Variability studies for needle and wood traits of different half sib progenies of *Pinus roxburghii* Sargent

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Abstract Genetic variability studies for needle and wood traits were carried out for the different half sib progenies of Chir pine, raised in 1985 at the main campus of University. There existed a significant variation for these traits among the different half sib progenies, viz., needle length (18.1–24.6 cm), needle thickness (0.53–0.71 mm), number of stomata per mm of a row (7.3–12.0), specific gravity of wood (0.36–0.46), tracheid length (1.51–1.85) and moisture content of wood (47.76–58.81). This variability was found under genetic control, as all these progenies are growing under same environment, and are of same age. Traits having high heritability and genetic gain like, needle thickness, wood specific gravity, tracheid length and others, indicate high genetic control. This variability can be exploited in tree improvement programs through selection and breeding approaches for development of advanced generations. Correlation studies for different traits at genotypic and phenotypic levels provided the basic knowledge of association to chalk out efficient breeding strategy for higher productivity through indirect selection.

Keywords *Pinus roxburghii* · Heritability · Tracheid length · Needle · Principal component analysis

Introduction

Pinus roxburghii Sargent, commonly known as ‘Chir pine; Chir; Chil’, a member of family Pinaceae (order Coniferales), is the most principal pine among the six indigenous pine species of India, commercially tapped for oleoresin, besides for diversity of purposes, viz., timber, fuel wood, charcoal formation, needles for fuel briquetting, cattle bedding and for manufacturing organic manure, etc. It is distributed in the monsoon belt of the outer Himalaya, from Arunachal Pradesh in India to north eastern parts of Pakistan at elevations varying from 450 to 2300 m asl, over a long strip of about 3200 km between latitudes 26°N to 36°N and longitudes 71°E to 93°E from Afghanistan in the West to Bhutan in the East. Its bark is dark red–brown, grows thick, deeply and longitudinally fissured, scaly; winter buds are brown, small, ovoid, and not resinous. Chir pine is distinguished from other pine species on the basis of its slender needle shaped leaves, flabellate-triangular in cross section and 3 needles per bundle. Chir pine reaches up to 55 m and over 100 cm diameter at breast height (Ghildiyal et al. 2010).

Chir pine has achieved its mile stone in being the most established pine amongst all the conifers in the western Himalayas (FSI 2013). Selection of superior genotypes and their mass multiplication is the need of the hour, for which evaluation of physiological and wood traits required (Singh et al. 2009). The pine resin productivity can be increased many folds as significant variation is being observed on the basis of its natural distribution under diverse environmental conditions. Himachal Pradesh is the most suitable region

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for Chir pine plantation and improvement. It is the need of hour to conserve and manage genetic resources of this species (Sharma et al. 2002).

Keeping in view of these aspects, genetic evaluation of needle and wood traits becomes necessary for the delineation of genotypes which have better wood quality and physiological aspects, and for the formulation of advanced breeding strategies. The best way to tell if a parent is of superior genetic quality is to compare the performance of the offspring against other's offspring by giving all the progenies the same environment to grow through progeny trials (Frampton 1996) and indirect selection (Gapare et al. 2009). For selection and advanced breeding to generate the best quality planting stock for plantation programmes, improve forest productivity to mitigate climate change and meet the demand of local people, the present study on this subject was carried out on a progeny trial of Chir pine, with the following objectives:

1. To study the variability among the needle and wood traits of Chir pine
2. To carry out heritability studies and other genetic parameters for the needle and wood traits
3. To work out association analysis and principal component analysis for different needle and wood traits.

Materials and methods

Details of progeny trial

The Chir pine progenies under study have been raised in the mid-hills of western Himalayas in 1983 in the Nauni campus of the Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, with the identification of plus trees from different parts of Himachal Pradesh, India (Table 1) by Dogra (1985).

The progeny trial is located at 1150 m altitude on the south-western aspect with latitude 30° 51' N and longitude 76° 11' E. Nauni falls under subtropical climate with moderate hot summers and cold winters. During winter, frost occurrence is common. Annual temperature ranges from 35 °C in May–June to just 2 °C in January. Average annual precipitation, chiefly in the form of rainfall, ranges from 1000 to 1300 mm, of which major share is received during July–September. During winter also, rains with lower intensities generally, occur under the influence of western disturbances. Soil has sandy loam texture with pH 6.5. Available nitrogen, phosphorus, potassium and calcium were 273.62, 35.08, 181.23 and 522.70 kg/ha, respectively in the soil.

Experimentation

Mature needles were collected from lower, middle and top branches of each tree. Thirty needles were taken from each section of the crown. The average length of these needles was measured with the help of simple scale and expressed in centimeters. With the help of Digital Vernier Calliper, the average thickness of thirty needles was measured in millimeters. For observation and counting of number of stomata per mm of row, around 15 needles from each tree were taken randomly, which were immediately preserved in 100 ml of FAA solution (Formalin, glacial acetic acid and 70 % ethyl alcohol in the ratio 5:5:90, respectively) (Johansen 1940) and standard procedure was followed.

Wood specific gravity was calculated as the ratio of weight of given volume of wood sample to the weight of equal volume of water. Moisture content was noted as the difference in fresh weight and oven dried samples. Wood shavings from each sample were taken separately and were macerated in a standard Jeffrey's solution (10 % nitric acid and 10 % chromic acid in water) for 48 h (Pandey et al. 1968). The macerated shavings were washed with distilled water, stained in 2 % safranin and teased with the help of a needle in 10 % glycerine. The measurements were taken with the help of an ocular micrometer standardized with the help of a stage micrometer. The average length of 25 tracheids was taken as mean tracheid length.

Statistical analysis

The general linear model (GLM) procedure of SPSS-16 was employed for analysis of variance (ANOVA). The following linear model was used for analysis of variance for different needle and wood trait:

$$y_{ij} = \mu + P_i + e_{ij}$$

where y_{ij} is needle and wood trait of j th replication of the i th progeny, μ is the overall mean, P_i the effect due to i th progeny ($i = 1..0.21$) and e_{ij} is the error (Singh et al. 2012).

Phenotypic (V_p) and Genotypic (V_g) and environmental variances were calculated as:

$$V_p = \frac{MSG}{r}; \quad V_g = \frac{MSG - MSE}{r}; \quad V_e = \frac{MSE}{r}$$

where, MSG, MSE and r are the mean squares of progenies, mean squares of error and number of replications, respectively (Singh and Chaudhary 1985). The phenotypic variance (V_p) is defined as being the total variance among phenotypes when grown in different environments of interest while as the genotypic variance (V_g) is the part of the phenotypic variance that is resultant from genotypic

Table 1 Origin of the 21 half sib progenies of Chir pine under study

S.no.	Progeny	Range	Forest division	District
1	Leda-10	Kamloh	Suket	Mandi
2	Kaldoo P8	Kamloh	Suket	Mandi
3	Kaldoo P3	Kamloh	Suket	Mandi
4	Kaldoo P9	Kamloh	Suket	Mandi
5	Leda-P8	Kamloh	Suket	Mandi
6	Kaldoo P1	Kamloh	Suket	Mandi
7	Leda-P5	Kamloh	Suket	Mandi
8	Kaldoo P5	Kamloh	Suket	Mandi
9	Chret Mansu P4	Palampur	Palampur	Kangra
10	Kopra-P5	Nurpur	Nurpur	Kangra
11	Rakni-P8	Jungi	Suket	Mandi
12	Banethi-PT-Black Base	Jamta	Nahan	Sirmour
13	Kaldoo P10	Kamloh	Suket	Mandi
14	Sandrohal-P5	Pangna	Suket	Mandi
15	Dibkon P3	Urla	Mandi	Mandi
16	Jubble-PT-Green Centre	Jubbal	Rohru	Shimla
17	Bagthan-PT-Black Centre	Sarahan	Rajgarh	Sirmour
18	Bagthan-PT-Black Top	Sarahan	Rajgarh	Sirmour
19	Dhami Shimla Yellow Top-PT	Dhami	Kunihar	Solan
20	Kuthar-PT-Black Centre	Kuthar	Kunihar	Solan
21	Jainagar Yellow Base-PT	Arki	Kunihar	Solan

variation among the phenotypes and the error variance (V_e) is part of the phenotypic variance due to environmental effects. Phenotypic (PCV) and genotypic (GCV) coefficients of variation were computed as Burton and DeVane (1953) to compare the variation among traits.

$$\text{PCV (\%)} = \sqrt{(V_p/\bar{x})} \times 100$$

$$\text{GCV (\%)} = \sqrt{(V_g/\bar{x})} \times 100$$

where, V_p and V_g are phenotypic and genotypic variances, respectively and ' $\bar{x}$ ' the population mean of the character. Broad sense heritability (H^2) was calculated as suggested by (Johnson et al. 1955; Singh and Chaudhary 1985).

$$H^2 = (V_g/V_p) \times 100$$

where, H^2 , V_p and V_g are broad sense heritability, phenotypic variance and genotypic variances, respectively. Johnson et al. (1955) was followed to estimate the genetic advance (GA) expected and GA as per cent of the mean (Genetic gain), assuming selection of the superior 5 % of the progenies, as:

$$\text{Genetic advance} = (V_g/V_p) \sqrt{V_p} \times K$$

$$\text{Genetic gain (\%)} = (\text{Genetic advance}/\bar{x}) \times 100$$

where, K is the selection differential at 5 % selection intensity = 2.06). Phenotypic (r_p) and genotypic (r_g) correlations were estimated to investigate the inter character

relationships among needle and wood traits, as per Varghese et al. (1976) as:

Phenotypic correlation coefficient between character x and y ,

$$r_{(xy)p} = V_p(xy) / \sqrt{V_x(p) \times V_y(p)}$$

Genotypic correlation coefficient between character x and y ,

$$r_{(xy)g} = V_g(xy) / \sqrt{V_x(g) \times V_y(g)}$$

where, $V_p(xy)$ and $V_g(xy)$ are the phenotypic and genotypic variance between x and y , respectively. The significance of correlation coefficients were tested against ' r ' values as given by Fisher and Yates (1963) at $(n-2)$ degree of freedom.

Principal component analysis or canonical (vector) analysis was carried out to study the amount of variation along different axis of differentiation (Rao 1952).

Results

Variability estimates

Significant variation was found for different needle characteristics (needle thickness, needle length and number of

stomata per mm of the row on needle) and wood traits (moisture content, wood specific gravity and tracheid length). The results are presented in Table 2, perusal of which shows that some other progenies were also found statistically at par with the maxima and minima.

The mean value of needle length was 20.78 cm. The highest value of 24.60 cm in Leda-10, while as the minimum (18.10 cm) was found in Kaldoo P8. Needle thickness varied from 0.53 mm in Chret Mansu P4 to 0.71 mm in Bagthan-PT-Black Centre. The data further revealed that the range of number of stomata/mm of a row within progenies ranged from 7.33 in Kaldoo P10 to 12 in Bagthan-PT-Black Top attained maximum value of 12.0 in Jainagar Yellow Base-PT.

However, for wood traits, the Table 2 revealed that progeny Dhami Shimla Yellow Top-PT recorded the maximum moisture content of 61.08 % in wood, while the minimum of 47.76 % was found in the progeny Kaldoo P3. Tracheid length ranged from 1.51 mm in the progeny Kuthar-PT-Black Centre to 1.85 mm in the progeny Kaldoo P5. The maximum wood specific gravity was observed in progeny Leda-P8 (0.46) and the minimum in progeny Kaldoo P8 (0.38).

Genetic analysis

Genetic parameters were analyzed for these needle and wood traits (Table 3). Highest coefficient of variation was observed for number of stomata/mm of row at both phenotypic (15.28 %) and genotypic (7.95 %) levels. These traits were found moderately to highly heritable. Wood specific gravity had maximum heritability (66.30 %) with a genetic gain of 7.09, while the minimum was observed for the moisture content (28.0 %) with genetic gain of 5.29 % moisture content of wood had maximum genetic advance (2.8), while needle thickness had maximum genetic gain (10.69 %).

Association analysis

Correlation studies at phenotypic and genotypic levels were carried out for these needle and wood traits, and oleoresin yield of the respective progenies, to reveal the association of one trait with the other for indirect selection and the results are hereby presented in Table 4. Phenotypic and genotypic correlation coefficients amongst these half sib progenies revealed that phenotypic

Table 2 Estimates of variability and genetic parameters for needle and wood traits of among different half sib progenies of Chir pine

Progeny	Needle length (cm)	Needle thickness (mm)	No. of stomata/mm	Moisture content (%)	Tracheid length (mm)	Wood specific gravity
1	24.60	0.70	9.33	51.84	1.75	0.38
2	18.10	0.60	8.67	48.21	1.72	0.36
3	24.37	0.69	9.00	47.76	1.76	0.40
4	18.27	0.56	11.00	52.66	1.73	0.42
5	19.30	0.64	9.00	58.37	1.56	0.46
6	20.93	0.58	9.00	58.63	1.74	0.40
7	23.17	0.65	10.00	54.34	1.71	0.41
8	20.43	0.67	10.67	52.43	1.85	0.38
9	19.40	0.53	10.00	57.31	1.75	0.41
10	21.10	0.63	10.00	52.94	1.64	0.43
11	23.27	0.65	7.67	50.30	1.63	0.43
12	18.60	0.56	9.67	57.57	1.55	0.42
13	19.87	0.56	7.33	56.31	1.65	0.40
14	20.10	0.57	9.67	55.17	1.72	0.41
15	19.00	0.60	10.67	55.11	1.61	0.43
16	23.97	0.69	10.00	58.20	1.61	0.43
17	22.57	0.71	10.33	51.71	1.74	0.41
18	21.13	0.61	9.33	50.78	1.72	0.41
19	20.20	0.60	10.00	61.08	1.81	0.40
20	20.62	0.55	10.33	55.66	1.51	0.44
21	21.23	0.59	12.00	54.03	1.60	0.42
Mean	20.78	0.61	9.71	54.31	1.68	0.41
CD _(0.05)	3.28	0.07	2.09	6.97	0.11	0.02

Table 3 Estimates of variability and genetic parameters for needle and wood traits of among different half sib progenies of Chir pine

Trait	Mean	Range	Std error	Coefficient of variation	Coefficient of variation		Heritability (H ² %)	Genetic advance	Genetic gain (%)
					Genotypic	Phenotypic			
Needle length (cm)	20.78	18.1–24.6	1.461	9.58	7.85	12.39	40.18	2.13	10.26
Needle thickness (mm)	0.61	0.53–0.71	0.035	7.77	7.48	10.79	48.06	0.07	10.69
No. of stomata/mm	9.71	7.3–12.0	0.855	13.05	7.95	15.28	27.03	0.83	8.51
Sp. gravity	0.41	0.36–0.46	0.012	3.01	4.23	5.19	66.30	0.03	7.09
Tracheid length (mm)	1.68	1.51–1.85	0.064	4.28	4.73	6.38	55.08	0.12	7.22
Moisture content (%)	54.42	47.76–58.81	2.742	7.63	4.81	9.03	28.01	2.8	5.29

Table 4 Association studies for needle and wood traits among different progenies of Chir pine

		Tracheid length	Wood specific gravity	Needle length	Needle thickness	No. of stomata along surface/mm of row	Total yield oleoresin
Moisture content	r _g	−0.498**	0.558**	−0.505**	−0.692**	0.317*	−0.756**
	r _p	−0.156	0.131	−0.158	−0.270*	0.028	−0.179
Tracheid length	r _g		−0.923**	0.274*	0.473**	0.093	0.240
	r _p		−0.645**	0.035	0.081	−0.054	−0.140
Wood specific gravity	r _g			−0.124	−0.212	0.260*	0.380**
	r _p			−0.089	−0.208	0.041	0.016
Needle length	r _g				0.893**	−0.187	0.961**
	r _p				0.640**	−0.081	0.604**
Needle thickness	r _g					0.006	0.797**
	r _p					−0.111	0.486**
No. of stomata/mm of row	r _g						−0.914**
	r _p						−0.018

* Significant at 5 % level of significance

** Significant at 1 % level of significance

correlation coefficients were lesser than their respective genotypic correlation coefficients amongst the same traits studied.

Highly significant correlation (at 1 % level of significance) at both genotypic and phenotypic levels was observed for tracheid length and wood specific gravity (−0.923 and −0.645, respectively), needle length and needle thickness (0.893 and 0.640, respectively), needle length and total oleoresin yield (0.961 and 0.604, respectively), and needle thickness and oleoresin yield (0.797 and 0.486, respectively).

However, highly significant correlation at genotypic level was observed for moisture content with tracheid length (−0.498), wood specific gravity (0.558), needle thickness (−0.692) and oleoresin yield (−0.756). Total

oleoresin yield was also found having highly significant correlation at genotypic level with wood specific gravity (0.380) and number of stomata/mm of row along the surface (−0.914). Same results were obtained for needle thickness and tracheid length (r_g = 0.473).

Principal component analysis

Principal component analysis (PCA) for needle and wood traits was carried out to reduce the data of correlated variables into a substantially smaller set of variables, through linear combination of variables that account for most of the variation present in the original variables. Table 5 shows factor pattern and summary of PCA for the needle characters and wood traits. It was observed that only

Table 5 Principal component analysis for needle and wood traits among different progenies of Chir pine

Traits	Principal components			Communalities
	I	II	III	
Moisture content	−0.675	−0.029	0.074	0.462
Tracheid length	0.709	−0.577	0.187	0.870
Wood specific gravity	−0.707	0.627	0.048	0.895
Needle length	0.647	0.644	0.056	0.836
Needle thickness	0.739	0.550	0.158	0.874
No. of stomata/mm	−0.209	−0.045	0.966	0.979
Eigen value (λ)	2.467	1.445	1.004	
Percentage of variance	41.121	24.090	16.734	
Cumulative percentage of variance	41.121	65.211	81.945	

three components had eigenvalue greater than one and such components were retained for further genetic analysis. These components explained 81.94 % variation.

For component I ($\lambda_1 = 2.467$) explaining 41.12 % variation, needle thickness was attached with maximum loading value (0.739), followed by tracheid length (0.709), wood specific gravity (−0.707), moisture content (−0.675) and needle length (0.647). Component II ($\lambda_2 = 1.445$) explained 24.09 % of variation with maximum loading value attached to needle length (0.644), followed by wood specific gravity (0.627). Component III ($\lambda_3 = 1.004$) explained 16.734 % of variation with maximum loading value attached to number of stomata/mm (0.966), followed by tracheid length (0.187).

Discussion

Variability estimates

Since all the half sib progenies were originally collected from all over the state of Himachal Pradesh over a variety of sites differing with regard to locality factors, but at present these are growing at one site in the same environmental conditions in the progeny trial, so the differences in the performance of all the progenies are due to genetic factors, as suggested by Han et al. (1987) in *Pinus koriansis*, Matziris (2000) in *Pinus halepensis*, Alia et al. (2001) in *Pinus sylvestris*, Rui et al. (2011) in *Pinus sibirica*, Boratynska et al. (2014) in *Pinus mugo*.

Variation in needle characteristics is also in congruence with Fowler and Morris (1977) in *Pinus resinosa*, Sagwal (1978) in *P. roxburghii*, Rajendra (2009) in *P. merkusii*, Nikolic et al. (2013) in *Picea omorika*, Nikolic et al. (2014) in *Pinus heldreichii*, Boratynska et al. (2014) in *P. mugo*, Nikolic et al. (2015) in *P. peuce* and Donnelly et al. (2016) in *P. sylvestris* and Huang et al. (2016) in *Pinus yunnanensi*.

Variation in wood traits, viz., specific gravity, moisture content and tracheid length has been reported at individual tree level, within individuals of a population and amongst sites/populations of a species. Variability in such traits has already been reported by Zhang and Morgenstern (1995) in *Picea mariana*, Gapare et al. (2012b) in *Pinus radiata*; Fries (2012) in *P. sylvestris*, Doran et al. (2012) in *Endospermum medullosum* and Lapointe et al. (2014) in *P. sylvestris*.

Further, to signify the importance of variability of needle and wood traits studied, positive association has been reported between oleoresin yield and needle length and thickness (Sharma et al. 2013), needle length (Mathauda 1956) their evaluation for the diverse half-sib progenies may prove fruitful through indirect selection of Chir pine.

Genetic analysis

Amongst the needle traits studied, the genetic analysis of needle thickness implies that moderate heritabilities along with high genetic gain can be considered for selection purposes in Chir pine improvement program, as suggested by Johnson et al. (1955).

It has been reported that specific gravity and tracheid length in conifers are under strong genetic control by Zobel (1961) in conifers; Zhang and Morgenstern (1995) in *P. mariana*, Atwood et al. (2002) in *P. teada*, Ericsson and Fries (2004) in *P. sylvestris*, Guller et al. (2012) in *Pinus brutia*, Gapare et al. (2012b) in *P. radiata*, Fries (2012) in *P. sylvestris*, Hong et al. (2014) in *P. sylvestris* and Chen et al. (2014) in *Picea abies*. Therefore such variation and a high estimated value of heritability, as revealed in our study, indicated that genetic improvement can be made by selection for specific gravity and tracheid length. Furthermore, Zobel and Jett (1995) and Hong et al. (2014) in *P. sylvestris* also advocated that wood specific gravity has higher heritability ($h^2 = 0.3–0.6$) in forest trees, indicating

that such traits can improve the selection process in trees efficiently (Isik et al. 2011).

It is pertinent to say here that the principal objective of estimation of genetic parameters is to predict the response to selection imposed on the progenies raised in the trial. Genetic gain estimates for different traits serves as a guideline for deciding the method and extent for selection to be applied in the progenies. Also, traits with higher heritability, followed by higher genetic gain reflect additive genetic variation, and are least affected by environment. Selection based on such inferences shall be helpful in generation of advanced seed orchard.

Association studies

Correlation is one of the most important biometrical tools for investigation of the magnitude and degree of association between various traits and aides indirect selection. For correlation studies, oleoresin yield of the progenies was also used for analysis. Highly significant correlation (at 1 % level of significance) at both genotypic and phenotypic levels was observed for tracheid length and wood specific gravity (−0.923 and −0.645, respectively), needle length and needle thickness (0.893 and 0.640, respectively), needle length and total oleoresin yield (0.961 and 0.604, respectively), and needle thickness and oleoresin yield (0.797 and 0.486, respectively). However, highly significant correlation at genotypic level was observed for moisture content with tracheid length (−0.498), wood specific gravity (0.558), needle thickness (−0.692) and oleoresin yield (−0.756). Total oleoresin yield was also found having highly significant correlation at genotypic level with wood specific gravity (0.380) and number of stomata/mm of row along the surface (−0.914). Same results were obtained for needle thickness and tracheid length ($r_g = 0.473$).

Many workers have already advocated such relationships, which include Lekha (2002), Nimkar (2002), Nimkar et al. (2007) in *P. roxburghii*, and Kumar et al. (2007) in *P. wallichiana* for needle length and oleoresin yield; Sharma et al. (2013) in *P. roxburghii* for needle length and needle diameter; Lekha and Sharma (2008) for needle thickness and oleoresin yield in *P. roxburghii*; and Matziris and Zobel (1973) in *P. taeda* for wood specific gravity and tracheid length.

This can be either due to pleiotropy or linkage effects at the genetic levels, as has been reported in Hardiyanto (1996), Woolaston et al. (1990), Rehfeldt et al. (1991) and Haapanen et al. (1997), Jayawickrama and Carson (2000), Kumar (2002), Wu et al. (2008). Further, the estimation of genotypic correlation for two traits either from linkage or pleiotropy or induced mutation or from developmentally induced relationship between components that are only

indirectly the consequence of gene action (Lone et al. 2013). The basic knowledge of association at genotypic and phenotypic levels helps the breeder to chalk out efficient breeding strategy for higher productivity.

Principal component analysis

Principal component analysis (PCA) is a multivariate statistical technique which helps to reduce the data of correlated variables into a substantially smaller set of variables, through linear combination of variables that account for most of the variation present in the original variables (Singh and Chaudhary 1985).

It was observed that three components had eigenvalue greater than one for needle and wood traits (Table 5), which explained 81.945 % variation. Only such components were retained for further genetic analysis, following Kaiser (1958).

Such studies have already been conducted by Pezzottii et al. (1994) in *Dactylis glomerata*, Tsitsoni et al. (1997) in *P. halepensis*, Tuncaner (2002), Kehl et al. (2008), Singh et al. (2012), Gupta (2005) in *Salix*, Singh (2006) in *Populus* sp., Banderas et al. (2009) in *Pinus leiophylla*, Gouvea et al. (2010) in rubber tree, Huang et al. (2016) in *P. yunnanensis*. They have also reported different components having eigenvector greater than one, and explaining the different percent of variance by each component for different traits evaluated.

Conclusions

The study revealed that there existed a good variability for different needle and wood traits, which can form a base for conversion of the progeny trial into a seed orchard. Traits having high heritability and genetic gain, like crown height, needle thickness, wood specific gravity, tracheid length and others, indicate high genetic control. This variability can be exploited in tree improvement programmes through selection and breeding approaches for development of advanced generations. Correlation studies for different traits at genotypic and phenotypic levels provided the basic knowledge of association to chalk out efficient breeding strategy for higher productivity through indirect selection.

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