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Review on Effect of Some Selected Wood Properties on Pulp and Paper Properties

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Abstract: The aim of this review was to know and highlight the effect of some selected wood properties such as, chemical composition, anatomical properties and density on pulp and paper properties. Before recommending any raw material for pulp and paper production, investigation of fiber characteristics and chemical composition is important, since they affect the quality of pulp and paper. Chemical composition of wood, affect pulp quality, pulp yield and pulp and paper mechanical strength. Fiber dimensions influence the performance of pulp and paper propertiesin terms of pulp quality, paper strength and uniformity, pulp beating, bursting strength, tensile strength, tearing strength and folding endurance of paper. Density is important parameter for pulp and paper properties since it affects pulp yield, sheet density, tensile strength, bursting strength, folding endurance, tearing resistance and energy consumption during pulping.

Key words: Chemical composition · Fiber dimension · Basic density · Pulp and paper

INTRODUCTION

The economic value of wood is affected by its properties, which are generally influenced by the anatomical features. The knowledge of wood anatomy and chemical composition is widely regarded decisive in understanding wood properties and its behavior in service [1]. Hardwood and softwood pulping accounts for 95% of the total worldwide pulp production and the rest 5% comes from non-wood raw materials, mainly agro-residues and grasses [2].

Ligno-cellulosic biomass has a complex structure containing mainly cellulose, hemicellulose and lignin [3]. In addition to these three major components, extractives and ash are contained in wood which is organic and inorganic, respectively [4].

Cellulose is the main constituent of wood and other biomass (38-50% of dry substance). It forms the structural framework of the cell walls. It is a linear polysaccharide with a repeating unit of glucose strung together by β-glycosidic linkages (10, 000 to 15, 000 glucose units) [5]. Hemicellulose is a highly complex, branched polymer made up of five different monomeric sugars attached through different linkages and contains five carbon sugars [6]. Lignin is a complex, a three-dimensional networked polymer comprising variously linked phenyl propane units [7]. It occurs between cell walls as a binding agent, holding cells together and within cell walls giving rigidity to the cell and reduces dimensional change with moisture-content in wood [8].

Extractive is the collective term given to the different classes of chemical compounds that can be extracted from wood or bark by means of polar and non-polar solvents, e.g. ether, acetone, ethanol, water [9]. They include tannins and other polyphenolics, coloring matter, 23 essential oils, fats, gums, resins, waxes and starch [10].

Ash is inorganic substances found in the wood, including silicates, sulfates, carbonates, or metal ions [11]. It is a residue remaining after ignition at a high temperature. The fraction of ash constitutes of Ca, K, Mg, P, Mn, Fe, Si, Al and Na salts and the actual composition varies between wood species and also influenced by the local compositions of the soil [6].

The fiber length is the distance from one end to another end and serves as a bonding, sites that are available on an individual fiber to form an interwoven network of fibers. However, fiber diameter is the diameter of fiber measured from side to side end and it is usually

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measured across the fiber length. The cell lumen diameter is the diameter of the internal cavity and is determined by averaging the radial diameter and tangential diameter [12].

However, cell wall thickness was defined as half values of double wall thickness including compound middle lamella [12]. The general objective of this paper is to review effect of wood chemical compositions, fiber dimensions and basic density on pulp and paper properties.

Effect of Chemical Composition on Pulp and Paper Properties: The chemical composition of raw materials of lignocelluloses is the basis for many properties of the paper that is produced later. Previously many scholars reported the relationship between cellulose content and pulp and paper properties. For instance, Kiaei *et al*. [13] reported that, cellulose content positive relationship with pulp quality. High cellulose content gives high pulp yield also reported by Khoo and Peh [14] and pulp mechanical strength especially tensile strength [15]. Moreover, Shakhes *et al*. [16] also reported that cellulose content has a positive effect on mechanical properties of paper. On the other hand, the pulp yield of chemical pulping is related to contents of cellulose and holocellulose present in the raw material.

Hemicellulose affects pulp and paper properties. According to the report of different scholars there is a relationship between hemicellulose and pulp and paper properties. For instance, higher hemicellulose values result in higher strength of paper (especially tensile, burst and fold) and the yield of pulp [17]; however, it may have a negative effect during pulping, because hemicellulose is the cell wall polymer component having the highest water sorption [18]. A low content of hemicellulose decreases the capacity of water absorbing thus, minimizing the duration of pulping activity [19].

The amount and reactivity of lignin have a marked effect on the pulp ability of the material which depends upon the type of raw material (hardwoods, softwoods, bamboos, etc.). Its determination in raw materials provides information to use for pulp and paper. Pulpwood requires a low lignin content since lignin content is negatively correlated with pulp yield [20, 21]. Moreover, hardness, bleachability and other pulp properties, such as color, are associated with the lignin content of raw material [22]. Lignin also delays fiber to fiber bonding in paper and all of its properties have negative effects in paper production; therefore, high-quality papers are made of fibers with no lignin at all. It causes the paper to become fragile and because of light oxidation which results in the production of color bands which gives the paper a dark or yellowish look [23]. Additionally, high lignin content indicates the potential of raw materials difficult to bleach with the consumption of more chemicals and long cooking cycle [24, 25]. Extractives of a raw material are undesirable parts since they can have a negative impact on the pulping and bleaching operations. Its influences on pulp and paper properties are previously reported by different scholars.

For instance, high amount of extractive substance in the raw material may result in poor quality of pulp and resulting in higher operating costs and an increased incidence of quality defects. According to Ates *et al*. [26], high extractive content will be an indicator of low pulp yield as well as higher chemical consumptions both in pulping and bleaching. However, low extractives content was related to higher pulp yields [27] and extractive will cause pitch problems in the paper making process, which causes processing and production stopped for a moment [28].

Ash constituents had a detrimental effect on the processing and quality of dissolving pulp. Consequently, the amount of ash in the raw material will indicate the measure to be taken on pulp processing. Although residual ash in a dissolving pulp is considered a contaminant for the preparation of cellulose derivatives, the mineral components are not distributed homogeneously in the plant cell fractions, mainly accumulated in the parenchyma cells [29]. Therefore, the pressure screening of unbleached pulp and centrifugal cleaning after bleaching can be utilized to reduce the amount of harmful ash components [30]. Moreover, high ash content is undesirable for pulping as they affect normal alkali consumption, create problems at waste liquor recovery and operational problems in material handling, pulp washing and beating [25, 31] as well as interferes with bleaching [32].

Effect of Fiber Dimensions on Pulp and Paper Properties: The pulp and paper qualities can be evaluated by wood properties including anatomical characteristics [33, 34]. The distribution of cell types and cell dimensions determine wood quality attributes pulp and paper quality such as smoothness and tear strength [35, 36]. Anatomical characteristics form the basis for wood utilization in pulp and paper making industry because of its relation with properties of the final product. For instance, Mousavi *et al*. [37] reported a direct correlation between fiber morphology and paper properties. The properties of paper depend on the fiber properties, anatomy and method of separation of the fibers. Fiber characteristics that influence the quality of paper are; fiber length, fiber diameter, lumen width, fiber cell wall thickness, Runkel ratio, coefficient flexibility and slenderness ratio [38]. Fiber length is an important descriptor factor of pulp quality, given its relationship with paper strength properties [39].

It also influences the paper sheet formation and its uniformity [40, 41]. Fiber biometry has been found a correlation with other pulp variables.

For instance, the pulp yield correlated positively with fiber length and negatively with fiber width [42] and Wimmer *et al*. [43] also reported that fiber length of *E. globulus* had a strong effect on pulp yield and freeness, as well as active alkali consumption, in addition, to tear index and bending stiffness. Additionally, higher fiber length has an effect on the resistance of the paper to tearing [44]. Shimoyama and Wiecheteck [45] also reported that high fiber length and cell wall thickness values and reduced total lumen diameter values may give higher paper strength and higher pulp yield.

The cell lumen diameter is the diameter of the internal cavity. It is determined by averaging the radial diameter and tangential diameter [12]. Cell lumen diameter affects the beating of pulp. The larger the cell lumen width, the better will be the beating of pulp because of the penetration of liquids into empty spaces of the fibers [46]. Moreover, Akpakpan *et al*. [47] also reported that lumen size affects on the rigidity and strength of paper.

Matured wood has thick wall while juvenile wood fibers are thin walled. Thick wall fibers adversely affect the bursting strength, tensile strength and folding endurance of paper. The paper manufactured from thick-walled fibers will be bulky, coarse surface and contain a large amount of void volume [48].

Derived Fiber Values: Derived values from the fiber dimensions are important to determine the suitability of the material for paper production. The pulp and paper quality, based on wood properties like anatomical characteristics, can be estimated using Runkel ratio [49], flexibility coefficient [50], slenderness ratio [51] and wall coverage ratio [52]. These indices have been used for fast growing tree species, such as acacia species [53]. The description of these indices and their relation with pulp and paper properties are discussed as followed:

Runkle Ratio: Runkel ratio is the ratio of fiber cell wall thickness to its lumen that determines the suitability of a fibrous material for pulp and paper production [13]. Raw materials with low Runkel ratio are preferred for paper making [54].

According to Santos *et al*. [55], if Runkle ratio < 1, the fiber is highly appropriate for pulp and paper production, from 1 to 2 is regular and above 2 it may not be used for pulp and paper making. If a wood species has a high Runkel ratio, its fiber will be stiff and less flexible and poor bonding ability [13].

Previously, Santos *et al.* [55] reported Runkle ratio was lower in earlywood than in the latewood and showed no significant variation along the stem of *A. melanoxylon*.

Slenderness Ratio: Is the ratio of the fiber length to its diameter and it indicate tearing resistance of a paper [51]. The slenderness ratio is related to the tearing strength and folding endurance of paper [53] and a high ratio indicates a better formed and well-bonded paper [56]. Ververis *et al*. [24] reported that, fiber with less than 70 slenderness ratio is not appropriate to use as raw material in wood and pulp industry. Previously, Pirralho *et al*. [33] reported values for the slenderness ratio ranging from 39.4 to 48.4 for several *Eucalyptus* species. Ohshima *et al*. [54] also reported a ratio of 50.5 to 56.5 and 57.7 to 59.9 in 14-year-old *E. camaldulensis* and *E. globulus*, respectively.

Flexibility Coefficient: Flexibility coefficient usually expressed in percentage is derived from the ratio of lumen width to its fiber diameter. It relates lumen diameter and fiber length and the higher its value, the more flexible will be the fiber, with more connections being likely to occur between them, what would increase tension and burst resistance [45]. The tensile and bursting strength depends mainly on the fiber bonding in the paper sheet which is largely related to the flexibility and compressibility of the individual fibers [57].

The flexibility coefficient is related to paper strength [33]. Moreover, Ashori and Nourbakhsh [56] reported that the flexibility coefficient expresses the potential of the fiber to collapse during beating or during drying of the paper web.

The collapsed fibers then provide a greater bonding area and therefore a stronger paper. According to Bektas [58] the flexibility coefficient (FC) can be separated in four classes: high elastic fibers with FC over 75; elastic fibers with FC between 50 and 75; rigid fibers with FC between 30 and 50; highly rigid fibers with FC less than 30. Previously, authors reported values for the flexibility coefficient ranged from 50% to75% in *A. melanoxylon* [55], 37% to 65 % in several *Eucalyptus* species [33] and 70% in *E. camaldulensis* and 72% in *E. globulus* [59].

Table 1: Derived Fiber values and Their Relation with Pulp and Paper Properties

Derived fiber Properties	Relation to pulp and paper properties	References
Runkel ratio	Pulp yield (+) and Digestibility (-)	[49]
Slenderness ratio	Tearing strength (+)	[59]
Flexibility coefficient	Tearing and Tensile strength (+)	[50]
Wall coverage ratio	Bending resistance (-)	[52]

Wall Coverage Ratio: Wall coverage ratio is an index for bending resistance [53] and related to fiber flexibility [20]. A material with a wall coverage ratio value less than 0.4 is considered to be good pulpwood since it is not too rigid [60].

Effect of Basic Density on Pulp and Paper Properties: Basic density was closely related and important parameter in pulping properties: wood with a low basic density produces paper with high sheet density; tensile, bursting and folding strengths; and lower resistance to beating; but with low pulp yield and tearing strength [42, 53]. Wood density is also an indicator of energy consumption during pulping [61, 62].

In high-density hardwoods, fibers with thicker cell walls represent a larger proportion of xylem gives porous paper and more compressible, giving better printability and opacity [63, 64]. However, in low-density hardwoods, vessels occupy a major proportion of wood and fibers have thin walls, producing a denser paper, smooth and with high tensile and burst strength [63].

According to the report of different scholars, there is no correlation, weak relationship or positive correlation between pulp yield and wood density. For instance, data from clonally replicated full-sub families and unrelated *E. globulus* clones suggested that pulp yield can be independent of wood density and growth rate [65]. Additionally, Seca and Domingues [66] reported that pulp yields were independent of wood density and instead associated with lignin composition in *E. globulus*. Mokfienski *et al*. [67] also observed that, a weak correlation between pulp yield and wood density in ten Eucalyptus species and with a negative impact of wood density on pulp yield. Moreover, Miranda and Pereira [68] did not observe a significant correlation between pulp yield and wood density in provenances of *E. globulus*. However, two types of *E. globulus* clones which showed markedly different wood density values, grown in different sites in Portugal showed a positive correlation between wood density and pulp yield [69].

CONCLUSION

Information on wood properties important to utilize for pulp and paper production. Chemically, cellulose content affects pulp quality, pulp yield and pulp and paper mechanical strength. Lignin affects hardness, bleach ability and other pulp properties. Extractives also have a negative impact on the pulping and bleaching and high extractive content lead to low pulp yield as well as higher chemical consumptions both in pulping and bleaching of pulp and paper.The fiber characteristics and its derived values influence the performance of pulp and paper properties in terms of pulp quality, paper strength and uniformity, pulp beating, bursting strength, tensile strength, tearing strength and folding endurance of paper. Basic density was closely related and important parameter for pulp and paper properties: since it affects pulp yield, sheet density, tensile strength, bursting strength, folding endurance, tearing resistance and energy consumption during pulping.

REFERENCES

1. Bowyer, J.L., R. Shmulsky and J.G. Haygreen, 2003. In Olarescu, A.M., M. Cio_Ca, L. Gurau and L.A. Badescu, 2009. Flatness of Eco-panels made of crosscut softwood branches. The 3rd European DAAAM International Young Researchers´ and Scientists´ Conference 25-28th November 2009, Vienna, Austria
2. Jiménez, L., A. Rodríguez, J.L. Ferrer, A. Pérez and V. Angulo, 2005. Paulownia, a fast-growing plant, as a raw material for paper manufacturing. Afinidad, 62(516): 100-105.
3. Winandy, J.E. and R.M. Rowell, 2005. 11 Chemistry of Wood Strength. Handbook of Wood Chemistry and Wood Composites, pp: 303.
4. Miller, R.B., 1999. Structure of Wood; Wood handbook-Wood as an engineering material. General technical report. FPL-GTR-113 Madison, WI: US department of Agriculture. Forest Service, Forest Products Laboratory, pp: 463.
5. Goldstein I.S., 1981. In organic chemicals from biomass, CRC press, Inc., Boca Raton, FL.
6. Theliander, H., M. Paulsson and H. Brelid, 2000. Introduktion till Massa-ochpappersframställning. Chalmers tekniskahögskola.
7. Sjöström, E., 1993. Wood Chemistry: Fundamentals and Applications, 2nd Ed., San Diego, California: Academic Press Inc., pp: 293.

8. Hillis, W.E., 1987. Heartwood and Tree Exudates Springer-Verlag. *Berlin Heidelberg*.
9. Cole, B., 2011. Extractive components of wood. University of Maine.
10. Wilson, K. and D.J.B. White, 1986. The Anatomy of Wood: Its Diversity and Variability within a silver maple tree. Wood Sci., 1: 227-237. London: Stobart and Son Ltd.
11. Rydholm, S.A., 1965. Pulping Processes. Inter science Publications, New York, pp: 1049.
12. Ishiguri, F., H. Aiso, M. Hirano, R. Yahya, I. Wahyudi, J. Ohshima, K. Iizuka and S. Yokota, 2016. Effects of radial growth rate on anatomical characteristics and wood properties of 10-year-old Dysoxylummollissimum trees planted in Bengkulu, Indonesia. Tropics, 25(1): 23-31.
13. Kiaei, M., M. Tajik and R. Vaysi, 2014. Chemical and biometrical properties of plum wood and its application in pulp and paper production. Maderas. Ciencia Y Tecnología, 16(3): 313-322.
14. Khoo, K.C. and T.B. Peh, 1982. Proximate chemical composition of some Malaysian hardwoods. The Malaysian Forester (Malaysia).
15. Madakadze, I.C., T. Radiotis, J. Li, K. Goel and D.L. Smith, 1999. Kraft pulping characteristics and pulp properties of warm season grasses. Bioresour. Technol., 69: 75-85.
16. Shakhes, J., F. Zeinaly, M.A. Marandi and T. Saghafi, 2011. The effects of processing variables on the soda and soda-aq pulping of kenafbast fiber. Bio Resources, 6(4): 4626-4639.
17. Biermann, C.J., 1996. Handbook of Pulping and Papermaking, Academic Press, United Kingdom, pp: 754.
18. Madsen, B., 2004. Properties of plant fiber yarn polymer composites: an Experimental Study.
19. Bakker, R.R. and H.W. Elbersen, 2005. October. Managing ash content and quality in herbaceous biomass: an analysis from plant to product. In 14th European Biomass Conference, pp: 17-21.
20. Amidon, T.E., 1981. Effect of the wood properties of hardwoods on kraft paper properties. Tappi, 64(3): 123-126.
21. Dutt, D. and C.H. Tyagi, 2011. Comparison of various eucalyptus species for the morphological, chemical, Pulp and Paper Making Characteristics.
22. Malik, R.S., D. Dutt, C.H. Tyagi, A.K. Jindal and L.K. Lakharia, 2004. Morphological, anatomical and chemical characteristics of Leucaena Leucocephala and its Impact on Pulp and Paper Making Properties.
23. Dahmardeh Ghalehno, M. and M. Nazerian, 2013. The investigation on chemical and anatomical properties of Roselle (*Hibiscus sabdariffa*) stem. International J. Agric. and Crop Sci., 5(15): 1622.
24. Ververis, C., K. Georghiou, N. Christodoulakis, P. Santas and R. Santas, 2004. Fiberdimensions, lignin and cellulose content of various plant materials and their suitability for paper production, Industrial Crops and Products, 19(3): 245-254. DOI:10.1016/J.INDCROP.2003.10.006.
25. Ogunsile, B.O. and C.F. Uwajeh, 2009. Evaluation of the pulp and paper potentials of a Nigerian grown *Bambusa vulgaris*. World Applied Sciences Journal, 6(4): 536541.
26. Ates, S., Y. Ni, M. Akgul and A. Tozluoglu, 2008. Characterization and evaluation of Paulownia elongota as a raw material for paper production. African Journal Ofbiotechnology, 7(22).
27. Lourenço, A., I. Baptista, J. Gominho and H. Pereira, 2008. The influence of heartwood on the pulping properties of Acacia melanoxylon wood. Journal of Wood Science, 54(6): 464-469.
28. Allen, L.H., 1980. Mechanisms and control of pitch deposition in newsprint mills. Tappi, 63(2): 81.
29. Sixta, H., 2006. Pulp properties and applications, in: Handbook of pulp, H.Sixta (ed.), Wiley, Weinheim, Germany, pp: 1022-1067.
30. Rosli, W.W., C.P. Leh, Z. Zainuddin and R. Tanaka, 2003. Optimization of soda pulping variables for preparation of dissolving pulps from oil palm fibre. Holzforschung, 57(1): 106-113.
31. Kristova, P. and I. Karar, 1999. Soda-Anthraquinone pulp from three Acacia niloticaspecies. Bioresource Technology, 68: 209-213.
32. Dutt, D., J.S. Upadhyaya, B. Singh and C.H. Tyagi, 2009. Studies on Hibiscus cannabinusand Hibiscus sabdariffaas an alternative pulp blend forsoftwood: an optimization of delignification process. Industrial Crops and Products, 29: 16-26.
33. Pirralho, M., D. Flores, V.B. Sousa, T. Quilhó, S. Knapic and H. Pereira, 2014. Evaluation on paper making potential of nine Eucalyptus species based on wood anatomical features. Industrial Crops and Products, 54: 327-334.
34. Istikowati, W.T., H. Aiso, Sunardi, B. Sutiya, F. Ishiguri, J. Ohshima, K. Iizuka and S. Yokota, 2016. Wood, chemical and pulp properties of woods from less-utilized fast-growing tree species found in naturally regenerated secondary forest in South Kalimantan, Indonesia. Journal of Wood Chemistry and Technology, 36(4): 250-258.

35. Downes, G.M., R. Wimmer and R. Evans, 2002. Understanding wood formation: gains to commercial forestry through tree-ring research. Dendrochronologia, 20(1-2): 37-51.
36. Gartner, B.L., 2008. Prediction of Wood Structural Patterns in Trees by Using Ecological. Characterization of the Cellulosic Cell Wall, pp: 38.
37. Mousavi, S.M.M., S.Z. Hosseini, H. Resalati, S. Mahdavi and E.R. Garmaroody, 2013. Papermaking potential of rapeseed straw, a new agricultural-based fiber source. Journal of Cleaner Production, 52: 420-424.
38. Zobel, B.J. and J.P. Buitjeenen, 1989. Wood Variation Its Causes and Control Springer-Verlag. New York.
39. Ek, M., G. Gellerstedt and G. Henriksson, eds., 2009. Wood Chemistry and Biotechnology (Vol. 1). Walter De Gruyter.
40. Niskanen, K.J., 1998. Paper physics (Book 16 of series on Papermaking Science and Technology). Fapet OY, Helsinki, Finland.
41. Paavilainen, L. and J. Pöyry Oy, 2000. Quality-competitiveness of Asian short-fibre raw materials in different paper grades. Paperijapuu, 82(3): 156-161.
42. Santos, A., O. Anjos, M.E. Amaral, N. Gil, H. Pereira and R. Simões, 2012. Influence on pulping yield and pulp properties of wood density of Acacia melanoxylon. Journal of Wood Science, 58(6): 479-486.
43. Wimmer, R., G.M. Downes, R. Evans, G. Rasmussen and J. French, 2002. Direct effects of wood characteristics on pulp and handsheet properties of Eucalyptus globulus. Holzforschung, 56(3): 244-252.
44. Oluwadare, A.O. and O.S. Ashimiyu, 2007. The relationship between fiber characteristics and pulp-sheet properties of Leucaena leucocephala (lam.) de wit. Middle-East Journal of Scientific Research, 2(2): 63-68.
45. Shimoyama, V.R. and M.S.S. Wiecheteck, 1993. Características da Madeira e da pasta termomecânica de Pinuspatula var. tecunumaniiparaprodução de papelimprensa. Serietécnica IPEF, 9(27): 63-80.
46. Emerhi E.A., 2012. Variations in anatomical properties of Rhizophoraracemosa (Leechm) and Rhizophoraharrisonii (G. Mey) in a Nigerian mangrove forest ecosystem. International Journal of Forest, Soil and Erosion, 2(2): 89-96.
47. Akpakpan, A.E., U.D. Akpabio and I.B. Obot, 2012. Evaluation of physicochemical properties and soda pulping of Nypafruticans frond and petiole. Elixir Appl. Chem, 45: 7664-7668.
48. Mercy, O.B., F.J. Adeola, O.A. Olajide, A. Babatunde and F.J. Sunday, 2017. Evaluation of fiber characteristics of Ricinodedronheudelotii (Baill, Pierre ExPax) for pulp and paper making. International Journal of Science and Technology, 6(1): 634-641.
49. Runkel, R.O., 1949. Uber die Herstellung von ZellstoffausHolz der Gattung Eucalyptus and Versuchemitzweiunterschiedlichen Eucalyptus arten. Das papier, 3: 476-490.
50. Malan, F.S. and G.F.R. Gerischer, 1987. Wood property differences in South African grown Eucalyptus grandis trees of different growth stress intensity. Holzforschung-International Journal of the Biology, Chemistry, Physics and Technology of Wood, 41(6): 331-335.
51. Varghese , M., Vishnu Kns, Bennetsr and S. Jagades, 1995. Genetic effect on wood and fibre traits of Eucalyptus Grandisprovenances, pp: 64-67 in Eucalypt Plantations: Improving Fibre Yield and Quality. CRCTHF–IUFRO Conference. 19-24 February 1995, Hobart.
52. Hudson, I., L. Wilson and Van K. Beveren, 1998. Vessel and fibre property variation in Eucalyptus globulus and Eucalyptus nitens: some preliminary results. IAWA Journal, 19(2): 111-130.
53. Yahya, R., J. Sugiyama, D. Silsia and J. Gril, 2010. Some anatomical features of an Acacia hybrid, A. mangium and A. auriculiformis grown in Indonesia with regard to pulp yield and paper strength. Journal of Tropical Forest Science, pp: 343-351.
54. Ohshima, J., S. Yokota, N. Yoshizawa and T. Ona, 2005. Examination of within-tree variations and the heights representing whole-tree values of derived wood properties for quasi-non-destructive breeding of Eucalyptus camaldulensis and Eucalyptus globulus as quality pulpwood. Journal of Wood Science, 51(2): 102-111.
55. Santos, A.J., H.Pereira and O. Anjos, 2018. Characterization and within-tree variation of wood anatomy of Acacia melanoxylon. Millenium-Journal of Education, Technologies and Health, 2(5): 13-19.
56. Ashori, A. and A. Nourbakhsh, 2009. Studies on Iranian cultivated paulownia– a potential source of fibrous raw material for paper industry. European Journal of Wood and Wood Products, 67(3): 323-327.
57. Alao, O., 2009. Fibre morphology and its extent in pulp and paper making.Unpublished S' Industrial Work Experience Scheme (SIWES) notebook FRIN, Ibadan, Nigeria.

58. Bektas, I., 1997. The physical and mechanical properties of Calabrian pine (*Pinus brutia* Ten.) and their variations according to regions. The Scientific Institute of Istanbul University, Istanbul, pp: 200-249.
59. Ona, T., T. Sonoda, K. Ito, M. Shibata, Y. Tamai, Y. Kojima, J. Ohshima, S. Yokota and N. Yoshizawa, 2001. Investigation of relationships between cell and pulp properties in Eucalyptus by examination of within-tree property variations. Wood Science and Technology, 35(3): 229-243.
60. Nisgoski, S., R. Trianoski, G.I.B. De Muniz, J.L.M. De Matos and F.R.R. Batista, 2011. Anatomia da Madeira de Toonaciliatacaracterísticas das fibrasparaprodução de papel. Floresta, 41(4).
61. Li, B., H. Li, Q. Zha, R. Bandekar, A. Alsaggaf and Y. Ni, 2011. Effects of wood quality and refining process on TMP pulp and paper quality. BioResources, 6(3): 3569-3584.
62. Dvorak, W.S., 2004. World view of Gmelina arborea: opportunities and challenges. New Forests, 28(2): 111-126.
63. Butterfield, B., 2006. The structure of wood: form and function. Primary Wood Processing, pp: 1-22.
64. Raymond, C.A., P. Banham and A.C. MacDonald, 1998. Within tree variation and genetic control of basic density, fibre length and coarseness in Eucalyptus regnans in Tasmania. Appita Journal, 41(4): 299-305.
65. Silva, J.C., N.M. Borralho, J.A. Araújo, R.E. Vaillancourt and B.M. Potts, 2009. Genetic parameters for growth, wood density and pulp yield in Eucalyptus globulus. Tree Genetics & Genomes, 5(2): 291-305.
66. Seca, A.M.L.D. and F.M.D.J. Domingues, 2006. Basic density and pulp yield relationship with some chemical parameters in eucalyptus trees. Pesquisa Agropecuária Brasileira, 41(12): 1687-1691.
67. Mokfienski, A., J.L. Colodette, J.L. Gomide and A.M.M.L. Carvalho, 2008. Relative importance of wood density and carbohydrate content on pulping yield and product quality. Ciência Florestal, 18(3): 401-413.
68. Miranda, I., M.H. Almeida and H. Pereira, 2001. Variation of fibre biometry in different provenances of *Eucalyptus globulus* Labill. Appita Journal, 54(3): 272-275.
69. Santos, A., M.E. Amaral, A. Vaz, O. Anjos and R. Simo˜es, 2008. Effect of Eucalyptus globulus wood density on papermaking potential. Tappi J., 7(5): 25-32.