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ASSESSMENT OF WOOD VARIABILITY IN STEMS OF *POPULUS NIGRA* L. FOR DIFFERENT END USES, FROM TEMPERATE CLIMATE OF KASHMIR HIMALAYA

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ABSTRACT

Populus nigra L. is regarded as an important natural resource almost throughout the temperate regions of the world but relatively little is known about the within-tree variability of the anatomical characteristics of its wood. For this purpose three sites were selected and from each site three trees were felled and five discs were extracted from base upto merchantable top of the each tree, equally spaced along vertical direction. The wood anatomical features viz. fiber length, fiber diameter, fiber wall thickness, varied significantly from different positions of trees. Also the derived wood properties like Runkel ratio, Slenderness ratio, Luce's shape factor were evaluated from wood anatomical features as these parameters are directly related to industrial utility of wood especially paper qualities.

Key words: Anatomy, fiber, *Populus nigra*, wood

INTRODUCTION

Wood is unique among the world's important raw materials virtually used by every one in diverse ways. It is a remarkable material with a variability and flexibility that makes it useful for many kinds of products. Wood is known to have been used for various structural and other purposes since the dawn of history and has been serving mankind even in modern times with enormous technological know how. It is the fifth most important product of the world trade. The complex make up of wood (cellulose, hemicelluloses, lignin and pectin) makes it an ideal raw material for what could replace the petro-chemical industry, in providing not only plastic and all kinds of chemical products, but also food and textile products (Plomion *et al.*, 2001). The durable properties of wood vary considerably from species to species often within the species, and selection of wood depends upon the conditions it is required to endure.

This variability arises from the dimensions of its anatomical structures like vessel elements, fibers, rays etc in both vertical i.e. from base up to the top of the tree and in radial direction from pith (inside) to the bark (peripheral) of tree respectively. The variability of wood anatomical features directly or indirectly has a bearing on the efficient use of wood for different end uses. Keeping in view the importance of wood anatomy in predicting the suitability of different woods for their varied utility purposes, the present work is an attempt to elucidate wood anatomical variation patterns within and among trees of *Populus nigra* L. from three different sites of Kashmir valley as its wood is suitable for manufacturing of packing cases (Anon, 1980), matchboxes (Anon, 1970), handles and wedges of badminton and tennis rackets frames (Anon, 1979; Anon, 1980) and artificial limbs (Anon, 1977). Poplars have also been found suitable for the manufacture of plywood and hardboard (Shukla *et al.*, 1986) and also for varieties of writing, printing and wrapping papers (Rai and Chand, 1988; Labosky *et al.*, 1983). Besides it the wood of poplar is also used a lumber (Hall *et al.*, 1982; Hernandez *et al.*, 1988)

MATERIAL AND METHODS

(a) Source of Material

The present study was carried out on *Populus nigra* L. a hardwood trees with deciduous type of habit, belonging to family *Salicaceae* from natural provenances of Kashmir Himalaya for its anatomical characteristics.

The sites which were surveyed are Khrew, Pampore, Ladhoo, Pulwama, Shopian, Ahrabal, Charsoo, Anantnag, Qaimoh, Budgam, Brenward Surasyar, Gowharpora, Shalimar, Darbagh, Naranag, Batpora, Habbak. Out of the sites, three were selected for the wood anatomical characteristics viz., Khrew (site-1), Surasyar (site-2), Shopian (Site -3).

These sites were selected on the basis of the following criterions:-

a. Accessibility of sites

b. Availability of the material

1. The geographical locations along with other characteristics of the selected sites are summarised in the Table -1.

Three trees of each species were felled and 10 cm thick discs were cut at five positions equally spaced along the vertical directions from base up to the merchantable top of tree. These were named as DI, DII, DIII, DIV and DV from base up to the top respectively.. From these discs, in order to study a vertical variation, a disc wedge was removed at any cardinal directions (Chauhan *et al.*, 2001). The wedge was further divided into three parts as per locations viz., inner (Pith), middle and outer (peripheral). All samples were studied for wood element dimensions and variations within tree and among replicates at each site as per Pande and Singh (2005).

Table 1. Salient features of the sites and age of trees selected for the present study

Factor	Site I (Khrew)	Site II (Surasyar)	Site III (Shopian)
North Latitude	30° 12′	34° 32′	33° 34′
East Longitude	75° 35′	74° 55′	75° 20′
Elevation (m)	2000	2400	2800
Soil	Sandy clay	Loamy soil	Sandy clay
Age in years	10- 13	10-13	10-13

(b) Maceration

Maceration was done as per Jeffery's method (Johansen, 1940) for all the samples studies. In this method, small slivers of wood were taken from the samples collected into the test tube and then filled with 10% chromium trioxide and 10% nitric acid and left for one to several days at room temperature and the process was hastened by heating up to approximately 60°C for few minutes. After that, the material was thoroughly washed with distilled water till traces of the acid were removed. The mixture was teased/shaken thoroughly to separate the wood elements and stained with 1% Safranin and mounted in glycerine on microscopic slides.

$$\text{Runkel ratio} = \frac{\text{fiber wall thickness} \times 2}{\text{fiber lumen diameter}}$$

$$\text{Slenderness ratio} = \frac{\text{fiber length}}{\text{fiber diameter}}$$

$$\text{Luce's shape factor} = (\text{fiber diameter}^2 - \text{fiber lumen diameter}^2) / (\text{fiber diameter}^2 + \text{fiber lumen diameter}^2)$$

(c) Wood Element Measurements

The measurements/dimensions of fibers were done with the help of ocular-stage micrometry. Twenty-five measurements were made from unbroken fibers for diameter, wall thickness and length.

The derived wood properties of Runkel ratio, Luce's shape factor, and Slenderness ratio were calculated from measurements of the fiber morphology as per Ohshima *et al.* (2005).

(d) Statistical Analysis

The data collected for present study was statistically analyzed by using Sigma Plot 12.0 statistical software (SPSS. Chicago. IL.USA) and Minitab 11.0 for windows.

RESULTS

(a) Fiber Length

In *Populus nigra*, the fiber length varied significantly among the sites. The average fiber length ranged from 812.46 µm in site I (Khrew) to 1075.33 µm in site III (Shopian). In site I (Khrew), the fiber length varied from 812.46 µm in disc IV to 921.71 µm in disc II, with the highest values of fiber length in the disc II, followed by disc I disc III, disc IV and disc V.

In site II (Surasyar), the average fiber length ranged from 952.37 µm in disc V to 1062.33 µm in disc II. In this site, the highest values for fiber length were found in the disc II, followed by discs I, III, IV and disc V,

In site III (Shopian), the average fiber length ranged from 993.70 µm in disc V to 1075.33 µm in disc II, having the highest values in the disc followed by disc III, disc I, disc IV and disc V respectively (Table 2a)

The fiber length within disc i.e., from inner to outer (inner, middle and outer);

within tree i.e., from base upto merchantable top of tree (DI, DII, DIII, DIV and DV) and among sites (site I, site II, site III) is statistically significant. But, the interaction of site, disc and location i.e. site × disc, site × location, disc × location and site × disc × location does not show any statistical significance (Table 2b).

Table 2a. Fiber Length in µm at different sites and locations of *Populus nigra*

Position	Location	Site I	Site II	Site III
Disc I	Inner	851.60	1008.37	1008.70
	Middle	874.20	1019.45	1033.80
	Outer	892.92	1038.33	1044.00
Disc II	Inner	867.05	997.97	1032.33
	Middle	905.74	1027.93	1057.33
	Outer	921.71	1062.33	1075.33
Disc III	Inner	834.80	977.70	1012.67
	Middle	874.44	982.83	1043.00
	Outer	885.29	987.80	1047.67
Disc IV	Inner	829.28	964.47	1003.73
	Middle	848.47	974.30	1012.00
	Outer	860.69	989.60	1031.33
Disc V	Inner	812.46	952.37	993.70
	Middle	831.13	962.37	1009.17
	Outer	835.45	965.40	1020.00

Table 2b. ANOVA for fiber length of *Populus nigra*

Source	Sum of Squares	df	Mean Square	F	Sig.
Model	125569431.3	45	2790431.807	1998.850	.000
Site	697032.705	2	348516.352	249.650	.000
Disc	64563.542	4	16140.885	11.562	.000
Location	26460.806	2	13230.403	9.477	.000
Site * Disc	6838.086	8	854.761	.612	.765
Site * Location	898.357	4	224.589	.161	.958
Disc * Location	3147.374	8	393.422	.282	.970
Site * Disc * Location	1632.606	16	102.038	.073	1.000
Error	125641.667	90	1396.019		
Total	125695072.975	135			

(b) Fiber Diameter

In *Populus nigra*, the mean fiber diameter varied significantly among the sites. In site I (Khrew) the mean fiber diameter varied from 18.51 µm in disc V to 22.45 µm in disc II. In site I, the highest values are found in disc II followed by disc I, disc III, disc IV and disc V respectively.

In site II, (Surasyar) the mean fiber diameter varied from 18.88 µm disc IV to 21.37 µm disc I. In these discs, the highest values for fiber diameter were found in disc I with followed by disc II, disc III, disc IV and disc V respectively.

In site III (Shopian), the average fiber diameter ranged from 18.64 µm in disc V to 21.51 µm in disc II, having highest values in disc II, followed by disc I, disc III, disc IV and disc V respectively (Table 3a). The interaction of site, disc and location i.e. site * disc, site * location, disc * location and site * disc * location does not show any statistical significance (Table 3b).

Table 3a. Fiber diameter in µm at different sites and locations of *Populus nigra*

Position	Location	Site I	Site II	Site III
Disc I	Inner	20.60	20.40	19.75
	Middle	21.23	20.86	20.65
	Outer	21.91	21.37	21.01
Disc II	Inner	20.85	20.37	20.30
	Middle	21.77	20.54	21.03
	Outer	22.45	20.99	21.51
Disc III	Inner	19.93	19.89	19.53
	Middle	20.49	20.03	20.16
	Outer	20.80	20.82	20.84
Disc IV	Inner	18.97	18.88	19.09
	Middle	20.05	19.67	19.76
	Outer	20.28	19.99	20.18
Disc V	Inner	18.51	18.97	18.64
	Middle	19.20	19.59	19.05
	Outer	20.20	19.84	19.44

Table 3b. ANOVA for fiber diameter of *Populus nigra*

Source	Sum of Squares	df	Mean Square	F	Sig.
Model	55359.855	45	1230.219	2380.032	.000
Site	4.417	2	2.208	4.272	.017
Disc	64.827	4	16.207	31.354	.000
Location	28.807	2	14.403	27.865	.000
Site * Disc	4.954	8	.619	1.198	.309
Site * Location	.858	4	.215	.415	.797
Disc * Location	.437	8	.055	.106	.999
Site * Disc * Location	1.558	16	.097	.188	1.000
Error	46.520	90	.517		
Total	55406.375	135			

(c) Fiber Wall Thickness

The fiber wall thickness in *Populus nigra* varied significantly among the sites. The average fiber wall thickness ranged from 3.47 µm in site II (Surasyar) to 5.05 µm in site III (Shopian). In site I, the fiber wall thickness varied from 3.63 µm in disc V to 4.13 µm in disc I. The highest values of fiber wall thickness within the site I were found in disc II, followed by discs I disc III disc IV and disc V respectively.

In site II (Surasyar), the fiber wall thickness varied from 3.47 µm in disc V to 3.87 µm in disc II. The highest values of fiber wall thickness within the site were found in disc II, followed by discs I, disc III, disc IV and disc V respectively

In site III (Shopian), the mean fiber wall thickness varied from 4.07 µm in disc V to 5.05 µm in disc II. The highest values of fiber wall thickness within the site were found in disc II, followed by discs III, disc I, disc IV and disc V respectively (Table 4a). Besides these, the interaction of site, disc and location i.e. site * disc, site * location, disc * location and site * disc * location does not show any statistical significance (Table 4b).

Hence statistically there is no effect of these interactions on the dimensions of fiber wall thickness.

Table 4a. Fiber wall thickness in µm at different sites and locations of *Populus nigra*

Position	Location	Site I	Site II	Site III
Disc I	Inner	3.92	3.58	4.23
	Middle	4.01	3.71	4.38
	Outer	4.13	3.78	4.69
Disc II	Inner	4.11	3.69	4.69
	Middle	4.01	3.78	4.84
	Outer	4.09	3.87	5.05
Disc III	Inner	3.88	3.61	4.23
	Middle	3.90	3.67	4.54
	Outer	3.98	3.82	4.77
Disc IV	Inner	3.76	3.52	4.16
	Middle	3.76	3.60	4.38
	Outer	3.84	3.71	4.58
Disc V	Inner	3.63	3.47	4.07
	Middle	3.78	3.56	4.24
	Outer	3.79	3.69	4.45

Table 4b. ANOVA for fiber wall thickness of *Populus nigra*

Source	Sum of Squares	df	Mean Square	F	Sig.
Model	2203.525	45	48.967	1392.169	.000
Site	15.895	2	7.947	225.949	.000
Disc	2.294	4	.573	16.304	.000
Location	1.358	2	.679	19.304	.000
Site * Disc	.576	8	.072	2.048	.049
Site * Location	.421	4	.105	2.992	.023
Disc * Location	.044	8	.006	.157	.996
Site * Disc * Location	.077	16	.005	.136	1.000
Error	3.166	90	.035		
Total	2206.690	135			

Derived Wood Properties of *Populus nigra* Linn.

(a) Runkel Ratio

In *Populus nigra*, the Runkel ratio varied significantly among the sites from 0.54 in site II to 0.89 in site III (Table 5a). In site I (Khrew), it varied from 0.58 in disc II to 0.65 in disc IV, having the maximum values in disc V followed by disc IV, disc III, disc I and disc II respectively (Table 5).

Table 5. Derived wood properties of *Populus nigra*

Populus nigra		Runkel ratio			Luce's shape factor			Slenderness ratio		
Position	**Location**	**Site I**	**Site II**	**Site III**	**Site I**	**Site II**	**Site III**	**Site I**	**Site II**	**Site III**
Disc I	Inner	0.62	0.54	0.77	0.45	0.41	0.51	41.55	49.43	51.14
	Middle	0.61	0.55	0.75	0.44	0.41	0.50	41.30	48.87	50.11
	Outer	0.61	0.55	0.83	0.44	0.41	0.53	40.83	48.60	49.72
Disc II	Inner	0.65	0.57	0.86	0.46	0.42	0.55	41.71	49.00	50.87
	Middle	0.59	0.58	0.86	0.43	0.43	0.55	41.72	50.09	50.28
	Outer	0.58	0.58	0.89	0.43	0.43	0.56	41.14	50.61	50.00
Disc III	Inner	0.64	0.57	0.77	0.46	0.42	0.51	42.05	49.17	51.87
	Middle	0.62	0.58	0.82	0.45	0.43	0.54	42.81	49.10	51.75
	Outer	0.62	0.58	0.84	0.45	0.43	0.55	42.69	47.47	50.30
Disc IV	Inner	0.66	0.60	0.77	0.47	0.44	0.52	43.77	51.13	52.59
	Middle	0.60	0.58	0.80	0.44	0.43	0.53	42.43	49.57	51.26
	Outer	0.61	0.59	0.83	0.44	0.43	0.54	42.53	49.53	51.15
Disc V	Inner	0.65	0.58	0.78	0.46	0.43	0.52	43.96	50.23	53.34
	Middle	0.65	0.57	0.80	0.46	0.42	0.53	43.34	49.17	53.01
	Outer	0.61	0.59	0.85	0.44	0.43	0.55	41.44	48.71	52.49

In site II (Surasyar), Runkel ratio varied from 0.54 in disc I to 0.60 in disc IV, having the maximum values in disc IV followed by disc V, disc III, disc II and disc I respectively (Table 5).

In site III (Shopian), Runkel ratio varied from 0.77 in disc IV to 0.89 in disc II, having the maximum values in disc II followed by disc III, disc V, disc IV and disc I respectively (Table 5). In all the discs, among the sites three locations i.e., inner, middle and outer are statistically significant with one another within the disc. The interaction of site, disc, location i.e., site * disc, disc * location, site * location and site * disc * location does not show any statistical significance (Table 5a).

Table 5a. ANOVA for Runkel ratio of *Populus nigra*

Source	DF	SS	MS	F	P
Site	2	1.45554	0.72777	186.86	0.000
Disc	4	0.02046	0.00511	1.31	0.269
Location	2	0.00441	0.00220	0.57	0.569
Error	126	0.49074	0.00389		
Total	134	1.97115			

(b) Luce's Shape Factor

In *Populus nigra*, the Luce's shape factor varied significantly among the sites from 0.41 in site II to 0.56 in site III (Table 5b). In site I (Khrew), it varied from 0.43 in disc II to 0.47 in disc IV, having the maximum values in disc V followed by disc III ,disc IV, disc I and disc II respectively (Table 5).

In site II (Surasyar), Luce's shape factor varied from 0.41 in disc I to 0.44 in disc IV, having the maximum values in disc IV followed by disc V, disc III, disc II and disc I respectively (Table 5).

In site III (Shopian), Luce's shape factor varied from 0.51 in disc I to 0.56 in disc II, having the maximum values in disc II followed by disc V, disc III , disc IV and disc I respectively (Table 5). In all the discs, among the sites, three locations i.e. inner, middle and outer are statistically significant with one another within the disc. The interaction of site, disc, location i.e. site * disc, disc * location, site * location and site * disc * location does not show any statistical significance (Table 5b).

Table 5b. ANOVA for Luce's shape factor of *Populus nigra*

Source	DF	SS	MS	F	P
Site	2	0.287162	0.143581	191.89	0.000
Disc	4	0.004918	0.001230	1.64	0.167
Location	2	0.000556	0.000278	0.37	0.691
Error	126	0.094277	0.000748		
Total	134	0.386913			

(c) Slenderness Ratio

In *Populus nigra,* the Slenderness ratio varied significantly among the sites from 41.14 in site I to 53.34 in site III (Table 5c). In site I (Khrew), it varied from 41.14 in disc II to 43.96 in disc V, having the maximum values in disc V followed by disc IV, disc III, disc II and disc I respectively

(Table 5).

In site II (Surasyar), Slenderness ratio varied from 47.47 in disc III to 51.13 in disc IV, having the maximum values in disc IV followed by disc II, disc V, disc I and disc III respectively.

In site III (Shopian), Slenderness ratio, varied from 50.28 in disc II to 53.34 in disc V, having the maximum values in disc V with 53.34 followed by disc IV, disc III, disc II and disc I respectively (Table 5). The interaction of site, disc, location i.e. site * disc, disc * location site * location and site * disc * location does not show any statistical significance (Table 5c).

Table 5c. ANOVA for Slenderness ratio of *Populus nigra*

Source	DF	SS	MS	F	P
Site	2	2069.62	1034.81	165.73	0.000
Disc	4	46.78	11.70	1.87	0.119
Location	2	21.30	10.65	1.71	0.186
Error	126	786.74	6.24		
Total	134	2924.44			

DISCUSSION

Fiber Morphology

Fiber length varied significantly among the sites in presently studied species of *Populus nigra* (812.46 µm to1075.33 µm), Previous reports on the variation of fiber length among sites were reported by Murphy *et al.* (1979); Phelps *et al.* (1982); Chauhan *et al.* (1999, 2001); Jorge *et al.* (2000); Rao *et al.* (2002); Yanez-Espinosa *et al.* (2004); Monteoliva *et al.* (2005) and Pande and Singh (2005). Thus the present results are in agreement with the said authors. Cheng and Bensend (1979); Einspahar *et al.* (1963) and Peszlen (1994) reported that fiber length is under genetic control. On the contrary in present study, the pattern of fiber length and the dimensions of anatomical characters varied with site for the same clone, which is indicative of overshadowing of genetic control by environmental factors on fiber dimensions.

Cell size and relating dimensions of fibers have a major influence on the quality of paper and pulp products as well as solid products Clark (1962); Monteoliva *et al.* (2005). For pulp and paper production, species with higher lengths are preferred since a better fiber net is achieved, resulting in higher resistance of the paper. The existence of significant variation between sites for the fiber morphological traits indicates good opportunities for exploitation of these sites and superior trees among them for specific end uses.

Fiber morphological parameters, such as fiber length, diameter, and wall thickness were found to be significantly influenced by their radial positions within tree. Fibers in the pith region were shorter, thin walled and less wide in diameter as compared to those at periphery, there being a gradual increase radially from centre.

Most reports on radial pattern of variation in hardwoods dealing with fiber dimensions agrees that fibers near the centre of the tree are shorter, thin walled and narrow in diameter as compared to periphery fibers. To quote some authors in favour are Hejnowicz and Hejnowicz (1959); Carvalho (1962); Denne (1971); Bhat and Karkkanian (1981); Furukawa *et al.* (1983); Tomazello Filho (1987); Stringer and Olson (1987); Sennerby-Forse (1989); Bhat *et al.* (1990); Peszlen (1994); Kauba *et al.* (1998); Adamopoulos and Voulgaridis (2002) and Marsoem *et al.* (2002).

The increase of fiber length from pith to periphery could be explained on the basis of the increase in length of cambial initials with increasing cambial age from pith to periphery (Ghouse and Siddiqui, 1976; Jorge *et al.*, 2000).

There is increase in fiber dimensions upto certain height and thereafter decrease in it. Same pattern was also observed by Bisset and Dadswell (1949); Carvalho (1962); Sardinha and Huges (1978); Wilkes (1998); Bhat *et al.* (1990); Jorge (1994); and Jorge *et al.* (2000) in hardwood species. The decrease of wood fiber dimensions towards the top was also described by Stringer and Olson (1987) for *Robinia pseudoacacia* L., Ridoutt and Sands (1993) for *Eucalyptus globulus* Labill. and Chauhan *et al.* (2001) for *Populus deltoides* Bartram. ex Marsh. This increase in fiber dimensions from base up to certain height and there after decreasing upto top of tree in vertical direction is due to differential proportion of juvenile wood in trees (Zobel and Talbert, 1984).

Derived Wood Properties (Ratios and Factors)

Different types of ratios such as Runkel ratio, Luce's shape factor and Slenderness ratio were determined from the respective basic data related to fiber morphology. These ratios are important particularly for determining the suitability of a particular material for pulping and paper making.

Runkel ratio is obtained by dividing double wall thickness by fiber lumen diameter. The approximate limits of Runkel ratio appears to be from 0.25 to 1.5 (Singh *et al.*, 1991) for a species. Dadswell and Wardrop (1959) suggested Runkel ratio to be less than 1 which can produce pulp of reasonable quality, while Ona *et al.* (2001) suggested that Runkel ratio is significantly related to pulp yield. The values obtained in this investigation shows significant variation between sites for Runkel. The value of Runkel ratio is less than one; hence the result from this study suggests suitability of the sites for reasonable quality of pulp with good conformability and fiber to fiber contact in paper in *Populus nigra* (with site II surasyar having best preferences followed by site I Khrew and site III Shopian)

Slenderness ratio (fiber length/fiber diameter) showed significant differences among the sites in *Populus nigra*. Higher the ratios, greater will be the expected fiber flexibility that will give better tensile and tear property to the paper. In present study the highest values of slenderness values are present in site III (Shopian) followed by site

II (Surasyar) and site I (Khrew). Hence among the sites, site III (Shopian) with highest values of Slenderness ratio, its wood is suitable for paper having higher flexibility, hence better tensile and tear property, followed by site II and site I respectively

Luce's shape factor an important derived wood property is obtained by equation (fiber diameter^2- fiber lumen diameter^2)/(fiber diameter^2 + fiber lumen diameter^2) (Oshima *et al.*, 2005) and is directly related to the paper sheet density (Ona *et al.*, 2001). In the present study the highest values of Luce's shape factor are found in site III (Shopian) followed by site I (Khrew) and site II (Surasyar). Hence among the sites; site III (Shopian) with highest values of Luce's shape factor, possess the highest values of paper sheet density by, followed by site I and site II respectively.

CONCLUSIONS

In the present study fiber length varied significantly among the sites, which is indicative of overshadowing of genetic control by environmental factors on fiber dimensions. The existences of significant variation among sites for the fiber morphological traits indicate good opportunities for exploitation of these sites and superior trees among them for specific end uses. For pulp and paper production, species with higher lengths are preferred since a better fiber net is achieved, resulting in higher resistance of the paper. Also the derived properties of wood like Runkel ratio, Slenderness ratio and Luce's shapes factor varied among the sites as these ratios are important particularly for determining the suitability of a particular material for pulping and paper making.

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