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RESEARCH ARTICLE

Wood Fiber Characteristics of Underutilized Poplar Species and Comparision with *P. deltoides* in Terms of their Pulp and Paper Quality

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ABSTRACT

The pulp and Paper industries are growing at a tremendous rate. To satisfy the raw material supply and sustainability of their future industries need an alternative resource from fast-growing tree species. Poplar is one of the world's fastest-growing lightwood trees with its used in several industries. The present work relies on the comparative fiber morphological dimensions of four species of poplar i.e. *Populus alba* L, *Populus ciliata* Wall. ex Royle, *Populus euphratica* Oliv, and *Populus nigra* L. The quality of pulp and paper was directly related to the fiber dimensions i.e., fiber length, fiber lumen diameter, and fiber wall thickness. A number of wood properties related to paper quality were also derived from the fiber dimensions including the runkel ratio, flexibility coefficient, solid factors, luce's-shape factors, slenderness ratio and wall coverage ratio. The mean value of fiber length, fiber diameter, fiber wall thickness and basic density of these four species ranged from 919-1425 µm, 19.71-25.85 µm, 2.72-4.99 µm and 0.38-0.54 g cm^{-1} respectively. The prominent objective was to compare the fiber quality of these four poplar species within among self and also with an exotic poplar species *Populus deltoides* and other fast-growing tree species.

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- Fibers, Pulp and paper quality
- Runkel ratio and wall coverage ratio

Introduction

Paper and paper products are essentials in our daily lives and the applications of paper products are virtually limitless. Due to increasing population, there is a limited supply of wood as a raw material for paper manufacturing [1]. Tree species that grow quickly are suitable alternative sources for reducing the gap between the supply and demand of wood [2]. The paper industry strives to find alternative sources of raw materials for future endeavors [3]. For the quality of pulp and paper, wood properties and wood anatomical characteristics (mainly fiber dimensions) played an imperative role [4,5]. Among fiber dimensions, fiber wall thickness is one of the major factor because it is directly related to sheet density, pulp yield, and paper strength [6]. The wood of different species has different anatomical, chemical, mechanical, and physical qualities that make them useful for specific purposes. Paper quality is closely related to the fiber dimensions of their wood [7], in particular, tracheids and libriform fibers as softwood pulp is generally more in demand than hardwood pulp based on fiber dimensions [8].

India is one of the rarest country in the world where five *Populus* sections are indigenous. But on account of their limited and scattered distributions, none of the indigenous poplar could gain any commercial importance [9]. However, poplar is a very important tree for cultivation in forests and farms; it can grow quickly,

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produce a high return on investment, and are very useful for industries [10]. A variety of poplar species are used in industries such as paper, particleboard, matchmaking, box-making, MDF (Medium Density Fibreboard), veneer, plywood, and furniture; they are also used as sources of energy [9].

Among indigenous poplar species, *Populus ciliata* is the most widespread native species which is distributed throughout the Himalayas from northwestern Jammu and Kashmir to northeast Arunachal Pradesh at an altitude between 1000-3000 m. *Populus alba* (white poplar) is a native of Central Europe and Central Asia. In India, it is found in the North-West Himalayas in Kashmir at 1200-3300 m, wild or cultivated [9]. White poplar has not been considered a commercially important woody species for a long period of time [11]. *Populus nigra* (Black Poplar) is frequently cultivated in North-West Himalayas between 900-3700 m and attain a height of 30 m. *Populus euphratica* occurs in the plains of Punjab and also at an altitude of 4000 m in Ladakh and western Tibet [9]. *P. euphratica* holds excellent promise as a source of fiber for fine paper, packing paper and newsprint and various grades of paper [12]. Rather cultivated our native species a number of exotics/hybrids/clones have been introduced in India, among them Eastern cottonwoods (*P. deltoides*) from North America are very common in fields of farmers as agroforestry plantations mostly in northern states like Punjab, Haryana, Uttarakhand and Uttar Pradesh. Among all the exotic poplars in the plains of North India, *P. deltoides* performed best, and the remaining exotic *Populus* species have been relegated to obscurity [13].

So keeping in view, numerous exotic species of poplar have been planted in northern India taking advantage of their fast-growing nature; however, not much attention has been given to indigenous species. A study performed at Khaltoo (Himachal Pradesh) in 1976 on the forest clones of six species of poplars namely *P. ciliata, P. trichocarpa, P. casale; P. yunnanensis, P. oxford* and *P. deltoides* planted with spacing 60 x 30 cm demonstrated that maximum survival was recorded in *P. ciliata* followed by *P. deltoides* while maximum height and diameter were recorded in *P. yunnanensis* followed by *P. ciliata*. They found that *P. ciliata* is suitable for making various grades of plywood and blackboards like *P. deltoides* had been tested earlier [14,15]. The main objective behind this study was to demonstrate the potential alternative resource for industries through the study of fiber morphologies of indigenous poplar species for pulp and paper making.

A limited amount of research has been conducted on the anatomical study of wood fiber, which reveals that wood can be used as a raw material in the paper industry. Considering the anatomical characteristics of the wood, the following indices can be used to estimate pulp and paper quality: Runkel ratio (Runkel Advance View Proofs 108 TROPICS Vol. 25 (3) Ryosuke Takeuchi, Imam [16], Luce's shape factor [17], flexibility coefficient [18], slenderness ratio [18], solids factor [19], and wall coverage ratio [20].

Materials and Methods

In the present study, ten authentic wood samples from the different localities of four poplar species i.e., *Populus alba, Populus ciliata, Populus euphratica* and *Populus nigra* available in the Xylarium (DDw) of the Forest Research Institute, Dehradun. The list of wood samples along with their accession number, specific gravity and localities given in Table 1.

Methods

For basic density: According to [21] the basic density was calculated by dividing the oven dry weight by the green volume. In spite of the fact that there are several different methods of measuring wood density, the standard way is to divide the dry weight of the wood by the green volume of the same wood.

For maceration: For the determination of fiber quantitative characters, small radial chips were macerated following *Schultz's method* (30% Nitric acid and a pinch of Potassium Chlorate to employ this method, radial chips of wood having size of a half matchstick were placed in different test tubes for each sample. The test tubes were placed in direct sunlight for two to three days until all the chips were fully macerated. As a strong oxidizing agent, potassium chlorate reacts almost instantly with nitric acid and causes maceration. The macerated materials were washed thoroughly with water to remove the acid. The separated wood elements were stained in safranin and made a temporary slide for recording the data [22] (Figure 1).

From this macerated material, 25 measurements of fiber length, fiber diameter, and fiber lumen diameter were taken with the help of a compound microscope (Figure 2A,B). Using this formula (FWT = (FD-FLD)/2) fibre wall thickness was calculated. For writing the description of microstructure, the terminology given by the International Association of Wood Anatomists IAWA, 1989 was followed [23].

The Photomicrographs of the sections and macerated material were taken from the Carl Zeiss compound light microscope (Scope.A1.Axio) equipped with a Carl Zeiss camera. AxioVision Rel 4.0 software was used to capture the microscopic images.

Wood properties related to pulp and paper quality

To evaluate the pulp quality, the following wood properties were calculated: Runkel ratio, Luce's shape factor, flexibility coefficient, slenderness ratio, solids factor, fiber coarseness, and wall coverage ratio. The fiber morphologies were determined by the method described below in this step

Table 1: List of the poplar specimen available in Xylarium, FRI along with their accession number, specific gravity and locality.

Sr. No.	Species Name	Accession Number	Locality	Specific Gravity
	P. alba L.	DDw 138	Lahaul, Himachal Pradesh	0.46
	P. ciliata Wall. ex Royle	DDw 770	Dalhousie, Himachal Pradesh	0.38
	P. ciliata Wall. ex Royle	DDw 970	Tibet	0.42
	P. ciliata Wall. ex Royle	DDw 2884	Shimla, Himachal Pradesh	0.46
	P. ciliata Wall. ex Royle	DDw 4696	Jaunsar, Uttarakhand	0.41
	P. euphratica Oliv.	DDw 883	Multan, Pakistan	0.50
	P. euphratica Oliv.	DDw 1384	Sind, Pakistan	0.54
	P. euphratica Oliv.	DDw 5345	Multan, Pakistan	0.53
	P. euphratica Oliv.	DDw 5747	Sukkur	0.46
	P. nigra L.	DDw 7338	Kashmir	0.46

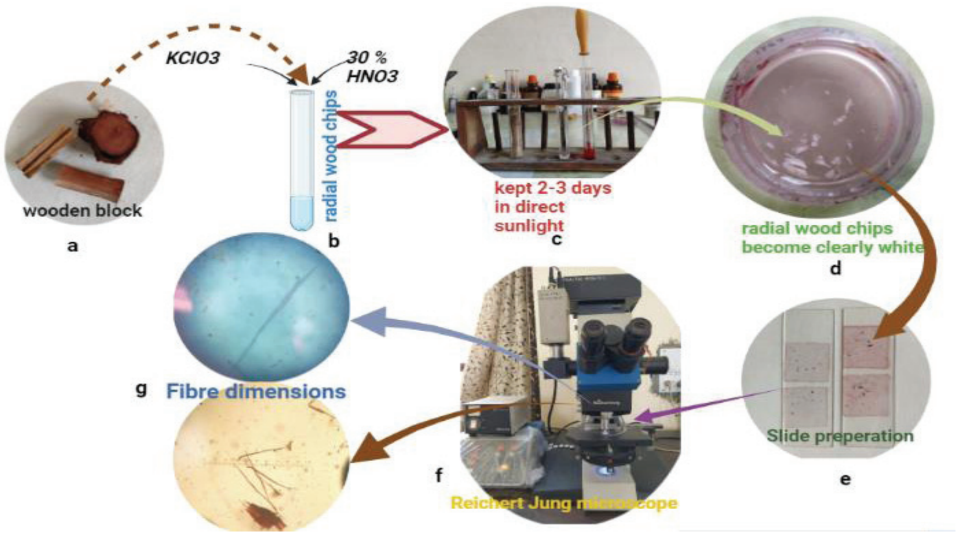

Figure 1 Complete process of Maceration (*Schultz's method*) from radial wood chips to record fiber dimensions (step a-g).

Table 2: List of calculations formulas of wood fiber properties related to pulp and paper quality.

Sr. No.	Related to Pulp and Paper Properties	Property	Formula	Reference
1	Pulp yield (positively) & digestibility (negatively)	Runkel ratio	(2×FWT)/FLD	[24]
2	Resistance to beating (positively)	Luce's shape factor	(FD2–FLD2)/(FD2 /FLD2)	[17]
3	Tearing and tensile strength (positively)	Flexibility coefficient	FLD/FD	[18]
4	Tearing strength (positively)	Slenderness ratio	FL/FD	[6,18]
5	Sheet density (negatively)	Solids factor	(FD2 –FLD2)×FL	[6,19]
6	Bending resistance (negatively)	Wall coverage ratio	(2×FWT)/FD	[20]
7.	Fiber coarseness	--	(FD2 –FLD2)	

Note: FWT: Fiber Wall Thickness; FLD: Fiber Lumen Diameter; FD: Fiber Diameter; FL: Fiber Length

to calculate these properties. The formulas related to wood properties are listed in Table 2.

Results

Basic density

The mean values of the basic density of the wood of four species of genus *Populus* ranged from 0.38 to 0.54 g cm^{-3} with the lowest density in *P. ciliata* (0.38 in wood sample DDw 770) and highest in *P. euphratica* (0.54 in wood sample DDw 1384) respectively. Pulp properties are closely related to wood density or basic density: low-density wood produces paper with high sheet density, tensile, bursting, and folding strengths, and lower resistance to beating, but with low pulp

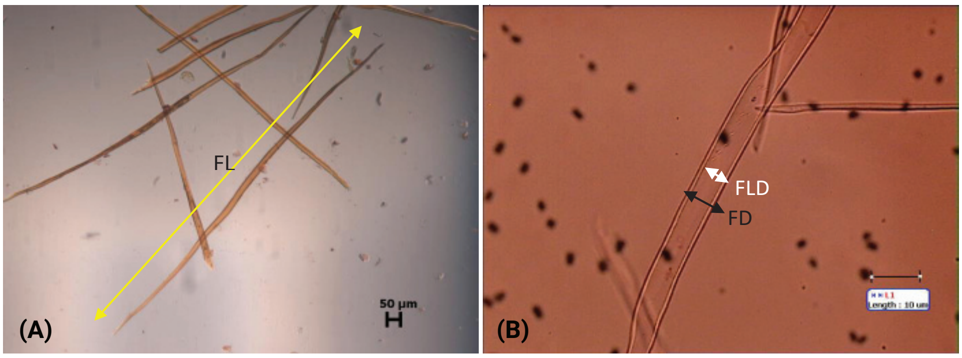

Figure 2 Photomicrographs of fiber dimensions of poplar species.
A). Measure Fiber length.
B). Measure fiber diameter and fiber lumen diameter.

yield and tearing strength [25,26]. Within this work, the lowest wood density of *P. ciliata* (0.38) produces the longest fibers up to 1356.48 μm in length while the highest wood density is 0.54 in *P. euphratica* which produces fiber lengths up to 1425.6 μm.

The mean value for the basic density of a *Eucalyptus* species was 0.79 g cm^{-3} for 10-year-old *E. tereticornis* trees [27]. However, all four species of poplar have lower wood density values (Tables 2,3) compared with *Eucalyptus* species commonly used for paper production.

Wood properties related to pulp and paper quality

According to results presented in tables 3,4, significant differences can be found in fiber Morphometry (dimensions), basic density, Runkel ratio, slenderness ratio, wall coverage ratio, etc., between the ten authentic samples among four species of poplar used in this study. A comparison of the mean values among the authentic wood samples and the species revealed very significant differences.

P. euphratica has the longest fibers followed by *P. ciliata*, *P. nigra* with the smallest fiber in *P. alba* (white poplar). The fiber wall thickness was lowest in the wood sample of *P. ciliata* (DDw 4696) with a maximum in *P. euphratica* (4.99 μm in wood sample DDw 1384). According to Rydholm, 1967 for better quality paper, paper industries need long fibers with thin walls [8]. Hence, *P. ciliata* and *P. euphratica* species of poplar have one feature that's essential for paper quality, such as long fiber (*P. euphratica*) and lesser wall thickness (*P. ciliata*) (Table 3).

During paper manufacturing, the Runkel ratio provides useful pulp yield or digestibility for good quality papers, the values of Runkel ratio in present work *P. alba* (0.61), *P. ciliata* (0.41-0.64), *P. euphratica* (0.51-0.92) and (0.53). The Runkel ratio of *P. deltoides* was reported 0.53 [28] and the average value of *P. ciliata* was 0.49 in the present study with a range of 0.41-0.64 and the mean value of the Runkel ratio of *P. nigra* was 0.53 followed by *P. alba* (0.61) and *P. euphratica* (0.67) respectively (Table 5).

The above given average values of the Runkel ratio of poplar, were responsible for the high specific surface areas which have desirable bonding capability. Therefore, it is expected that the paper-produced wood with a Runkel ratio of less than one will be compact and have a smooth surface, and have excellent folding endurance, tensile and bursting strength [29]. The higher the Runkel ratio is, the higher the tearing strength of the paper will be [30].

The Runkel ratio and coverage ratio of the wall should be less than 1.0 and 0.4, respectively, for pulpwood use [31]. All the species of poplar examined in the present study showed a Runkel ratio of less than 1 and a wall coverage ratio of less than 0.4. The results of this study suggest that all four tree species of poplar have superior quality fibers which are capable of producing a good quality paper.

The strength of the fiber is directly proportional to the slenderness ratio and length of the fiber [32]. Therefore, fibers with a high slenderness ratio will greatly facilitate the collapsing of fibers resulting in stronger inter-fiber bonds [33]. The mean values of the slenderness ratio in *P.alba* (51.04), *P. ciliata* (50.5), *P. euphratica* (60.75) and *P. nigra* (58.37) which are responsible for the higher bursting and tensile strength of the paper produced (Table 5).

For resistance to beating, calculate Luce's shape factor and Flexibility coefficient for tearing and tensile strength of paper, the range of Luce's shape factor is 0.33 to 0.46 in *P. ciliata* and 0.38 to 0.56 in *P. euphratica* with 0.63 and 0.66 in white poplar and black poplar, respectively. The range of the flexibility coefficient is 0.61-0.71 (*P. ciliata*) and 0.52- 0.66 (*P. euphratica*) (Table 5). According to Moriya (1967), the strength of the paper produced was positively related to the flexibility coefficient, as well as the burst and tear factors [. The flexibility coefficient ranged from 0.37 to 0.65 in several *Eucalyptus* species reported by Pirralho [4] (Table 6). In the present study poplar species, the flexibility coefficient ranged from 0.52-0.71 which is similar as reported in *Eucalyptus* species.

The Solid factor was directly related to the paper sheet

Table 3: Mean values of basic density and fiber characteristics of four poplar species.

Species	Accession Number	Basic Density	FL (µm)	FD (µm)	FLD (µm)	FWT (µm)
P. alba	DDw 138	0.46	1049.22	21.73	13.77	3.98
P. ciliata	DDw 770	0.38	1356.48	22.82	13.91	4.46
P. ciliata	DDw 970	0.42	919.77	23.32	15.51	3.91
P. ciliata	DDw 2884	0.46	1379.02	25.85	18.04	3.91
P. ciliata	DDw 4696	0.41	1045.60	23.28	17.84	2.72
P. euphratica	DDw 883	0.50	1264.68	19.71	11.61	4.05
P. euphratica	DDw 1384	0.54	1425.6	21.6	11.61	4.99
P. euphratica	DDw 5345	0.53	1084.55	21.67	14.63	3.52
P. euphratica	DDw 5747	0.46	1209.1	22.99	15.29	3.85
P. nigra	DDw 7338	0.46	1291.14	23.49	15.52	3.98

Table 4: Mean value ± Stander error of the fiber dimensions of four species of genus *Populus*.

Species	Fiber Length Mean ± Std error	Fiber Diameter Mean ± Std error	Fiber Lumen Diameter Mean ± Std error	Wall Thickness Mean ± Std error
P. alba	1049.22 ± 42.73	21.73 ± 1.04	13.77 ± 0.85	3.98 ± 0.24
P. ciliata	1266.8 ± 34.18	25.29 ± 0.64	17.05 ± 0.61	4.11 ± 0.13
P. euphratica	1234.96 ± 25.09	21.58 ± 0.47	13.47 ± 0.43	4.05 ± 0.12
P. nigra	1291.14 ± 48.02	23.49 ± 1.19	15.52 ± 0.89	3.98 ± 0.31

Table 5: Mean values of fiber wood properties related to pulp and paper quality of four poplar species.

Species	Accession Number	Runkel Ratio	Luce's Shape Factor	Flexibility Coefficient	Slenderness Ratio	Solids Factors (x 10^3)	Wall Coverage Ratio	Fiber Coarseness
P.alba	DDw 138	0.61	0.43	0.63	51.04	296	0.18	289.77
P. ciliata	DDw 770	0.41	0.33	0.71	49.75	641	0.29	436.23
P. ciliata	DDw 970	0.64	0.46	0.61	59.46	443	0.39	327.18
P. ciliata	DDw 2884	0.50	0.39	0.67	39.44	278	0.33	303.26
P. ciliata	DDw 4696	0.43	0.34	0.70	53.35	472	0.30	342.78
P. euphratica	DDw 883	0.71	0.48	0.58	67.33	320	0.20	263.16
P. euphratica	DDw 1384	0.92	0.56	0.52	68.16	472	0.23	334.61
P. euphratica	DDw 5345	0.51	0.38	0.66	53.42	277	0.16	262.57
P. euphratica	DDw 5747	0.57	0.39	0.65	54.19	356	0.17	294.03
P. nigra	DDw 7338	0.53	0.39	0.66	58.37	401	0.16	322.58

density and could significantly predict the breaking length of the paper [6]. Like the solid factor, Luce's shape factor was also found to be directly connected to paper sheet density and could be correlated to paper-breaking length [27]. The mean values of the solid factors of the present studied four poplar species were given in Table 5.

Discussion

According to a previously published report, *P. deltoides* use as a raw material for industries has neglected the importance of other poplar species [13]; however; a study on *P. ciliata* and *P. deltoides* and four other poplar species reported that the maximum survival with maximum height and diameter were recorded in *P. ciliata* as compare to *P. deltoides* [14]. Moreover, this study indicates that the fiber properties of *P. ciliata* are best for pulp and paper production since the value of the Runkel ratio and wall coverage ratio are less than 1.0 and 0.4, respectively. Rajawat, et al. [15] also report its usefulness like *P. deltoides* in producing various grades of plywood and blackboards.

The average value of the Runkel ratio, slenderness ratio, and flexibility coefficient of *P. deltoides* were 0.53, 46.59, and 0.65 [28], whereas in the present study *P. ciliata* was 0.49, 50.5, and 0.67, respectively. Due to the above-given facts and comparison of paper properties, it's quite obvious that *P. ciliata* has all the qualities of *P. deltoides*. While the other three species under the present study also show a value nearer to the reported values of *P. deltoides* in terms of their

Table 6: Comparative account of wood properties related to pulp quality of four poplar species and other commercial plantation tree species.

Species	Runkel Ratio Mean (Range)	Luce's Shape Factor Mean (Range)	Flexibility Coefficient Mean (Range)	Slenderness Ratio Mean (Range)	Solids Factors Mean (Range)	Wall Coverage Ratio Mean (Range)	Reference
P.alba	0.61	0.43	0.63	51.04	296	0.18	Present study
P. ciliata	0.495 (0.41 – 0.64)	0.38 (0.33 – 0.46)	0.67 (0.61 – 0.71)	50.5 (39.44 – 59.46)	458.5 (278 – 641)	0.3275 (0.29 – 0.39)	Present study
P. euphratica	0.67 (0.51-0.92	0.45 (0.38 – 0.56)	0.60 (0.52 – 0.66)	60.77 (53.42 – 68.16	356.25 (277 – 472)	0.19 (0.16 – 0.23)	Present study
P. nigra	0.53	0.39	0.66	58.37	401	0.16	Present study
P. deltoides	0.53	----	0.65	46.59	----	----	[28]
E. globules	0.54-0.67	0.39-0.44	----	57.7-59.9	96.3-97.6	-----	[36]
E. globules	0.85	----	----	----	----	0.46	[20]
E. camaldulensis	0.5	0.37	----	50.5-56.6	48.6-61.2	----	[36]
Macaranga species*	0.08 – 0.09	0.08 – 0.09	0.92 – 0.93	58.7 – 60.8	167 – 182	0.07 – 0.08	[31]
Acacia spp.*	0.37 – 0.55	----	0.67 – 0.73	51.3 – 52.7	----	----	[24]
G. arborea	0.624	----	0.67	40.01	----	----	Chukwunonso, *et al.*
A. indica	1.22	----	0.43	42.5	----	----	Chukwunonso, *et al.*

Note: The Runkel ratio and coverage ratio of the wall should be less than 1.0 and 0.4, respectively, for pulpwood.

fiber quality (Table 6).

The present study compared the wood properties related to the pulp and paper quality of various commercially grown tree species. In Table 6, there is a comparison of fiber properties of the present study's four poplar species (*P. alba*, *P. ciliata*, *P. euphratica* and *P. nigra*) with the 7 most frequent fast-growing tree species i.e., *P. deltoides*, *Macaranga species*, *Acacia* species, *E. globules*, *E. camaludensis*, *G. arborea and A. indica.* The value of Runkel ratio was minimum in *Macaranga* species (0.08) reported by Takeuchi, et al [31], followed by *P. ciliata* (0.49), *E. camaludensis* (0.50), and in both *P. deltoides* and *P. nigra* (0.53). Luce's shape factor value was lowest in *Macaranga* species followed by *E. camaludensis* and *P. ciliata* (0.38). The values for different parameters were given in this table for showing the comparison of four poplar species within or between the seven different fast-growing species.

The exotic species alter their distribution as a response to climate change to shift that climatic track, they move into new geographical areas. This can allow these exotic species to become invasive [34]. The early concern with climate change was that existing exotic species would gain an advantage over natives and become invasive and that already invasive species could become worse for native communities and ecosystems [35]. It can be concluded that our native species mostly *P. ciliata* have substantial potential as an alternative for *P. deltoides* as exotic species may have the tendency to become invasive in the future due to climate change or climate adaptation.

Conclusion

This study investigates whether poplar species could be a viable source for making high-quality pulps and paper. Wood is an ideal raw material for paper industries because it is a renewable resource when it is used sustainably. The study suggests that all four tree species of poplar showed a Runkel ratio and wall coverage ratio less than 1 and 0.4, respectively which is capable of producing good quality papers. Among these four species of Poplar, *P. ciliata* is a good alternative for Industries of exotic species *P. deltoides* in the quality of their fibers. To obtain more accurate and reliable results in determining the quality of pulp and paper processing, furthermore, future research should also investigate the chemical properties like soda or kraft pulping of the selected poplar species as well as chemical components of the wood such as cellulose, hemicelluloses, lignin, etc. Among these components, lignin is generally considered low for the application in paper making because it reduces the brightness and brings brittleness of the paper. In the future, exotic species may become invasive due to shifting climatic tracks, affecting the native flora and ecosystems, so there is a need to take action for unforeseen threat and invest more in native species.

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