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Variation in wood anatomical properties and specific gravity in relation to sexual dimorphism in *Populus deltoides* Bartr. ex Marsh

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This study deals with intra- and inter-ramet, and inter-clonal variation in dimensions of wood elements and specific gravity of 6-year-old *Populus deltoides* based on sexual dimorphism of a female clone (G48) and male clone (G3). The origin of both the clones is USA. The trial used uniform spacing (5 m × 5 m). Variance ratio (*F*) test revealed that both clones differ significantly in fibre length and diameter, wall thickness, vessel element length and diameter, and specific gravity. The G48 clone showed higher fibre and vessel element dimensions but lower specific gravity than G3 clone, suggesting better fibre dimensions for G48 and specific gravity for G3. It showed female dominance on wood anatomical properties. Fibre length and specific gravity increased with height. Dimensions of wood element and specific gravity also increased from pith to periphery. Non-significant intra-ramet variations for both the clones indicated that homogeneous wood properties could be achieved from the single bole. Intra-clonal variations in G48 revealed non-significant differences, suggesting stable wood properties in the clone.

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DIFFERENT forestry programmes have used *Populus deltoides* Bartr. ex Marsh. extensively as clonal plantations to ensure its genetic superiority, better growth and wood quality. Most of them were propagated through shoot-cuttings. The wood is used in plywood, wood composite and paper industry.

Tree performance assessment usually used two important parameters: wood quality (structure and dimensions of wood elements) and growth. Wood specific gravity and dimensions of fibre are reliable indicators of wood quality[1]. Variation in the dimension of wood elements for different species was studied in India for *Eucalyptus tereticornis*[2–4]. Similar studies were also carried out on *Pinus roxburghii*[1], *Dalbergia sissoo*[4], *Pinus caribaea*[5] and *Populus deltoides*[6]. *P. deltoides* is a dioecious tree species. Some studies reported variation in wood quality parameters in *Populus* clones elsewhere[7–9]. The variability patterns in wood traits in the natural population and clonal plantation of *P. deltoides* in relation to sex however remain unknown. Hybridization is one of the important aspects in tree improvement programmes for gaining superior wood traits. The present communication deals with two aspects, viz. (1) the intra-ramet, intra- and inter-clonal variation in selected wood anatomical properties and specific gravity having technological applications, and (2) the influence of sex on wood traits (female and male clones). Consequently, this study aimed to determine the intra-, inter-ramet and inter-clonal variations in dimensions of wood elements and specific gravity for female (G48) and male (G3) clones of *P. deltoides*. The study also attempted to compare female and male clones based on wood traits.

The study site located in Rampur District, Uttar Pradesh, India lies between lat. 28°N and long. 78°E. The experimental trial was conducted at the foothills of Uttarakhand, at an altitude of 200 m amsl, which shares a border with Rudrapur District, Uttarakhand. The area receives annual rainfall of about 1200 mm, mean maximum summer temperature (April–June) of 36.7°C and mean minimum temperature (December–February) of 7.5°C (2005–06). The topography is almost flat, with loam soil (sand 61.4%, silt 14.1% and clay 14.1%). The following criteria were used for the selection of these clones: (i) they are diploid and (ii) both the clones are original and their origin is USA.

The material was collected from plantations of the G48 (female) and G3 (male) clones of *P. deltoids* of harvesting age (6 years), raised by WIMCO Plantations Ltd, Rudrapur. Plantation of the selected clones was propagated by macro-propagation and was planted under similar climatic and soil conditions. The plantation was raised in randomized block design. The spacing was 5 m × 5 m. The layout was four-way factorial design.

Table 1. Multivariate analysis (MSS) for the G48, G3 and G48 and G3 clones

Wood traits/ treatment	Fibre length	Fibre diameter	Wall thickness	Vessel element length	Vessel element diameter	Specific gravity
G48						
Replication	16,506.3	51.12	0.17*	3,513.45	202.02	6.16E-03
Height	22,134.6	49.88	4.04E-02	21,465.3*	186.25	0.0299*
Direction	58,366.9	43.62	1.98E-03	2,739.12	64.08	7.73E-04
Location	187,245.6*	37.01	5.01E-02	38,449.4*	304.5*	0.0561*
Height * direction * location	22,812.5	44.58	3.37E-02	2,144.01	37.43	1.35E-03
Direction * location	4,163.31	39.37	9.41E-03	60.91	31.65	5.17E-04
Error	23,969.3	46.38	2.97E-02	2,122.31	55.77	1.79E-03
G3						
Replication	238,056.7*	28.89*	4.5	15,315.6*	702.8*	0.007178*
Height	27,301.8	1.9	5.8	4,905.8	236.97	0.01494*
Direction	6,631	0.11	6.79	795.89	72.33	4.83E-05
Location	53,196.86*	0.58	5.78	3,865.81	150.52	0.006594*
Height * direction * location	5,346.34	0.95	4.84	1,912.14	27.9	4.30E-04
Direction * location	5,389.9	0.59	5.32	733.89	34.19	2.15E-03
Error	7,256.61	0.95	5.15	1,263.95	89.82	1.02E-03
G48 and G3						
Clone	1,540,942.3*	654.6*	52.29*	1,05,868.2*	2360.2*	0.02188*
Replication	189,891	31.34	1.47	9,032.7	823.7*	1.37E-03
Height	29,792.1	18.84	2.8	5,953.11	358.7*	0.0419*
Direction	48,722.8	19.89	3.51	2,551.63	58.63	3.47E-04
Location	215,576.3*	21.81	2.74	33,333.6*	398.4*	0.04369*
Error	15,465.4	23.63	2.58	2,138.25	61.7	1.57E-03

*$P \leq 0.001$.

Three ramets each of G48 and G3 clones were selected during April 2009. Collection time of the wood samples was during the harvesting of the plantation. Ten centimetre wooden discs were collected at the base and three different heights at 2.5 m intervals, to cover vertical variations. From each disc, sampling was also made in three directions, i.e. north, southeast and southwest to cover radial variations. Each peripheral direction was further divided into three radial pith to periphery positions.

A total of 216 samples (2 clones × 3 ramets × 4 discs × 9 samples) were collected to analyse wood density by gravimetric method, using single-pan balance. After soaking the samples in water, the green volume was measured by water displacement. The samples were oven-dried at 103 ± 2°C to constant weight and the weights were recorded[2]. Wood density of the sample was calculated as oven dried weight over volume of saturated wood sample. Specific gravity was determined as a ratio of sample wood density over water density.

Small radial chips from each sample were macerated to determine vessel element length, diameter, fibre length and diameter, and wall thickness using Schultz's method. Five grams of wooden chips was taken in a test tube and 15 ml of 50% nitric acid and 2 g potassium chlorate were added to the test tube. The test tubes were kept under sunlight for two to four days until the chips turned milky white. Then the chips were washed two to three times with water and a few drops of saffranin were added. The macerated chips were mixed and spread over a glass slide. Twenty-five observations of fibre length, outer diameter, lumen diameter, vessel element length and diameter for each of the radial positions were taken under a compound microscope[10].

The data were statistically analysed using SPSS 10. Multivariate analysis was carried out to test the intra-ramet vertical and horizontal, intra- and inter-clonal variations, because more than one variable needs to be analysed. The independent variables were clone, replicate ramets, ramet height (discs at different heights), direction and location, whereas the dependent variables were fibre length, diameter, wall thickness, vessel element length, diameter and specific gravity. The null hypothesis is that variations in fibre length, fibre diameter, wall thickness, vessel element length, diameter and specific gravity do not differ significantly due to clones, replication, height, direction and radial locations. The data were analysed in two sets; one, data of the G48 and G3 clones were analysed to observe intra- and inter-ramet variations in each clone separately and secondly, data of both the clones were analysed combined to observe variations between the clones. The level of significance to select or reject the hypothesis was $P \leq 0.001$.

Variance ratio (F) test indicated that intra-ramet vertical variation was significant for vessel element length whereas radial variations were significant for dimension of vessel element and specific gravity for the G48 clone, whereas vertical variations were significant for specific gravity and radial variations for fibre length and specific gravity for the G3 clone. The directional variations and interaction effects among variables (i.e. height, direction and location) were non-significant for all wood traits for both the clones ($P \leq 0.001$; Table 1). Bottom-to-top and pith outward trends of different wood traits showed an increase for both the vertical and radial variations studied (Tables 2 and 3). Yang and Zuo[11] and Gautam[12] also observed an increasing pattern in fibre length and width from the base to the top for seven poplar clones and the L-34 clone of *P. deltoides* respectively. On the contrary, fibre length showed a constant decrease from the base upwards in *Populus japanogigas*[13].

Non-significant intra-ramet vertical and radial variations and their interaction effects (height, direction and location) in most of the wood traits indicated that homogeneous wood properties could be achieved throughout the bole from both of clones due to the mature wood properties even at the early phase of tree growth (Table 1). Non-significant intra-ramet variations in clone-raised trees may be related to early maturity of the cambium because of the carrying over of physiological age in the clones. It causes lesser of juvenile wood formation resulting in non-significant intra-ramet variations in wood traits. Intra-ramet vertical variations in all the wood traits in micro-propagated ramet of L34 *P. deltoides* clone were observed[12]. Previous studies on wood element dimensions in the clonal ramets of *D. sissoo* and *E. tereticornis* found non-significant variations from the pith outwards, suggesting no impact of cambial age[4,14]. Veenin *et al.*[15] also reported non-significant radial variation in fibre length, vessel element diameter and vessel density in *E. camaldulensis* clones, and concluded less impact of juvenile wood on the wood properties. In contrast, Purkayastha *et al.*[2] reported variations in fibre length from pith to periphery in woods of 8–10-year-old seed-raised *E. tereticornis* plantations at different localities. Fibre-length was found to vary significantly from the base to the top with no definite trend in *E. tereticornis*[16]. Similarly, significant variation in fibre length from the pith to periphery was reported in *E. globulus*[17]. Radial variation in seed-raised progeny of different *Eucalyptus* species has also been reported in some[18–20].

Table 2. Vertical variation in wood element dimensions (μm) and specific gravity

Dependent variable	Height	Mean ± standard error
Fibre length	D1	1153.07 ± 16.92
	D2	1162.98 ± 16.92
	D3	1132.93 ± 16.92
	D4	1189.43 ± 16.92
Fibre diameter	D1	25.22 ± 0.66
	D2	24.46 ± 0.66
	D3	25.63 ± 0.66
	D4	24.43 ± 0.66
Wall thickness	D1	3.44 ± 0.22
	D2	3.52 ± 0.22
	D3	3.92 ± 0.22
	D4	3.46 ± 0.22
Vessel element length	D1	553.22 ± 6.29
	D2	576.37 ± 6.29
	D3	568.63 ± 6.29
	D4	574.48 ± 6.29
Vessel element diameter	D1	106.30 ± 1.07
	D2	100.50 ± 1.07
	D3	101.33 ± 1.07
	D4	102.09 ± 1.07
Specific gravity	D1	0.37 ± 0.01
	D2	0.393 ± 0.01
	D3	0.414 ± 0.01
	D4	0.429 ± 0.01

Note: D1 is basal disc and D2–D4 are the discs taken at three consecutive heights of 2.5 m interval.

The G48 clone showed significant intra-ramet radial differences for vessel element length and diameter. However, both clones revealed differential pattern of variation in vessel element dimensions. Similarly, significant intra-ramet radial variation in the vessel element length in micro-propagated L-34 *P. deltoides* clone was also reported[12]. The variation between micro- and macro-propagated plantation wood was also significant for vessel element length in *P. deltoides* clones[21]. Non-significant radial variations in vessel element dimensions were also reported in the clonal ramets of *D. sissoo* and *E. tereticornis*[4,14]. It indicated that the pattern of variation in vessel element dimensions was different in different clones of *P. deltoides*.

In this study, the average specific gravity showed significant radial variation. These variations may be related to age. Some studies reported radial variation in specific gravity[6,12,22]. For radial variation in wood quality parameters of *Populus* spp., some studies found differential patterns in variation[3,6–8,22]. Gautam[12] found a continuous increase in specific gravity from the pith outwards, for L-34 clone of *P. deltoides*. The increase followed a definite trend. Another study also reported that wood specific gravity of *Populus tremuloides* was high around the tree core and towards the cambium[23]. These results were similar to the findings of the present study, where specific gravity significantly varied from the pith outwards. The vertical and radial variations in specific gravity are related to differential heart/sap wood ratio from the pith outwards and from the base to the top.

Purkayastha *et al.*[24] reported non-significant variations in wood structure and specific gravity within a single tree of *Michelia champaca*. Likewise, in the clonal ramets of *D. sissoo* and *E. tereticornis*, certain studies also reported non-significant radial variations in specific gravity[4,14]. However, the present study showed significant radial variation for specific gravity, which contradicts the

Table 3. Radial variation in wood element's dimensions (μm) and specific gravity

Wood traits	Location	Mean ± standard error	95% Confidence interval	
			Lower bound	Upper bound
Fibre length	Pith	1102.75 ± 14.66	1073.85	1131.65
	Middle	1164.15 ± 14.66	1135.26	1193.05
	Outer	1211.90 ± 14.66	1183.01	1240.80
Fibre diameter	Pith	25.57 ± 0.57	24.44	26.70
	Middle	24.65 ± 0.57	23.52	25.78
	Outer	24.58 ± 0.57	23.45	25.71
Wall thickness	Pith	3.45 ± 0.19	3.07	3.82
	Middle	3.81 ± 0.19	3.43	4.18
	Outer	3.50 ± 0.19	3.13	3.88
Vessel element length	Pith	548.14 ± 5.45	537.39	558.88
	Middle	565.47 ± 5.45	554.73	576.22
	Outer	590.92 ± 5.45	580.17	601.66
Vessel element diameter	Pith	100.43 ± 0.93	98.61	102.26
	Middle	102.15 ± 0.93	100.33	103.98
	Outer	105.08 ± 0.93	103.26	106.91
Specific gravity	Pith	0.38 ± 0.01	0.37	0.39
	Middle	0.40 ± 0.01	0.39	0.41
	Outer	0.43 ± 0.01	0.42	0.43

Table 4. Clone mean wood element dimensions (μm) and specific gravity of G48 and G3

Wood traits	Clone	Mean ± standard error
Fibre length	G3	1075.14 ± 11.97
	G48	1244.07 ± 11.97
Fibre diameter	G3	23.19 ± 0.47
	G48	26.68 ± 0.47
Wall thickness	G3	4.08 ± 0.16
	G48	3.09 ± 0.16
Vessel element length	G3	546.04 ± 4.45
	G48	590.32 ± 4.45
Vessel element diameter	G3	99.25 ± 0.76
	G48	105.86 ± 0.76
Specific gravity	G3	0.41 ± 0.004
	G48	0.39 ± 0.004

Note: Collection of wood samples was done in May 2009.

foregoing findings[4,14,24,25]. The significant and non-significant intra-ramet variations for specific gravity, at different pith to outwards locations indicated the possible influence of environmental factors on this trait.

Most studies discussed above found an increasing pith to periphery trend of fibre length and specific gravity, which is similar to the results found in this study. However, the results of this study on the vessel dimensions of the G3 and G48 clones contradict the previous findings that found non-significant variations[4,14,24,25].

On the basis of the above discussion, it is evident that seed-raised trees are highly influenced by the juvenile wood properties due to the activity of immature cambium, whereas clone-raised ramets showed mature wood properties even at the early phase of tree growth due to the carrying over of the physiological age.

Intra-clonal variations in the G48 and G3 clones showed different variation patterns. The G48 female clone showed significant variations in the fibre wall thickness, whereas for the G3 male, variations were significant for fibre length, diameter, vessel dimensions and specific gravity, which suggests that the female G48 clone is more stable than the G3 clone in wood traits. Consequently, homogeneous wood properties can be achieved from the population of the G48 clone. Differential pattern of inter-ramet variation of wood traits was also observed in L-34 clone of *P. deltoides*[12]. This indicates that wood trait variability within the population of the same clone may vary from clone to clone. Valentine[26], and Son and Chung[27] reported that specific gravity variation was high in *P. tremuloides* and *Populus* spp. Gohre[28] found similar results for *Populus* spp. Inter-tree variations in specific gravity were also reported in *Liriodendron tuilipfera*[29]. However, Bhat[20], found non-significant variation in specific gravity and fibre length for all four age groups of *Eucalyptus grandis* seed raised progenies; clones of *D. sissoo*[4] and *E. tereticornis*[14]. Wood traits have differential patterns of variation in different species, different clones and even different modes of cultivation of the same species/clone as shown in this study and in the previous reports.

The mean values of dimension of wood elements and specific gravity of both the clones are given in Table 4. The values (μm) for fibre length, diameter, fibre wall thickness, vessel element length and diameter (μm) were

1244.07, 26.68, 3.09, 590.32 and 105.86 respectively, for the G48 clone while they were 1075, 23.19, 4.08, 546.04 and 105.8 for G3 clone. The specific gravity values were 0.39 and 0.41 for the G48 and G3 clones respectively.

The results indicated that the G48 and G3 clones were significantly different in fibre length, diameter, wall thickness, vessel element length, diameter and specific gravity ($P \leq 0.001$). G48 clone showed significantly higher values for fibre length, fibre diameter, vessel element length and diameter than the G3 clone, whereas the latter showed higher specific gravity and fibre wall thickness than the former clone (Tables 2 and 3).

Earlier studies have also reported significant differences in average fibre length among different clones and species[3,6,7,22,30]. Genetics controlled the fibre length differences[13,23,31,32]. Similar results were also obtained for *D. sissoo*[4]. Clone-to-clone variations for vessel element, fibre dimensions and specific gravity were also reported for *Tectona grandis*[33], *D. sissoo*[4] and *E. tereticornis*[14]. Clone-to-clone variations in wood traits found in the present study are also in agreement with previous reports for *Populus* spp.[6,7], *E. tereticornis*[3,14] and *D. sissoo*[4,14]. The clone-to-clone variations in the present study due to sexual dimorphism in *P. deltoides* showed female dominance over male for wood anatomical traits.

Intra-ramet vertical and radial variations were significant for specific gravity for both the G48 and G3 clones, and fibre length for the G3 clone. This suggests that fibre properties are stable within the ramet of the G48 clone, whereas weight varied from bottom to top and pith to periphery in both the clones. Non-significant interaction effect of intra-ramet variations of all the wood traits indicated that homogeneous wood properties could be achieved from the entire bole of these clones due to less impact of juvenile wood. The inter-ramet (intra-clonal) non-significant variations in fibre length, diameter, vessel dimensions and specific gravity in the G48 female clone and significant variations for these traits for the G3 male clone, suggest that the female G48 clone is more stable than the male G3 clone in wood traits and provides homogeneous wood properties from the population. Significant inter-ramet variations in the G3 clone for most of the wood traits indicated that homogeneous wood properties could not be achieved from the population of this male clone.

The fibre length, fibre diameter, vessel element length and vessel element diameter were higher in G48 than the G3 clone, and vice versa for wall thickness and specific gravity. It showed the influence of sexual dimorphism on wood traits. This further suggests that the female clone has better dimensions of fibre than the male clone, and vice-versa for specific gravity. Hence, the female clone could be used to produce good characteristics of fibre, and the male clone is for good weight. The result of this study can be used to explore the different combinations in hybridization programmes for development of such a clone with good fibre properties and specific gravity.

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