did not follow any trend with annual growth ring. The number of vessel per sq mm was 11 and 7 at the growth ring no 10 for first and second generation,

Table 1 Cell proportion of *Acacia auriculiformis* from first and second generation seed

Parameter	Annual growth ring number							
	1–3	4	5	6	7	8	9	10
First generation								
Vessels (%)	15.54	15.41	15.50	14.25	16.03	15.28	15.02	14.08
No. of Vessel/mm^2	7.44	7.44	6.44	6.44	8.28	8.28	10.12	11.04
Rays (%)	7.0	6.6	6.8	9.7	7.5	5.9	8.3	6.7
Fiber (%)	77.43	78.04	77.7	76.08	76.47	78.86	76.67	79.26
Second generation								
Vessels (%)	17.86	16.12	15.8	15.64	15.60	13.02	15.36	15.75
No. of Vessel/mm^2	9.34	8.40	7.36	9.12	9.10	9.3	9.3	7.36
Rays (%)	8.8	7.1	7.3	6.5	6.1	8.4	7.1	6.0
Fiber (%)	73.34	76.76	76.9	77.82	78.3	78.58	77.56	78.28

respectively. The vessel proportion was 14–16% for first generation and 13–18% for second generation. More than 9% vessel proportion was found in *A. mangium* (Sahri et al. 1993). Pirralho et al. (2014) studied radial variation of vessel area of different Eucalyptus species. It was constant for *E. sideroxylon, E. propinqua, E. ovata, E. maculata, E. tereticornis* and *E. globulus*, and an increase in *E. viminalis, E. melliodora* and *E. camaldulensis*. Rao et al. (2002) found that vessel frequency, vessel diameter and fiber length varied significantly from bottom to top with no definite trend.

During the papermaking process, high vessel coverage facilitates the penetration of pulping liquor into wood and increases bulk. On the other side, surface quality of the paper is lowered, because vessel elements may pick out from the paper surface during the printing process, leaving ink-free spots on the printed page (Amidon 1981; Colley 1973; Leal et al. 2003). Haygreen and Bowyer (1996) elucidated that wood with high proportion of vessels produce a lower pulp yield than wood with higher fiber content during processing due to break down of vessels during wood processing and pulping. Amidon (1981) showed that the vessel proportion and the number of vessels per sq mm were negatively correlated with pulp yield and paper strength properties. There was an irregular variation with ray cells proportion with first and second generation and annual growth ring. Ray cells proportion was 6–10%. The highest proportion of ray cells was found at the annual growth ring 6 of second generation *A. auriculiformis*. Ona et al. (2001) showed that the ray proportion negatively correlated with pulp yield, burst factor, breaking length, kappa number and unbleached brightness.

A very high proportion of the volume of fibers was found in *A. auriculiformis* (Table 1); on average, fiber proportion was 76–79% for first generation and 73–78% for second generation. This percentage includes the axial parenchyma cells, which was not measured separately. There are no definite variations with annual growth ring. Sahri et al. (1993) found more than 85% fiber in *A. mangium*.

Morphological characteristics

The morphological characteristics play a vital role in assessing the suitability of pulping raw material. As shown in Table 2, the fiber length and cell wall thickness of first and second generation *A. auriculiformis* increased with annual growth ring. The fiber length of first and second generation *A. auriculiformis* increased from 0.73 to 0.61 mm at the ring number of 1–3 to 0.91 mm and 0.88 mm, respectively. These results are in good agreement with Goyal et al. (1999) who reported similar changes in fiber length of hybrid poplar. Boyce and Kaeiser (1961) also found that the length of the fiber increased with the number of rings from the pith and with the diameter of the tree. Yahya et al. (2010) found fiber length of 0.879 mm for 7 years old *A. auriculiformis.* Kim et al. (2008) also observed that the fiber length of A. hybrid was shortest at the vicinity of the pith, reaching a maximum value close to the bark. A similar radial pattern was also reported in *Acacia mangium* grown in Malaysia and Indonesia by Honjo et al. (2005). The longer fiber length corresponded to a higher tearing resistance of paper (Gallay 1962).

The calculated Runkel ratio for *A. auriculiformis* fibers was 0.24–0.41, which was within the range of aspen (0.23) to *Ailanthus altissima* fibers (0.46) (Samariha et al. 2011). There was no relationship seen between slender ratio and annual growth ring and first and second generation *A. auriculiformis.* The slenderness ratio of *A. auriculiformis* varied from 40 to 60. Yahya et al. (2010) showed that slender ratio of *A. auriculiformis*, *A. mangium* and *Acacia hybrid* was 52.65, 51.29 and 57.4, respectively. The slenderness ratio positively correlated with folding endurance (Dinwoodie 1965; Ona et al. 2001). Generally, the

Table 2 Morphological properties and derived values of *Acacia auriculiformis* from first and second generation seed

Parameter	Annual growth ring number							
	1–3	4	5	6	7	8	9	10
First generation								
Fiber length (mm)	0.73	0.77	0.81	0.83	0.86	0.86	0.88	0.911
Fiber diameter (μm)	14.53	14.92	16.12	14.10	14.21	15.03	17.78	18.27
Lumen diameter (μm)	12.43	12.21	14.45	12.13	12.01	13.12	15.23	15.71
Wall thickness (μm)	1.50	1.74	1.77	1.70	2.01	1.98	2.31	2.46
Slenderness ratio	50.24	51.60	50.24	58.86	60.52	57.21	49.49	49.86
Flexibility coefficient	0.86	0.82	0.90	0.86	0.85	0.87	0.86	0.86
Runkel ratio	0.24	0.29	0.24	0.28	0.33	0.30	0.30	0.31
Second generation								
Fiber length (mm)	0.61	0.62	0.68	0.75	0.75	0.84	0.85	0.88
Fiber diameter (μm)	12.68	13.39	15.45	13.32	18.75	14.71	16.63	16.12
Lumen diameter (μm)	9.25	9.73	12.12	10.78	14.95	11.61	12.54	11.79
Wall thickness (μm)	1.72	2.01	1.93	1.67	2.21	2.13	2.02	2.42
Slenderness ratio	48.10	46.30	44.01	56.31	40.00	57.10	51.11	54.59
Flexibility coefficient	0.73	0.73	0.78	0.81	0.80	0.79	0.75	0.73
Runkel ratio	0.37	0.41	0.32	0.31	0.30	0.37	0.32	0.41

acceptable value for slenderness ratio of papermaking is more than 33, respectively (Xu et al. 2006).

The flexibility coefficient of *A. auriculiformis* fibers was above 70, which was similar to *Ailanthus altissima* fibers (Samariha et al. 2011). Bektas et al. (1999) divided fibers into four groups based on flexibility coefficient: (1) high elastic fibers having elasticity coefficient greater than 75 (2) elastic fibers having elasticity ratio between 50 and 75 (3) rigid fibers having elasticity ratio between 30 and 50 (4) highly rigid fibers having elasticity ratio less than 30., the flexibility coefficient of *A. auriculiformis* fibers was above 70, so it is included in the elastic fibers group.

Prediction of chemical compositions using fiber length

The correlation between fiber length with holocellulose, α-cellulose and lignin contents are shown in Figs. 6, 7 and 8. The fiber length was strongly correlated with holocellulose (R^2 = 0.82–0.85), α-cellulose (R^2 = 0.94–0.95) and lignin (R^2 = 0.91) contents when individual raw material is considered. If first and second generation *A. auriculiformis* are considered together for making correlation of fiber length with holocellulose, cellulose and lignin contents, then the correlation coefficient (R^2) decreased. The R^2 values for lignin, holocellulose and α-cellulose were 0.887, 0.651 and 0.765.

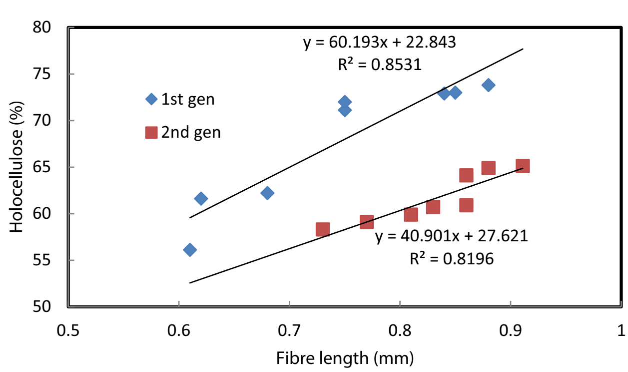

Fig. 6 Correlation between fiber length and holocellulose

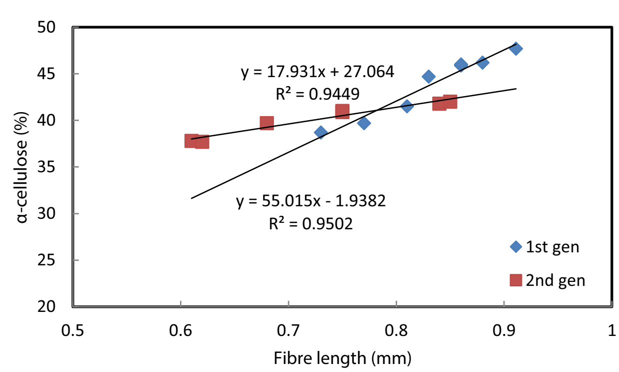

Fig. 7 Correlation between fiber length and α-cellulose

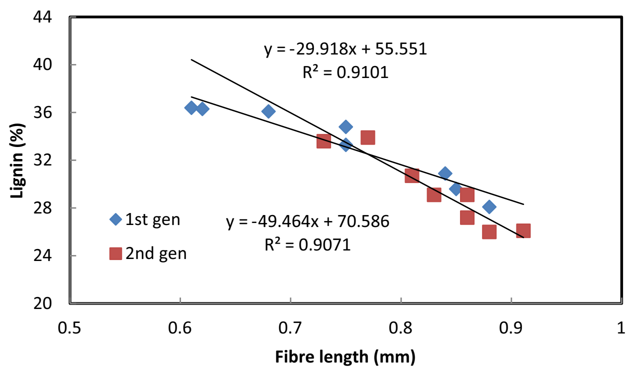

Fig. 8 Correlation between fiber length and lignin

Conclusions

The variations of anatomical, morphological and chemical properties with annual growth ring of 10 years old *Acacia auriculiformis* from first and second generation seed were investigated. All these properties varied in different magnitudes with the age due to growth in radial direction. Fiber length and wall thickness increased and ray cell proportion decreased with age. First generation wood showed longer fiber length and shorter fiber width than second generation *Acacia auriculiformis*. First generation wood also showed higher α-cellulose, pentosan and lignin. With increasing tree age, the α-cellulose and pentosan content increased and decreased lignin content. Considering the importance of these properties for pulping, the *Acacia auriculiformis* from first generation seed is significantly better than second generation.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

References

Amidon TE (1981) Effect of the wood properties of hardwoods on kraft paper properties. Tappi J 64:123–126

Bektas I, Tutus A, Eroglu H (1999) A study of the suitability of Calabrian pine (Pinus Brutiaten.) for pulp and paper manufacture. Turk J Agri 23:589–599

Boyce SG, Kaeiser M (1961) Environmental and genetic variability in the length of fibers of eastern cottonwood. Tappi 44(5):363–366

Chowdhury Q, Ishiguri F, Iizuka K, Hiraiwa T, Matsumoto K, Takashima Y, Yoshizawa N (2009) Wood property variation in *Acacia auriculiformis* growing in Bangladesh. Wood Fiber Sci 41(4):359–365

Colley J (1973) The influence of vessel elements on the picking tendency of eucalypt pulps. Paper Technol 14:293–296

Dinwoodie JM (1965) The relationship between fibre morphology and paper properties: a review of literature. Tappi J 48:440–447

Gallay W (1962) The formation and structure of paper. In: Bol L, Bolam F (eds) Tech. sect. British paper and board makers' assoc. London, pp 491–532

Goyal GC, Fisher JJ, Krohn MJ, Packood RE, Olson JR (1999) Variability in pulping and fiber characteristics of hybrid poplar trees due to their genetic makeup, environmental factors, and tree age. Tappi J 82(5):141–147

Haque MM, Uddin MN, Quaiyyum M, Nayeem J, Alam MZ, Jahan MS (2019) Pulpwood quality of the second generation *Acacia auriculiformis*. J Bioresour Bioprod 4(2):73–79

Haygreen JG, Bowyer JL (1996) Forest products and wood science: an introduction, 3rd edn. Iowa University Press, Ames

Honjo K, Furukawa I, Sahri MH (2005) Radial variation of fiber length increment in *Acacia mangium*. IAWA J 26(3):339–352

Ibrahim OAH (2017) Variations in axial and ray parenchyma cells in ten hardwood species growing in Nigeria. J Resour Dev Manag 38:64–68

Jahan MS, Sabina R, Rubaiyat A (2008) Alkaline pulping and bleaching of *Acacia auriculiformis* grown in Bangladesh. Turk J Agri For 32(4):339–347

Jahan MS, Haider MM, Rahman MM, Mondal GK, Biswas D (2011) Evaluation of rubber wood (*Heveabrasiliensis*) as a pulping and papermaking raw materials. Nordic Pulp Paper Res J 26(3):258–262

Jusoh I, Zaharin FA, Adam NS (2013) Wood quality of acacia hybrid and second-generation *Acacia mangium*. BioResources 9(1):150–160

Kim NT, Ochiishi M, Matsumura J, Oda K (2008) Variation in wood properties of six natural acacia hybrid clones in northern Vietnam. J Wood Sci 54(6):436–442

Leal S, Pereira H, Grabner M, Wimmer R (2003) Clonal and site variation of vessels in 7-year-old *Eucalyptus globulus*. IAWA J 24:185–195

Lourenço A, Baptista I, Gominho J, Pereira H (2008) The influence of heartwood on the pulping properties of *Acacia melanoxylon* wood. J Wood Sci 54(6):464–469

Luangviriyasaeng V, Pinyopusarerk K (2002) Genetic variation in a second-generation progeny trial of *Acacia auriculiformis* in Thailand. J Trop For Sci 14(1):131–144

Mun SP, Jahan MS, Al-Maruf A, Chowdhury DN (2011) Chemical characterization of six mangrove species in Bangladesh. Wood Sci Technol 45(2):281–288

Nath TK, Jashimuddin M, Inoue M (2016) Community-based forest management (CBFM) in Bangladesh, vol 22. Springer, Switzerland

Ona T, Sonoda T, Ito K, Shibata M, Tamai Y, Kojima Y, Yoshizawa N (2001) Investigation of relationships between cell and pulp properties in Eucalyptus by examination of within-tree property variations. Wood Sci Technol 35(3):229–243

Pereira H (2007) Variability in the chemical composition of plantation eucalypts (Eucalyptus globulus Labill.). Wood Fiber Sci 20(1):82–90

Pirralho M, Flores D, Sousa VB, Quilhó T, Knapic S, Pereira H (2014) Evaluation on paper making potential of nine eucalyptus species based on wood anatomical features. Ind Crops Prod 54:327–334

Rao RV, Shashikala S, Sreevani P, Kothiyal V, Sarma CR, Lal P (2002) Within tree variation in anatomical properties of some clones of Eucalyptus tereticornis Sm. Wood Sci Technol 36(3):271–285

Ribeiro RA, Colodette JL, Júnior SV (2019) Effect of residual effective alkali on eucalyptus kraft pulp yield and chemistry. CERNE 24(4):408–419

Roque RM, Fo MT (2007) Wood density and fiber dimensions of *Gmelina arborea* in fast growth trees in Costa Rica: relation to the growth rate. For Syst 16(3):267–276

Sahri MH, Ibrahim FH, Shukor NAA (1993) Anatomy of *Acacia mangium* grown in Malaysia. IAWA J 14(3):245–251

Samariha A, Kiaei M, Talaeipour M, Nemati M (2011) Anatomical structural differences between branch and trunk in *Ailanthus altissima* wood. Indian J Sci Technol 4(12):1676–1678

Xu F, Zhong XC, Sun RC, Lu Q (2006) Anatomy, ultrastructure and lignin distribution in cell wall of Caragana korshinskii. Ind Crops Prod 24(2):186–193

Yahya R, Sugiyama J, Silsia D, Gril J (2010) Some anatomical features of an Acacia hybrid, *A. mangium* and *A. auriculiformis* grown in Indonesia with regard to pulp yield and paper strength. J Trop For Sci 343–351

Yamada N, Khoo KC, Yusoff MNM (1991) Sulphate pulping characteristics of Acacia Hybrid, *Acacia mangium* and *Acacia auriculiformis* from Sabah. J Trop For Sci 4:206–214

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