ISSN: 2458-8989

Natural and Engineering Sciences

NESciences, 2025, 10 (1): 374-384 doi: 10.28978/nesciences.1651141

The Anatomical and Chemical Characteristics of Poloena Tomontosa Wood and the Extent of its Suitability in the Production of Pulp and Paper

Osamah Ibrahim Ahmed [1], Mohammed M. Ibrahim [2],
Iman Hussain Zainulabdeen [3], Rusul Muhammad Ahmed [4*]

[1] University of Kirkuk, Iraq. E-mail: osama_alzaidbagy@uokirkuk.edu.iq

[2] University of Kirkuk, Iraq. E-mail: albayatiiu@uokirkuk.edu.iq

[3] Northern Technical University, Iraq. E-mail: imanhuseyin@ntu.edu.iq

[4*] University of Kirkuk, Iraq. E-mail: rusulahmd0@gmail.com

Abstract

Paulowin tomentosa is one of the newly introduced species to Iraq. It is among the fastest growing species in the world and the production of wood material; to provide data on the anatomical and chemical characteristics of the wood and to determine its suitability for the manufacture of pulp and paper, several 7-year-old trees were selected from paulownia farms in the Erbil Governorate in northern Iraq. Some of the phenotypic, and anatomical characteristics of the fibres and estimated the proportions of the chemical components of the wood of the main stem and the lower branches and of the two types—sapwood and sapwood for them. The fibre length was 0.917mm, and the fibre diameter, lumen diameter and cell wall thickness were (27.31, 16.65, and 4.95) µm, respectively. Ratios of Runkel, slenderness and flexibility of the fibres were (0.613, 30.78, and 66.75%) respectively. There is a possibility of making paper with acceptable properties. The chemical analysis of wood was also discussed, the percentage of dissolved extracts in the mixture of ethanol-benzene and hot water were (5.7801, and 6.3408) % respectively, and the percentage of lignin, ash and holocellulose were (22.7240, 0.2505 and 64.9044) % respectively. These percentages give the possibility of producing good pulp, except that the percentage of extracts in it is high, which causes some problems in bleaching process. The study indicated the possibility of using branches wood in the manufacture of pulp and paper, also no noticeable differences appeared between the two types of sapwood and heartwood of the tree's stem and branches.

Keywords:

Paulowin tomentosa, anatomical and chemical properities, pulp and paper.

Article history:

Received: 19/11/2024, Revised: 20/01/2025, Accepted: 11/02/2025, Available online: 31/03/2025

**Corresponding Author: Rusul Muhammad Ahmed, E-mail: rusulahmd0@gmail.com*

Introduction

Wood is one of the most used materials by humans in pulp manufacturing (Manoj, 1996). In 2018, approximately 409 million cubic meters of paper and paper panels were produced according to the FAO for the year 202 (Jochem, et al. 2021), in the future (by 2050), the world's paper production is expected to rise to nearly (700 - 900) million tons, where the output of 1 ton of paper consumes approximately 2.5 tons of wood (Przybysz et al., 2018), In Europe, 85 million tons of paper were produced in 2022, of which 47.5 million tons were obtained from paper recycling, and 37.4 million tons were obtained from wood consumption and other fibre consumption sources, as 106.8 million tons of wood were consumed in operations (Mani et al., 2024). Manufacturing (CEPI, 2022). From 600 known species of trees in the world, there are less than 10 species used commercially in the paper industry, their cultivation and germination conditions may not be suitable in different regions of the world (Ates et al., 2008). Due to the limited wood resources that have been increasingly used not only for papermaking but also for the production of furniture, plywood and many other products, it is also necessary to consider other types of fibrous biomass for papermaking, one of the most attractive renewable fibre resources is the biomass of perennials and fast-growing plants (Przybysz et al., 2018). Mirski et al., (2017) point out that the main factor determining the high position in the European market is the continuous supply flow of raw materials in the wood panel industry, which faces a shortage of wood materials, which requires extensive research on fast-growing wood species and the technologies used (Inam et al., 2023). China is the second producer of paper in the world after the United States, and to develop the paper industry, 5.8 million hectares were allocated to establish plantations of fast-growing wood species (Barr et al., 2005).

Paulownia is one of the fastest-growing species in the world due to its rapid growth rate and the large amount of wood generated in a short period (Icka et al., 2016). Paulownia genus belongs to the paulowniaceae, there are at least eight species of Paulownia (P. tomentosa, P. kawakamii, P. coreana, P. australis, P. fortunei, P. elongata, P. catalpifolia and P. fargesii) (Lugli et al., 2023). Most of the mentioned species show rapid growth so that they can be harvested after 15 years of germination and can re-grown from stump (García et al., 2011). Koman et al., (2017) stated that under appropriate conditions, they can reach a stem diameter ranging between (30 - 40) cm, a stem height between (10 - 12) m, and a woody yield ranging between (0.2 - 0.6) m3 at the age of 10 years, under ideal cultivation conditions, its growth can be faster. Paulownia trees can be harvested within (6 - 7) years to obtain low-quality wood and within 15 years to obtain high-quality wood. The height of adult Paulownia ranges between (10 - 20) m and the rate reaches 3 m per year (in ideal conditions), which allows exploitation in short rotation periods (Barbu et al., 2022). Although it is one of the fastest growing trees in the world, its wood is one of the least dense, which for the Paulownia genus ranges from (250 - 300) kg/m3 (Koman 2023).

The properties of wood fibres and their chemical composition are important factors that determine their suitability as raw materials for the production of pulp and paper (Malešević et al., 2023). It depends on their anatomy and the method of separating the fibres (Hassan et al., 2023). Anatomy properties include: length, fiber diameter, fibre cavity width, thickness Fiber cell wall, Runkel ratio, elastic co-efficient and relative fibre length, chemically, the content of α-cellulose, cellulose, and lignin is mainly related to the behaviour of the pulp, extractives have a direct effect on the pulp yield, and high content reduces the pulp yield (Kiaei et al., 2014; Naddaf & Anbaran, 2016).

Paulownia was introduced to Iraq in the last decade, it was planted in the northern regions of Iraq (Lwako et al., 2013) and many farms were established to produce wood (Abdullah & Albarzinji, 2023). However, the available data on this species cultivated in Iraq are still few and did not address the technological characteristics, so this study was conducted to provide data on the anatomical and chemical characteristics of the wood of P. tomentosa trees and determine its suitability as a raw material for pulp and paper manufacture in Iraq.

Material & Methods

Study samples were prepared from P. tomentosa trees growing in one of the paulownia farms in Erbil Governorate/Northern Iraq. All tree's ages were 7 years, tree type was diagnosed based on its phenotypic characteristics according to (Tony et al., 2007; Mills- hicks, 2007), the trees were dropped and transferred to the Wood Technology Laboratory at the College of Agriculture/University of Kirkuk, where their phenotypic, anatomical and chemical characteristics were studied.

Anatomical characteristics: Samples were taken in the form of 5 cm thick discs at P.H.D. 1.33m of the main trunk of the selected trees and from the beginnings of the main branches (the first third of the lower branches). Observations of the phenotypic characteristics of the wood were taken from the cross-section of the wooden discs using a magnifying glass 10X. After removing the bark, samples were taken from the four sides of each disc including two locations (near the pith to represent the heartwood and near the outer cortex to represent the sapwood), they were divided into small pieces and the cells were separated according to the method used by (Al-Takay, et al. 2013; Ashori & Nourbakhsh, 2009), the separated cells were fixed on glass slides and the dimensions of the intact fibres were randomly taken using a microscope (fibre length, fibre diameter, fibre lumen diameter and fibre wall thickness), the Rankle ratio, Slendeness Ratio and Flexibility coefficient, were calculated from measured data for fibres.

Chemical characteristics: Wood samples were taken from the middle of the sapwood and the Heartwood (from all directions of the wood, stem and branches). The samples were ground and sieved into small particles that passed through a sieve of 40 mesh and settled on a size 60 mesh. The proportions of the chemical components were found based on the method used by (Almalah, 2011) including extracts dissolved in (Ethanol: Benzine mixture and hot water), lignin, holocellulose, and ash.

Results And Discussion

General Description of the Wood

The average diameter of the trees at d.b.h. 1.33m was 16 cm, with a range (of 15 - 17) cm, for the branches it reached 4.62cm. In cross-section, the stem wood of P. tomentosa trees showed a slight differentiation between sapwood and heartwood in terms of colour, the colour of the wood was light yellow, with the distinction of heartwood after drying to a white-pink colour. No distinct smell or taste of wood was observed. The growth rings were clear. Note the vessels with the naked eye, especially in early wood. The pores are spread in the form of annular bands within the annual growth rings (Figure 1a). The stem is straight and cylindrical, the formation of the branches appeared at a height of 2.25 m from ground level in the study samples. The bark is thin, light grey and smooth. It is slightly cracked in the mature specimens and its thickness in the studied trees reached 2.23 mm (Figure 1b, 1c). The tightness of the bark facilitates the removal of bark in the field and sawmills and peeling operations.

Paulownia wood is characterized by the presence of a cavity at the pith site, it varies with the height of the trunk and appears clearly in the branches as well (Figure 1d). It is a distinctive appearance characteristic of the wood of this species, but it negatively affects the sawing operations of wood panels. This result is consistent with what was mentioned by (Komán, 2023; Fos et al., 2023; Sánchez-Machado & Moya, 2021) about this tree species.

Figure 1. Cross-section of P. tomentosa at d.p.h. (a), stem with bark at d.p.h. (b), park in cross-section (c), a cavity at the pith site (d)

From observing the extension of the cavity at the marrow site, we notice that the cavity begins to narrow as the tree ages and gradually disappears (Figure 2).

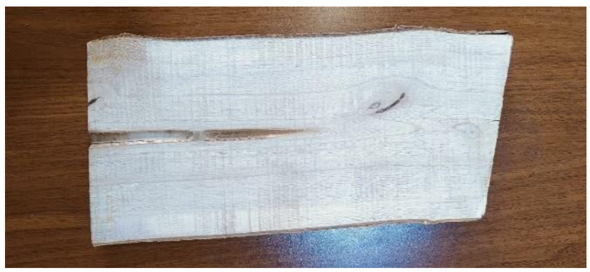

Figure 2. The direction of the cavity in a radial section of wood

Anatomical Characteristics of Wood

The anatomy of wood is related to the arrangement of the cellular structure and has a major impact on its final use (Riki et al., 2019). When studying the chemically separated cells, Figure (3) shows the presence of fibres, vessels, parenchyma cells, and ray cells in the wood of paulownia trees, this agrees with what was mentioned by (Ashori & Nourbakhsh, 2009; Ates et al., 2009).

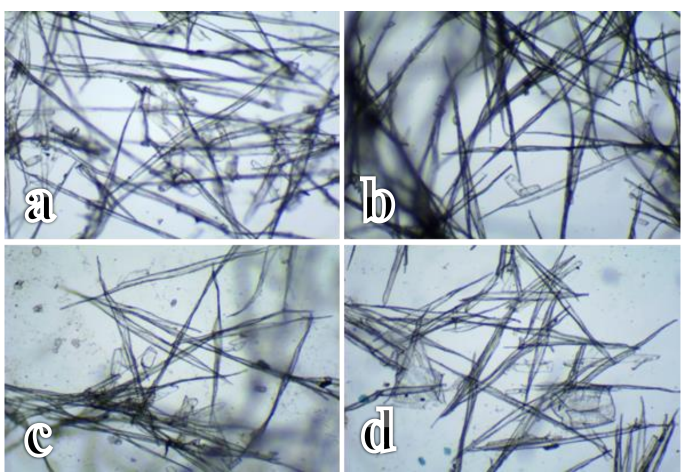

Figure 3. Wood cells of P. tomentosa at: stem sapwood (a), Branch sapwood (b), Stem heartwood (c), Branch heartwood (d)

Because fibres are the basic component material in the paper industry and on which the properties of paper depend (Kiaei, 2013), the dimensions of the fibres and the values of some of the anatomical characteristics related to them and affecting the paper industry have been listed as in (Table 1).

Fibre Length: Fiber length is associated with the number of bonding sites available on individual fibres to form a tangled network of fibres. It is measured from one end to the other. It is preferable to use long fibres in paper making, longer fibres give a more open and less uniform sheet structure, fibre length affects the tearing strength of paper and the folding endurance capacity of paper mainly depends on fibre length (Kiaei, et al. 2014) and (Riki, et al. 2021). The average fibre length of Paulownia tree wood was 0.917 mm. It was found that the average length of fibres for the sapwood of the main stem was 1.033 mm and the Heartwood was 0.857 mm. As for the wood of the branches, it reached (0.968 and 0.810) mm, respectively, for both types.

Fibre diameter: It controls the flexibility of the fibres, as an increase in the diameter of the fibres reduces the attachment points, which constitutes a weak point in the paper and fails under any lightweight (Al-take, et al. 2013), and is an influential factor in finding the Slenderness Ratio and Flexibility coefficient. The average fibre diameter of the wood of Paulownia trees in this study was 27.31 µm, while the diameter recorded was 34.3 µm for the sapwood and 28.7 µm for the heartwood. As for the branch wood, the readings for the sapwood and the Heartwood were (30.0, and 26.2) µm, respectively.

Table 1. Anatomical characteristics of P. tomentosa (Fiber Dimensions)

Characters	**Stem**		**Branch**		**Average**
	Sapwood	**Heartwood**	**Sapwood**	**Heartwood**	
Fibre Length (L) (mm)	1.033	0.857	0.968	0.810	0.917
Fiber Diameter (d)(µm)	34.3	28.7	30.0	26.2	27.31
Fiber Lumen Diameter (l) (µm)	23.2	18.5	20.9	17.1	16.65
Fiber Wall Thickness (w) (µm)	5.59	5.11	4.55	4.55	4.95
Runkel Ratio 2 w / l	0.481	0.552	0.435	0.532	0.613
Slenderness Ratio L / d	30.11	29.86	32.26	30.91	30.78
Flexibility coefficient (%) l / d*100	67.63	64.45	69.66	65.26	66.75

Lumen diameter: It indicates the diameter of the internal space of the fibres and directly affects the process of beating, increasing this value improves the quality of the dough (Al-take, et al. 2013), and it also helps in increasing the penetration of fluids into the empty spaces (Riki, et al. 2021). The average Lumen diameter of the wood of paulownia trees was 16.65 µm. The sapwood and heartwood recorded cavity diameters of (23.2, and 18.5) µm, respectively, while the wood of the branches recorded Lumen diameters of (20.9, and 17.1) µm, respectively.

Fiber Wall Thickness: Research shows that thin-walled fibres are very important in the manufacture of many types of paper. Thick-walled fibres negatively affect the bursting strength, tensile strength, and endurance of the paper (Ashori and Nourbakhsh, 2009). The stiffness of the fibres is related to their thick walls, which make them resist collapse and remain in their cylindrical shape, which provides less opportunity for the fibres to bond with each other, so the resulting paper is thick. It lacks transparency and dimensional stability, and it negatively affects the bursting and tensile strength and the folding ability of the paper (Nasir, 2008). The results of this study showed that the average wall thickness of paulownia wood reached 4.95 µm, while the thickness of the fibre wall in the sapwood, the core wood of the stem, the sapwood, and the heartwood of the branches reached (5.95, 5.11, 4.55, 4.55) µm, respectively.

Runkel ratio: One of the important measurements to find any suitable raw material for the manufacture of pulp and paper. In general, fibres with a high Runkel ratio are stiffer and less flexible and form larger paper with a smaller bonding area than fibres with a low Runkel ratio. Having a Runkel ratio of less than 1 would be suitable for papermaking because it collapses (becomes ribbon-like) and provides a large surface area for bonding (Ashori and Nourbakhsh, 2009). The results of the study showed that the Rankel ratio for fibres was low, as it reached an average of 0.613, and the Rankel ratio for each of the spring and core stem wood fibres and the spring and core branch wood reached (0.481, 0.552, 0.435, 0.532), respectively.

Slenderness Ratio: This is also called sintering strength; it is inversely proportional to the fibre diameter. In general, if the slenderness ratio of a fibre is less than 70, it will be not valuable for producing high-quality papers. A low slenderness ratio means low rupture resistance, which is partly because short and thick fibres do not produce good surface contact and fibre-to-fibre bonding (Riki, et al. 2021). Ates, et al. (2008) stated that some researchers have a different opinion because the strength properties depend not only on the sintering parameter alone but also on the thickness of the cell wall. Note that the average sintering coefficient for the wood of paulownia trees in this study reached 30.78, as the coefficient values were calculated for the stem sapwood, stem heartwood branches sapwood and heartwood (30.11, 29.86, 32.26, 30.91), respectively. This percentage is considered approximately acceptable, as indicated by (Lukmandaru, et al. 2024) to a slenderness ratio of more than 33 to produce paper with acceptable properties.

Flexibility coefficient: It is one of the important factors that determine the suitability of pulp for paper making. It is the key to developing burst and tensile strength as well as developing paper properties that affect printing. A high value of this ratio provides better-shaped and well-bonded paper. The fibers have relatively good length to diameter resulting in good elasticity for fiber binding during paper making. On the other hand, paper strength properties such as tensile strength, bursting strength and folding endurance are mainly affected by the way individual fibres are bonded together in paper sheets. The results showed a modulus of elasticity of 66.75 % for wood in general, where the sapwood and heartwood of the stem and the sapwood and heartwood of the branches recorded (67.63, 64.45, 69.66, 65.26) %, respectively. As is known, fibres with an elasticity ratio greater than 75 % are highly elastic fibres, (50-75) % are elastic fibres, (30-50) % are stiff fibres, and less than 30 % are known as very stiff fibres (Birinci, et al. 2017). According to this definition, it can be said that Paulownia wood generally has very elastic fibres.

Chemical Characteristics of Wood

The chemical composition of biomass and its fractionation technology can play a major role in predicting the viability of bioproducts. A large portion of the world's forest reserves are used to convert cellulosic pulp for use in the manufacture of paper and other products. Therefore, when choosing the starting material for preparing cellulosic pulp, the amount of pulp produced is an important factor in this industry and is usually associated with the content of lignin and polysaccharides (Ashori and Nourbakhsh, 2009) (Muhamadi, et al. 2013). Lignin is an unwanted polymer, and its removal during the wood digestion process requires large amounts of energy and chemicals. The extracts cause many problems in the cellulosic pulp preparation and paper-making steps and can hurt the digestion and bleaching processes (Kiaei, et al. 2014).

The results of the chemical analysis of the main compounds and extracts, in addition to the ash content of the wood of Paulownia Sentosa trees, along with their percentages in the stem, branches, sapwood and heartwood of both, are listed in (Table 2).

Table 2. Chemical characteristics of P. tomentosa (Fiber Dimensions).

Characters (%)	Stem		Branch		Average
	sapwood	Heartwood	sapwood	Heartwood	
Extraction in Ethanol-Benzin 1: 1	5.8775	6.3359	5.0121	5.8950	5.7801
Extraction in Hot Water	6.5835	7.5468	5.5690	5.6642	6.3408
Lignin	22.3590	24.0087	21.5423	22.9861	22.7240
Ash	0.2500	0.3100	0.2100	0.2321	0.2505
Holo cellulose	64.9300	61.7986	67.6666	65.2226	64.9044

Extracts: The average percentage of extracts reached 12.1209 % of the total dry weight of Paulownia wood, where the solutes in the mixture of ethanol-gasoline were estimated at 5.7801 % and hot water at 6.3408 %. The tree trunk contained slightly higher percentages of wood from the branches, with a noticeable increase in the percentages of extracts in the heartwood. It has a comparison with sapwood, as the percentage of extracts dissolved in ethanol: benzene mixture, and then hot water for sapwood reached (6.3359, 7.5468) % respectively, and for sapwood (5.8775, 6.5835) % respectively. As for the wood of branches, no clear differences appeared in terms of the content of extracts dissolved in the mixture of ethanol, benzene and hot water, and the content of sapwood and hardwood extracts. The percentages of extracts dissolved in the mixture of ethanol: benzene and then hot water for the sapwood and hardwood reached (5.0121, 5.5696, 5.8950 and 5.6642) % respectively (Figure 3).

The percentages of total extracts are relatively large compared to the general rate of wood content, which is usually less than 10 % of the dry weight of the wood (Riki, et al. 2021; Lehr et al., 2021) mentioned several methods used to address this problem, including removing bark and knots and wetting the logs in Collecting yards as well as biological treatment before the logs enter the digester.

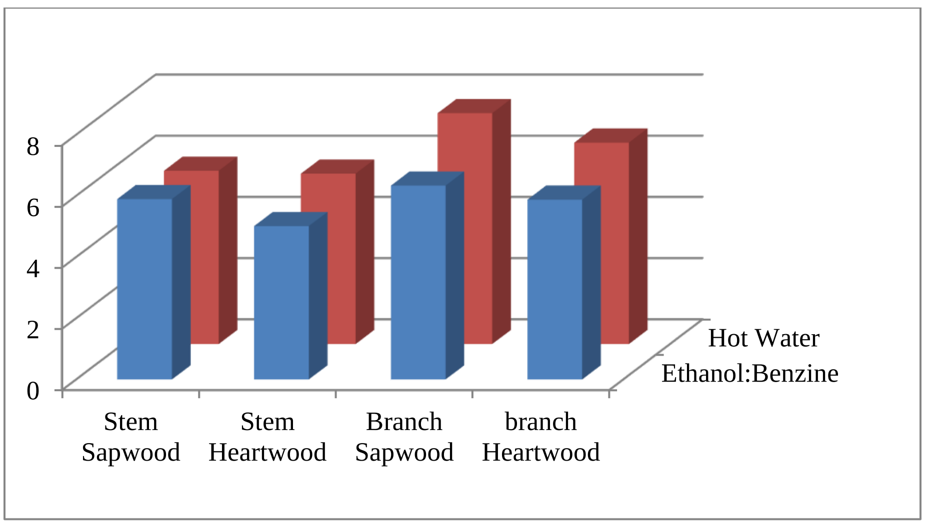

Figure 3. Percentages of extractions for each of the solutes in the mixture of ethanol - benzine and hot water %.

Lignin: The average content of lignin in the wood of paulownia trees was 22.7240% relative to dry weight. The results of its content relative to the sapwood and then to the core of the stem wood and branch wood were as follows (22.3590, 24.0087, 21.5423, 22.9861) % respectively. We notice that the stem wood contains Slightly higher percentages in the heartwood compared to the sapwood and for the two types of wood in the stem and branches, with an increase in the percentage approximately in the stem. The reason may be due to the age difference between the heartwood and the sapwood, where the concentrations of lignin and then the extracts increase with the progression of time, noting that the recorded percentage falls within the specified range for wood. Broad-leaved trees, which usually ranges between (18 - 25) % (Riki, et al. 2019).

Holocellulose: The average percentage of holocellulose (cellulose with hemicellulose) in the wood of Paulownia trees was 64.9044%, and its percentage varied between the wood of the stem and the wood of the branches, where the wood of the branches was superior in its hemicellulose content. The percentage of core wood of the stem reached 61.7986% a lower percentage than the percentage of sapwood of the stem, 64.9300%, while there did not appear Noticeable differences between the two types of branch wood (sapwood and sapwood) which amounted to (67.6666, 65.2226) %. The high hemicellulose content indicates good production of cellulose pulp, and the percentage of α-cellulose is considered acceptable for producing paper pulp when it exceeds 40% (Lukmandaru, et al. 2024; Kiaei, et al. 2014).

Ash: The estimated percentage of ash for paulownia wood is approximately low, as it was estimated at 0.2505 % as the average for wood of this type. The wood of the branches contained a lower percentage of ash and the percentage of ash for the sapwood of the stem was estimated at 0.25 % and for the heartwood was 0.31%.

Conclusions

- Fiber dimensional data for paulownia tree wood is suitable for making cellulosic pulp. The Runkel ratio is less than 1, reaching an average of 0.613. The sintering coefficient for paulownia wood in this study reached 30.78. This ratio is considered almost acceptable, as paper with acceptable properties can be produced and its quality can be improved. Paper is mixed with other types to produce high-quality papers, based on the value of the flexibility of the fibers, paulownia wood is a very flexible fibre.

- The proportions of chemical components indicate a good content of polysaccharides, which is considered economically acceptable for the production of cellulosic paste. The low content of lignin is a good factor in reducing the costs of removing them during wood digestion, but the proportions of the total extracts are relatively large compared to the general average content of wood which is Usually less than 10% of the dry weight of the wood, which requires treatment before bleaching operations for the cellulosic pulp.

- This study was conducted on 7-year-old trees. It is possible to extend the life of the cutting, as studies indicate that extending the life of the cutting cycle will improve the technological properties of the trees.

- It is possible to benefit from the wood of the branches in the paper industry because its data is close to the data of the main stem and falls within the limits for the use of raw materials in the paper industry.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

References

Abdullah, A. F., & Albarznjii, I. M. (2023). Magnetic Water Effects on Growth and Some Physiological Characteristics of Paulownia Tomentosa Thunb Under Cadmium Stress Conditions. *Science Journal of University of Zakho*, *11*(3), 440-446.

Almalah, A. R. (2011). Effect of Compression Wood on Some Chemical Properties of Pinus brutia Ten. Leaning Trees. *Mesopotamia Journal of Agriculture*, *39*(3), 135.

Al-Takay, T. K., Kasir, W. A., & Al-Daody, A. C. (2013). Fibers Dimensions and its Variation for Two Different Ages of Melia azedarach L. TREES GROWN IN MOSUL. *Mesopotamia Journal of Agriculture*, *41*(2), 181-0.

Ashori, Alireza and Amir Nourbakhsh (2009). Studies on Iranian cultivated paulownia – a potential source of fibrous raw material for paper industry. Eur. J. Wood Prod. (2009) 67: 323–327.

Ates, S., Ni, Y., Akgul, M., & Tozluoglu, A. (2008). Characterization and evaluation of Paulownia elongota as a raw material for paper production. *African journal of biotechnology*, *7*(22).

Barbu, M. C., Buresova, K., Tudor, E. M., & Petutschnigg, A. (2022). Physical and mechanical properties of Paulownia tomentosa x elongata sawn wood from Spanish, Bulgarian and Serbian plantations. *Forests*, *13*(10), 1543.

Barr, C., Dermawan, A., & He, D. (2005). China's development of a plantation-based wood pulp industry. A Summary of government policies and financial incentives, with a focus on South China. *Policy and Market Brief Policy*, *3*.

Birinci, E., Kaymakci, A., Kesik, H. A. C. İ., & Bektas, I. (2017). Some Mmorphological properties of Paulownia (Paulownia elongate SY Hu) wood. In *International Conference ICWSE* (pp. 105-109).

Cepi (2022). KEY STATISTICS 2022 European pulp & paper industry. Confederation of European Paper Industries. https://www.cepi.org/wp-content/uploads/2023/07/2022-Key-Statistics-FINAL.pdf.

Fos, M., Oliver-Villanueva, J. V., & Vazquez, M. (2023). Radial variation in anatomical wood characteristics and physical properties of Paulownia elongata x Paulownia fortunei hybrid Cotevisa 2 from fast-growing plantations. *European Journal of Wood and Wood Products*, *81*(4), 819-831.https://doi.org/10.1007/s00107-023-01941-8.

García, J. C., Zamudio, M. A., Pérez, A., Feria, M. J., Gomide, J. L., Colodette, J. L., & López, F. (2011). Soda-AQ pulping of Paulownia wood after hydrolysis treatment. *BioResources*, *6*(2), 971-986.

Hassan, S. G., Alshwani, S., & Al-Dawoodi, A. (2023) Design and Investigation of Modal Excitation in Tapered Optical Fiber for a Mode Division Multiplexed Transmission System. https://doi.org/10.58346/JOWUA. 2023.I4.001

Icka, P., Damo, R., & Icka, E. (2016). Paulownia tomentosa, a fast-growing timber. *Ann. Valahia Univ. Targoviste Agric*, *10*, 14-19. https://doi.org/10.1515/agr-2016-0003

Inam, U., Ali, Q. M., Ahmed, Q., & Bat, L. (2023). Morphological Description of Megalopal Stages of Three Portunid Species (Decapoda, 2 Brachyura, Portunidae) from Indus Deltaic Area (northern-Arabian Sea). *Natural and Engineering Sciences*, *8*(1), 46-60. http://doi.org/10.28978/nesciences.1281619

Jochem, D., Bösch, M., Weimar, H., & Dieter, M. (2021). National wood fiber balances for the pulp and paper sector: An approach to supplement international forest products statistics. *Forest Policy and Economics*, *131*, 102540. https://doi.org/10.1016/j.forpol.2021.102540

Kiaei, M. A. J. I. D. (2013). Technological properties of Iranian cultivated paulownia wood (Paulownia fortunei). *Cellulose Chemistry and Technology*, *47*(9-10), 735-743.

Kiaei, M., Tajik, M., & Vaysi, R. (2014). Chemical and biometrical properties of plum wood and its application in pulp and paper production. *Maderas. Ciencia y tecnología*, *16*(3), 313-322.

Komán, S. (2023). Quality characteristics of the selected variant of Paulownia tomentosa (Robust4) wood cultivated in Hungary. *Maderas. Ciencia y tecnología*, *25*.

Koman, S., Feher, S., & Vityi, A. (2017). Physical and mechanical properties of Paulownia tomentosa wood planted in Hungaria. *Wood Res*, *62*(2), 335-340.

Lehr, M., Miltner, M., & Friedl, A. (2021). Removal of wood extractives as pulp (pre-) treatment: A technological review. *SN Applied Sciences*, *3*, 1-22. https://doi.org/10.1007/s42452-021-04873-1.

Lugli, L., Mezzalira, G., Lambardi, M., Zhang, H., & La Porta, N. (2023). Paulownia spp.: A Bibliometric Trend Analysis of a Global Multi-Use Tree. *Horticulturae*, *9*(12), 1352. https://doi.org/10.3390/horticulturae 9121352.

Lukmandaru, G., Pujasmara, R., & Dewi, E. S. G. (2024). Characterization of Asoka (Saraca Indica L.) branch wood for pulp and paper manufacturing. *Forest Res Eng Int J*, *6*(1), 38-44.

Lwako, M. K. O., Byaruhanga, J. K., & Baptist, K. J. (2013). A review on pulp manufacture from non-wood plant materials.

Malešević, Z., Govedarica-Lučić, A., Bošković, I., Petković, M., Đukić, D., & Đurović, V. (2023). Influence of different nutrient sources and genotypes on the chemical quality and yield of lettuce. https://doi.org/10.59456/afts.2023.1529.049M

Mani, S., Kasi, A., Nagamalai, T., Subramani, V. A., Natarajan, A., Seikh, A. H., ... & Ramachandran, S. K. (2024). Enhancement of piezoelectric responses of electrospun PVDF nanofibers through mechanical stretching and annealing process. *Materials Science and Engineering: B*, *307*, 117538.

Manoj, D. (1996). Paper and Pulp Industry in India: Raw Material Problems and Unutilized Global Potential. *IPPTA*, *8*, 57-64.

Mills-hicks, James (2007). Gardeninig Encyclopedia (Botanic Pocket). ISBN-13: 978-3833129391. H F Ullmann (January 1, 2007)

Mirski, R., Boruszewski, P., Trociński, A., & Dziurka, D. (2017). The possibility to use long fibres from fast growing hemp (Cannabis sativa L.) for the production of boards for the building and furniture industry. *BioResources*, *12*(2), 3521-3529.

Naddaf, M., & Anbaran, A. M. (2016). Gain Flattening Improvements with Two Cascade Erbium Doped Fiber Amplifier in WDM Systems. *International Academic Journal of Science and Engineering*, 3(1), 143–149.

Nasir, G. M. (2008). Fiber morphology in relation to suitability for pulp and paper. Forest Products Research, Pakistan Forest Institute, Peshawar.

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

Riki, J. T. B., Sotannde, O. A., & Oluwadare, A. O. (2019). Anatomical and chemical properties of wood and their practical implications in pulp and paper production: a review. *Journal of Research in forestry, wildlife and environment*, *11*(3), 358-368.

Russell, T., Cutler, C., & Walters, M. (2006). *Trees of the World: An Illustrated Encyclopedia and Identifier*. Hermes House.

Sánchez-Machado, J. D., & Moya, R. O. G. E. R. (2021). Characterization of paulownia tomentosa steud trees grown in a 5-year-old plantation in costa rica. *Cellul. Chem. Technol*, *55*, 743-753.