Research Article

Revolution of Timber Based Industry's Landscape Through Paulownia Plantations

Muhammad Bilal Zia[1]*, Ashar Farooq[1], Hammad Ud Din[1], Barkat Ullah Khan[1] and Samee Ud Din[2]

[1]Pakistan Forest Institute, Peshawar-25130, Khyber Pakhtunkhwa, Pakistan; [2]Department of Soil and Environmental Sciences, University of Agriculture, Peshawar, Khyber Pakhtunkhwa, Pakistan.

Abstract | Paulownia is amongst the fastest growing trees in the world having a wide range of distribution. It has gained greater attention as a bioenergy crop in agro-forestry systems for its application as industrial raw material and a promising afforestation agent for phytoremediation of heavy metal-polluted soils. Pakistan Forest Institute, Peshawar introduced Paulownia species in 1989 and six species were evaluated in multi-location trials. The studies for optimal planting stock and propagation methods for Paulownia indicated that the root stumps grew substantially taller, having straight stems and symmetrical crowns. Highest survival was observed for *Paulownia fortunei, Paulownia tomentosa* and *Paulownia elongata. Paulownia fortunei* and *Populus deltoides*; both had comparable growth in diameter and physico-mechanical properties. Apart from its utilization in wood works, its scope is also emerging in pulp and paper industry. Uses of Paulownia standing in field or its products either timber or non-timber based, has grown interest for its expansion to develop advanced processes for its utilization.

Received | September 17, 2022; **Accepted** | November 19, 2022; **Published** | December 26, 2022
***Correspondence** | Muhammad Bilal Zia, Forest Geneticist, Pakistan Forest Institute, Peshawar-25130, Khyber Pakhtunkhwa, Pakistan; **Email:** bilalziaswl@gmail.com
Citation | Zia, M.B., Farooq, A., Din, H.U., Khan, B.U. and Din, S.U., 2022. Revolution of timber based industry's landscape through paulownia plantations. *Pakistan Journal of Forestry,* 72(2): 76-83.
DOI | https://dx.doi.org/10.17582/journal.PJF/2022/72.2.76.83
Keywords | Paulownia, Propagation, Physico-mechanical properties, Furniture and fixtures, Pulp and paper products, Drawback

Introduction

Paulownia is one of the world's rapidly growing trees, capable of reaching seven feet tall each year. Paulownia species are planted as aesthetic and commercial trees to produce light, robust wood that can be utilized for a variety of purposes. These species are endemic to China mainly and spread to Korea and Japan up to 2400 m elevations and can tolerate a wide range of temperature and humidity. Its introduction has expanded to Spain, Italy, Austria, Turkey, India, the United States, Canada, Brazil (Lucas *et al.*, 2011), and Pakistan (Haq and Khan, 2005). The majority of paulownia species grow incredibly rapidly and may be cut for valuable timber in 15 years. Low-quality lumber can be easily made from 6-7 year old trees (Akyildiz and Kol, 2010). Paulownia wood is light and flexible, but does not crack or deform easily and is known for its physical strength, texture (light to medium clay-sandy), grain, and color (Meng *et al.*, 2014).

Paulownia has been utilized for millennia for a variety of items due to its insulating and sound-absorbing characteristics, as well as its lightness and resistance. Its wood is classified as aluminum among wood species because of its stability in comparison to its low weight. Forest plantations of alien tree species contribute significantly to the economy by providing a variety of products and ecosystem services (Brundu and Richardson, 2016). Numerous research studies have contributed to updating and synthesizing knowledge about this tree, including species distribution, availability, features, and key chemical components (Alzagameem *et al.*, 2019; Cheng *et al.*, 2019). Paulownia has received increased attention for its use as an industrial raw material and as a bioenergy crop with good adaptability to poor soils and no or little competition with agriculture crops (Jimenez *et al.*, 2005) thus preferred in agro-forestry systems (Zia and Laeeq, 2012). Additionally, some Paulownia lines may be a suitable afforestation agent for phytoremediation of heavy metal polluted soils due to their propensity to absorb Cu, Zn, Ca, K and Cd (Tzvetkova *et al.*, 2015). Paulownia species are a rich source of biologically active secondary metabolites such as benzoic acids, flavonoids, phenylpropanoid glycosides, lignans, quinones, and triterpenes, according to phytochemical examination (Xing *et al.*, 2013; Moon *et al.*, 2014; Gao *et al.*, 2015; He *et al.*, 2016).

Because of the rising scarcity of wood raw resources, the rapidly increasing demand for paper, cardboard, and other pulp-related products in recent decades has generated a real challenge. Paper's role in the digital age remains vital, with this ubiquitous substance still used daily for a variety of reasons all around the world. Every year, the world generates 300 million tonnes of paper, and the paper industry will account for the largest increase in wood use by 2060 (Snow, 2015). In fact, global paper and cardboard manufacturing exceeds 400 million metric tonnes each year. The most common form of paper is packaging paper and board, which has grown in popularity in recent years as a result of the online shopping boom (Figure 1). The global pulp and paper market worth was 351.53 billion dollars in 2021 which is expected to increase at a compound annual growth rate (CAGR) of 0.72 percent from 2022 to 2029, reaching a value of more than $373 billion, with China being the world's largest manufacturer of paper and cardboard. To meet the demands of the local pulp and paper industry 15% of agricultural-based raw materials used are bagasse, rice straw, and cotton linter. The chemical process is the most appropriate for producing pulp from these raw materials and 96% of all pulp produced in Pakistan in 2019 was produced using the Neutral Sulphite Semi-Chemical (NSSC) process. Pakistan's paper industry is made up of approximately 57 pulp and paper mills with a combined installed capacity of 1,050,499 metric tonnes per annum (Pakistan Bureau of Statistics, 2019) and manufactures a wide range of goods based on their contribution to overall paper manufacturing.

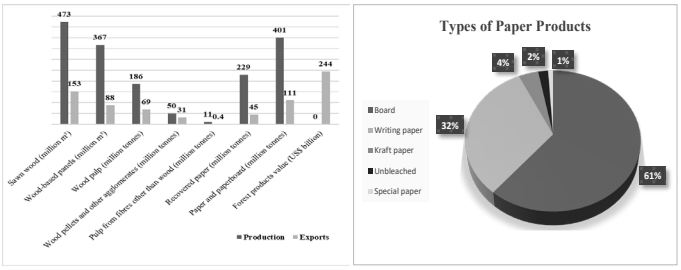

Figure 1: *Comparison between production and export, 2020 (FAOSTAT-Forestry database) and types of paper products.*

To meet the demands of pulp and paper industry using sources other than traditional material could be one approach. Perennial and deciduous plants, as well as agricultural waste, are examples of alternate raw materials. In this context, the potential of Paulownia, as a raw material for generating cellulose paper pulp was evaluated in order to reduce wood consumption and pulp and paper imports in the European Union. When this crop is developed, wood can be a final product. Branches are byproducts of periodic pruning are source for pulp and paper production which also promote biomass development (Swiechowski *et al.*, 2019). Paulownia wood can be used alone or in combination with other particles to improve the strength properties of single-layer particleboards and served as the core layer material in block boards, conferring lightness and homogeneity (Nelis *et al.*, 2018) with enhanced bending strength, decreased swelling, and reduced water absorption (Nelis and Mai, 2019). The purpose of this review article is to illustrate the extent of properties in order to maximize the value addition of rapidly developing tree i.e. Paulownia.

Materials and Methods

The project Paulownia Research in Pakistan was

initiated in 1989 with the assistance of International Developmental Research Centre of Canada at Pakistan Forest Institute, Peshawar. This project aimed at introducing paulownia species in Pakistan from the People's Republic of China. Six (06) Paulownia species i.e. *Paulownia elongata*, *Paulownia tomentosa*, *Paulownia fargesii*, *Paulownia fortunei*, *Paulownia catalpifolia* and *Paulownia australis* were trialed at different locations i.e. Peshawar (34° 1' 33.3012" N and 71° 33' 36.4860" E), Changa Manga (31° 5' 18.6576" N and 73° 57' 52.3116" E), Shinkiari (34° 28' 17.0364" N, 73° 16' 13.2924" E), Dhodial (34° 25' 59.99" N 73° 15' 60.00" E), Baffa (34° 26' 24.00"N, 73° 13' 15.00"E) and Mirpur (33° 8' 54.762"N, 73° 43' 57.5544"E) using Randomized Complete Block Design in 4 replications with standard spacing i.e. 3m x 3m to find the best planting stock and propagation means and also to perform comparable studies for growth and survival behavior among these Paulownia species. Irrigation measures were adopted as per the need for experiments conducted in irrigated areas. To study the timber quality for its utilization in furniture as well as pulp and paper industries, comparison studies of *paulownia fortunei* with *Populus deltoides, Eucalyptus camaldulensis, Broussonetia papyrifera* for various physico-mechanical properties and effect of density variation for preparation of particle board were conducted in the wood anatomy and technology labs of Forest Products Research Division at Pakistan Forest Institute, Peshawar. Paulownia pulping conditions and their evaluations using Kraft, soda and NSSC were also measured.

Results and Discussion

Paulownia adaptability trials in Pakistan

All the species of genus paulownia reflected different behavior for survival and growth. Species like *Paulownia fortunei* (61%), *Paulownia tomentosa* (69%) and *Paulownia elongate* (71%) showed highest survival percentage in the field nursery. Similarly, in container nursery, a maximum survival percentage of 61.5 was observed for *Paulownia kawakamii* followed by 48.2% survival for *Paulownia australis*. High survival percentage in Paulownia seedlings is crucial as it directly impacts the plantation's overall productivity and profitability. It ensures a robust and sustainable supply of Paulownia wood, which is prized for its rapid growth and versatile industrial applications, thereby enhancing the economic and environmental benefits of the plantation. Another study indicated that *Paulownia fortunei* (8.7 cm) and *Populus deltoides*; clone AY-48 (5.8 cm) both had comparable average growth in diameter. The growth in diameter of Paulownia trees is crucial for maximizing their commercial value. A wider diameter not only yields larger volumes of timber but also enhances the quality of wood, making it highly desirable for various industrial applications such as furniture production and construction.

Similarly, the best planting stock and propagation means of Paulownia through root cuttings, root stumps and entire plant were evaluated. Planting material i.e. root stumps unveiled high survival percentage for *P. tomentosa* and *P. fortunei* with an average of 99% followed by entire plant with 97% average survival percentage. Similarly, paulownia roots stumps and entire plants were mutually non-significant in diameter growth. However, root stumps attained significantly better height than the entire plant and root cuttings which ranged from 8.0 to 9.5 cm with an average value of 8.7 cm. Furthermore, the entire plant produced crooked stems and deformed crowns, whereas, plants raised from stumps developed straight stems with symmetrical crowns. Maximum percentage of 100 straight stems were recorded for root stumps in *P. elongata* and 97% for both *P. tomentosa* and *P. fortunei*. These results suggested that Paulownia stumps could be preferably used for the establishment of field plantations. The growth of straight stems with a symmetrical crown in Paulownia trees is vital for ensuring high-quality timber production. Straight stems yield long, defect-free logs, making them ideal for various industrial applications such as furniture, construction, and woodworking. This uniform growth pattern enhances the economic viability and overall value of Paulownia plantations.

Utilization in furniture and fixtures

Species trials in Pakistan at various localities revealed that plantations of *Paulownia fortunei* and *Paulownia elongata* could be successfully raised in Khyber Pakhtunkhwa and Punjab under irrigated conditions and may be used to extend the base of raw material for plywood and low-density chipboard industries. *Paulownia fortunei* has reddish-brown wood is comparatively soft and is not generally attacked by insects. It is used for making delicate furniture, cabinets etc, and is also used for items such as boxes, floats and general woodwork. While on the other hand, *Populus deltoids* wood is brittle, giving little value to lumber

Table 1: *Physico-mechanical properties of the Paulownia fortunei in comparison with fast growing tree species.*

S. No.	Property	Paulownia fortunei	Populus deltoides	Eucalyptus camaldulensis	Broussonetia papyrifera
1	Density (Kg/m^3)	391	480	705	515
2	Modulus of rupture (Kg/cm^2)	623	818	1009	673
3	Modulus of elasticity (Kg/cm^2)	49178	87267	77788	53034
4	Maximum crushing strength parallel to grain (Kg/cm^2)	282	385	397	436
5	Tensile strength perpendicular to grain (Kg/cm^2)	23	23	33	39
6	Impact bending strength (m-Kg)	1.40	3.06	2.50	3
7	Cleavage (Kg/cm)	17	23	32	32
8	Hardness (Kg) Side	205	314	599	632
	End	333	336	688	686

Table 2: *Effect of density variation on physico-mechanical properties of particle board.*

Properties	Board density Kg/m^3			Standard requirements
	400	425	450	
Modulus of rupture (Kg/cm^2)	105	141	177	97
Modulus of elasticity (Kg/cm^2)	18550	22776	25032	17240
Nail with drawl resistance (Kg)	25	29	34	-
Face screw with drawl resistance (Kg)	86	104	115	79.5
Linear expansion (%)	0.29	0.27	0.27	0.30

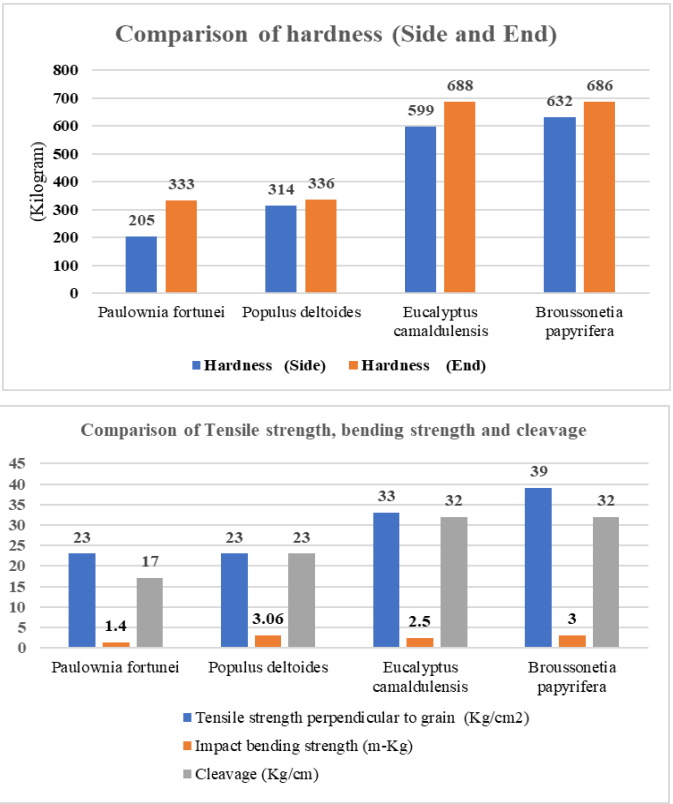

Figure 2: *Comparison studies for wood hardiness, tensile and bending strength and cleavage.*

and intolerant to shade and is relatively short lived. Similarly, *Eucalyptus camaldulensis* is controversial because of its adverse effects on the ecology and crop growth. *Broussonetia papyrifera* is a highly invasive species and upsets the natural ecosystem and is the main cause of pollen allergy in human beings.

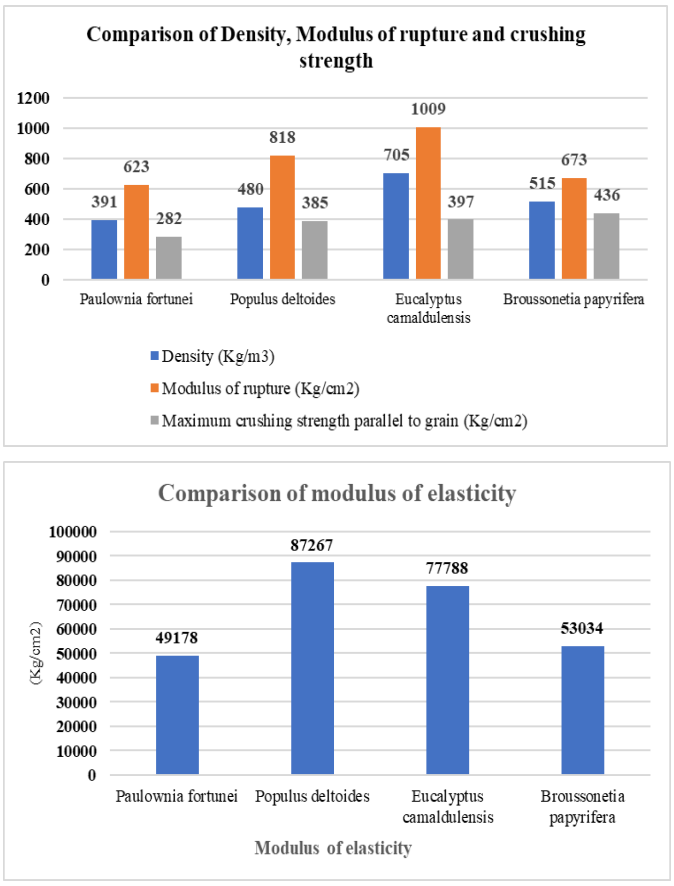

Figure 3: *Comparison of density, modulus of rupture and crushing strength and modulus of elasticity.*

Paulownia wood is considered as light wood with acceptable physico-mechanical properties (Table 1). It stands at-par for the most of physic -mechanical properties with Populus deltoides and determines scope of its utilization . Co-efficient of shrinkage is very small and hardness is low, hardly subject to split or crack and easily worked (Figures 2 and 3).

The results (Table 2) indicate that low density boards of acceptable properties as outlined in US commercial standard (CS-236-66) can be made from Paulownia. Increasing the density of board, improves the strength properties (NIST, Commercial Standards, 1966).

Research studies of forest products research division, PFI indicated the suitability of Paulownia species for plywood manufacturing. Veneers of thickness between 0.5 to 1.00 mm may be obtained from logs having diameter of 37 to 40 cm (14-16 inches) and recovery percentage was in the range of 70 to 72 percent. Fresh logs are preferred for veneer manufacturing.

Utilization in pulp and paper industry

Research studies carried out in Italy indicated that *Paulownia fortunei* may be pulped by NSSC, Bisulphite and Refiner pulping processes. Neutral Sulphite semi chemical pulp with 18% chemical consumption may yield about 75% unscreened pulp having 60% brightness. At 40° SR the paper manufactured from Paulownia wood may have tensile index 4.5 N.m/g and burst index 5.7 kPam^2/g.

It can be predicted from these observations (Table 3) that Paulownia wood may be very useful for pulp and paper manufacturing. Lower value of runkel ratio of Paulownia fiber represents its bonding properties as compared to other hard board fibers.

Table 3: *Anatomical features of Paulownia fortune.*

F. length (mm)	F. diameter (um)	F.wall thickness (um)	Lumen width (um)	Runkel ratio	L/W ration
1.03	26.00	2.81	2.38	0.28	39.61

In order to determine the suitability of *Paulownia fortunei*, for pulp and paper manufacturing, research was carried out in the Forest Products Research Division, Pakistan Forest Institute, Peshawar. Paulownia was digested by using different pulping techniques. It was evaluated that pulp manufactured from kraft process exhibit outstanding tensile strength properties comparable with eucalyptus and poplar kraft Pulps. Tear strength properties of kraft Paulownia pulp were quite inferior than most of hardwood pulps. Pulps obtained from NSSC and soda techniques were also of acceptable quality but NSSC Paulownia pulp gave quite lower screened yield (41.76%) as compared to screened yield achieved from soda and kraft pulps (Table 4).

The pulping tests (Table 4) revealed that paulownia wood may be a better raw material for the production of higher-quality pulp and paper products. Nonetheless, a specific quantity of long fibre is essential to give

Table 4: *Paulownia pulping conditions and their evaluations by using different pulping processes.*

Name of pulping proc.	Kraft	Soda	NSSC
Cooking conditions			
Active alkali	15%	14 %	Na_2So_3=15%
Sulphidity	25%	-	Na_2Co_3=4%
Cooking temperature	170°C	170°C	170°C
Cooking time	2 hours	2 hours	2 hours
Wood to liquor ratio	1:5	1:5	1:5
Wood yield (%)	60.89	58.22	77.45
Screened yield (%)	53.56	57.72	41.76
Kappa number	42.50	27.30	-
Pulp evaluations			
Pulp freeness (SR°)	57, 66, 72	52, 60, 74	55
Tensile index (KNm/Kg)	44.3, 56.3, 60.7	55.8, 69.7, 75.3	42.4
Tear index (mN.m^2.g)	3.93, 4.31, 4.03	4.15, 4.81, 5.05	4.62
Bulk (cm^3/g)	0.95, 0.88, 0.86	1.00, 0.95, 0.92	1.45
Double fold	15, 20, 22	20, 31, 49	10
Gurley air resistance (Sec./100 ml)	124, 200, 332	232, 300, 388	10

the product the required tensile strength features, to provide adequate run ability during manufacturing, and to enable the pulp to have the required drainage characteristics at the wet end of the paper machine.

The aforementioned discussion explores the establishment of commercial plantations of paulownia with rotation cycle of 7-10 years under irrigated conditions may serve to expand the raw material base for the forest products industries.

Trends in paulownia plantations

1. Positive aspects to raise the paulownia plantations:
2. Paulownia species are fast growing and complete the economic rotation cycle within 7-10 years.
3. It has higher strength to weight ratio because of higher lignin contents with respect to the wood density. Furthermore, it is stable and can be easily dried with no warping. Reported shrinkage from green to oven dry is only 2.2% radial and 4.0% tangential.
4. Paulownia is resistant to decay, acid and alkali, and is not easy to wear and burn, hence it is very useful as a wardrobe.
5. Paulownia has light weight texture, good air permeability and moisture barrier, the wood material is very loose, after air drying paulownia wood is not easy to deform and bend and paulownia wood is very suitable for making wardrobes and drawers, boards and boxes.
6. Resistance to deformation, and strong dimensional stability.
7. Paulownia wood is inflexible, easy to process, and light in air-drying bulk density. It can be easily carved with various textures and decorations on the wood when used as furniture, which is more beautiful and elegant.
8. In addition, there are advantages such as impermeability to smoke, moisture barrier, and resistance to insects.
9. The texture of paulownia wood is straight and uniform, and its natural texture is very beautiful. The furniture made is also very beautiful, even if it is dyed with paint, it is easy to stain.
10. Timber obtained from paulownia plantations is mostly knot free.
11. It may also be used as an alternative to basla, maranti and bass wood.
12. Paulownia species may extend the base of raw material for forest products industry.
13. Use of Paulownia timber may help the local furniture industry to explore the new market segment in light weight furniture and high priced for the manufacture of special items.
14. Logs of paulownia have export market.
15. Paulownia removes and converts many pollutants from the ground soil (Phytoremediation).

Drawbacks

1. Under poor field management Paulownia may turn into weed because one tree may produce upto 20 million seeds per year.
2. Sparse crowns of paulownia trees in plantations when directly exposed to strong winds/ storm may be damaged severely.
3. It has higher water requirements.
4. If there is rise in temperature during the summer, it may cause rupturing of the bark and tree may die.
5. Paulownia is rarely used for furniture. The wood is very soft and can be pressed with nails. The texture of paulownia furniture is very light due to its light air-dry bulk density.
6. There is no large board because the center of paulownia is hollow, it can only be processed into jigsaw panels, then pasted with veneer or processed into block board to make furniture.

Conclusions and Recommendations

The expanding interest in Paulownia from its versatile applications, driving efforts to cultivate and develop advanced processes for its utilization in timber, bioenergy, and environmental initiatives. Other minor fractions are a low-cost renewable source of valuable compounds and the design of future processes considering the integral utilization of the tree is encouraged. Particularly benefits are the high value-added compounds with biological properties, which could be obtained in the first stage, without limiting the further utilization of the Paulownia timber.

Acknowledgement

The author would like to acknowledge the financial support of the Forestry Sector Research and Development Project of PFI for conducting this research. The technical assistance provided by the Forest Products Research Division is also hereby acknowledged.

Novelty Statement

Paulownia plantations have considerable scope to be included in agroforestry systems in Pakistan for its utilization in timber industry and as a raw material for making cellulose paper pulp as means for reducing wood use and pulp and paper imports.

Author's Contribution

Muhammad Bilal Zia and Asher Farooq: conception of idea, devised the methodology and original draft writing. Hammad ud Din: Data compilation and formal analysis Barkatullah Khan and Samee Ud Din: review and editing.

Conflict of interest

The authors have declared no conflict of interest.

References

Akyildiz, M.H. and H.S. Kol. 2010. Some technological properties and uses of paulownia (*Paulownia tomentosa* Steud.) Wood. J. Environ. Biol., 31(3): 351-355.

Alzagameem, A., Klein, S.E., Bergs, M., Do, X.T., Korte, I., Dohlen, S., Huwe, C., Kreyenschmidt, J., Kamm, B., Larkins, M. and Schulze, M., 2019. Antimicrobial activity of lignin and lignin-derived cellulose and chitosan composites against selected pathogenic and spoilage microorganisms. Polymers (Basel), 11(4): 670. https://doi.org/10.3390/polym11040670

Brundu, G. and Richardson, D., 2016. Planted forests and invasive alien trees in Europe: A Code for managing existing and future plantings to mitigate the risk of negative impacts from invasions. Neobiota, 30: 5-47. https://doi.org/10.3897/neobiota.30.7015

Cheng C., Jia, X., Xiao, C. and Tang, W., 2019. Paulownia C-geranylated flavonoids: Their structural variety, biological activity and application prospects, Phytochem. Rev., 18: 549-570. https://doi.org/10.1007/s11101-019-09614-2

Forest Product Statistics, 2020. Retrieved from https://www.fao.org/forestry/statistics/80938/en/

Gao, T.Y., Jin, X. and Tang, W.Z., 2015. New geranylated flavanones from the fruits of *Paulownia catalpifolia* Gong Tong with their anti-proliferative activity on lung cancer cells A549. Bioorgan. Med. Chem. Lett. 25: 3686-3689. https://doi.org/10.1016/j.bmcl.2015.06.035

Haq, R. and Khan, M., 2005. Paulownia species trials in Pakistan. Pak. J. For., 55(2): 81-87.

He, T., Vaidya, B., Perry, Z., Parajuli, P. and Joshee, N., 2016. Paulownia as a medicinal tree: Traditional uses and current advances. Eur. J. Med. Plants, 14(1): 1-15. https://doi.org/10.9734/EJMP/2016/25170

Jimenez, L., Alejandro, R.J.L. and Ferrer A.P., 2005. Paulownia, a fast-growing plant, as a raw material for paper manufacturing. Afinidad Barcelona, 62(516): 100-105.

Lucas, M.E.B., Baena, C.W., Moreno, J.L., Dadi, T., Garcia, C. and Abellan, M.A., 2011. Microbial activity in soils under fast-growing Paulownia (*Paulownia elongata* x *fortunei*) plantations in Mediterranean areas. App. Soil Ecol., 51(2011): 42-51. https://doi.org/10.1016/j.apsoil.2011.08.011

Meng Z.F., Guo, X., Zhu, F.Y. and Jing, S.K., 2014. Analysis of antioxidant properties and major components of the extract of *Paulownia tomentosa Steud.* flowers. Adv. Mat. Res., 1010-1012: 164-177. https://doi.org/10.4028/www.scientific.net/AMR.1010-1012.164

Moon H.I., Jeong, M.H. and Jo, W.S., 2014. Protective activity of C-geranylated flavonoid analogs from Paulownia tomentosa against DNA damage in 137Cs irradiated AHH-1 cells. Nat. Prod. Commun., 9: 1295–1298. https://doi.org/10.1177/1934578X1400900919

National Institute of Standards and Technology (NIST), Commerce Department, 1966. The National Bureau of Standards 1966. [Government]. Commerce Department. https://www.govinfo.gov/app/details/GOVPUB-C13-32.

Nelis, A. and Mai, J., 2019. Improved strength properties of three-layered particleboards with different core and surface layers based on Kiri wood (*Paulownia* spp.). Eur. J. Wood Wood Prod., 77: 761-769. https://doi.org/10.1007/s00107-019-01442-7

Nelis, P.A., Michaelis, F. and Krause, K.C., 2018. Kiri wood (*Paulownia tomentosa*): Can it improve the performance of particleboards. Eur. J. Wood Prod., 76: 445-453. https://doi.org/10.1007/s00107-017-1222-7

Pakistan Bureau of Statistics (PBS), 2019. Pakistan Statistical Year Book.

Snow, W.A., 2015. Ornamental, crop, or invasive? The history of the empress tree (Paulownia) in the USA. Forests, Trees and Livelihoods, 24: 85-96. https://doi.org/10.1080/14728028.2014.952353

Swiechowski, K., Liszewski, M., Babelewski, P., Koziel, J.A. and Bialowiec, A., 2019. Fuel properties of torrefied biomass from pruning of oxytree. Data, 4: 55. https://doi.org/10.3390/data4020055

Tzvetkova, N., Miladinova, K., Ivanova, K., Georgieva, T., Geneva, M. and Markovska, Y., 2015. Possibility for using of two Paulownia lines as a tool for remediation of heavy metal contaminated soil. J. Environ. Biol., 36: 145-151.

Xing, Y.L., Bi, L.W., Zhao, Z.D. and Xia, T.J., 2013. Simultaneous determination of oleanolic acid and ursolic acid in leaves of Paulownia by HPLC. Adv. Mater. Res., 781: 787-791. https://doi.org/10.4028/www.scientific.net/AMR.781-784.787

Zia, M.B. and Laeeq, M.T., 2012. Performance based genetic variability of four Paulownia species at Peshawar. Pak. J. F., 62(1): 48-55.