Influence of altitude on seed and seedling characteristics in *Quercus leucotrichophora* A. Camus. ex. Bahadur

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Abstract

The present investigation was conducted to record variation of seed and seedling morphological characteristics and germination among eighteen provenances of *Quercus leucotrichophora*. These traits are important for improving the planting stock material in hand. Significant variations ($p < 0.05$) were recorded for different morphological parameters of seed and seedling among the different provenances. Seed weight was the most variable character among morphological characteristics. Shoot/root ratio and root growth were more variable characters among the seedling traits. Altitude had significant positive relationship with seed weight, seed length and germination per cent. Soil pH was positively correlated with seed weight and germination. These parameters could be used as important criteria for seed source selection. Broad-sense heritability (h^2) calculated for different seed and seedling traits showed a considerable portion of genetic variation suggesting the possibility of rapid genetic improvement of these traits. Furthermore, this variability appeared to be geographically structured and would be mainly genetically controlled. Thus the results of present study should be helpful for growing planting material of this potential tree species in afforestation of subtropical to temperate region of Garhwal Himalaya, India.

Key words: Seed origin, seed dimensions, genetic variability, heritability, *Quercus leucotrichophora* seedling, growth characteristics.

Introduction

Quercus leucotrichophora A. Camus. ex. Bahadur is a moderate-sized to large evergreen tree attaining a height of 12–18 m, belonging to family Fagaceae (GAUR, 1999). *Q. leucotrichophora* is the commonest oak of the western Himalaya, extending eastward to Nepal, within altitude range from 1000 to 2400 m asl (above sea level) but occasionally descending lower in moist situations (NEGI and NAITANI, 1995). In Garhwal Himalaya, there are a number of indigenous tree species used as fuelwood, fodder and small timber by local people. However, with substantial increase in human and bovine population coupled with decreasing forests, people of the region are facing acute scarcity of fuel, fodder and timber (SACHAN, 2007). *Q. leucotrichophora* is the commonest

oak of Central Himalaya, India, facing the anthropogenic pressure. Its regeneration is very poor partly due to over exploitation and partly due to damage of seed populations by insect (*Calandra sculpturata*) and Himalayan langoor (*Presbytis entellus*). Mast seed year in *Q. leucotrichophora* takes place in interval of every 2–3 years, which may be another reason for its poor regeneration. Establishment of plantations of this native multipurpose tree species is recommended as suitable conservation strategy. In this Himalayan region, lack of quality planting material could be improved by selecting more suitable provenance.

Despite its great importance, the efforts for the genetic improvement of *Q. leucotrichophora* are scanty. Populations of a species from different geographical locations (provenances) frequently show differential response due to genotype effect (MWASE et al., 2006; ANDERSON et al., 2008; SAIKIA et al., 2009; SINGH et al., 2010). Seed size and weight of several species varied among provenances (DHANAI et al. 2003; SINGH et al., 2006; ZHENG et al., 2009; GHILDIYAL et al., 2009), as well as germination (GINWAL et al., 1996; CHAUHAN et al., 1996; UNIYAL et al., 2002; SINGH et al., 2004) and growth and biomass performances (ISIK, 1986; HOLM, 1994; CHAUHAN et al., 1996; SINGH et al., 2006). Variation in seed and seedling growth between provenances have been observed in different tree species, but such information is lacking for *Q. leucotrichophora*. To mitigate the growing demand of this species, there is a need of selection of best provenance of *Q. leucotrichophora* so as to improve its productivity in agroforestry systems as well as in various afforestation programmes in Central Himalaya, India.

Material and Methods

Mature seeds of *Q. leucotrichophora* were collected from a wide altitudinal range within their natural distribution. The word seed/seeds refers to the true seed with the pericarp (true seed + pericarp = an acorn). For each site, seeds were collected from 10 randomly selected healthy and mature standing trees in the month of December. Each tree was 100 m apart from each other to avoid narrowing down the variation sampled due to relatedness (SCHMIDT, 2000). Seeds were collected from eighteen provenances of Garhwal hills and Himanchal Pradesh (H.P.) comprising the central parts of Himalaya, India. Geographical location of seed source ranged from 29°19'N to 30°57'N latitude and 78°3'E to 79°55'55"E longitude. The altitude of the entire range varied from 1015 to 2400 m asl. (Table 1, Figure 1). Soil

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Table 1. – Geographical origin of *Q. leucotrichophora* seed sampling locations and soil pH value.

Provenances	Districts	Altitude (m asl)	Latitude (N)	Longitude (E)	Rainfall (mm)	Soil pH
Dovsrikot	Pauri	1015	30° 10'	78° 47' 8"	965.0	5.84
Bankura	Pauri	1100	29° 55'	79° 2' 10"	996.0	5.86
Baijron	Pauri	1350	29° 55' 20"	79° 2' 50"	1065.9	5.82
Ranpunga	Chamoli	1400	30° 35'	79° 2' 55"	1620.3	5.80
Budashu	Pauri	1450	30° 11' 30"	78° 53'	989.0	5.82
Mandal	Chamoli	1600	30° 26'	79° 16'	1800.0	6.18
Solan	Solan	1650	30° 57'	79° 5'	1095.0	5.97
Bersuri	Pauri	1650	29° 55' 40"	79° 5' 55"	1268.5	5.89
Jamu	Rudraprayag	1700	30° 34' 35"	79° 2' 45"	1750.97	6.07
Kandoliya	Pauri	1700	30° 8'	78° 46' 30"	1066.0	5.92
Khirsu	Pauri	1800	30° 11'	78° 52'	1099.6	5.99
Randhar	Tehri	1830	30° 22' 45"	78° 55'	1497.23	6.08
Voranibeta	Chamoli	2000	30° 34' 10"	79° 2' 20"	1536.0	5.62
Damta	Uttarkashi	2020	30° 38'	78° 3'	1387.0	6.15
Gumkhal	Pauri	2025	29° 55'	78° 38'	1065.0	6.30
Kasturgamirgbihar	Chamoli	2150	30° 28'	79° 55' 55"	1800.0	6.24
Budna	Tehri	2300	30° 30' 15"	78° 55' 55"	1790.0	6.32
Chaurangikhal	Uttarkashi	2400	29° 19'	79° 38'	1769.0	6.19

pH was measured by Kelway Soil Tester directly in the field (Table 1).

From each provenance bulk seeds sample was collected and brought to the laboratory and allowed to dry in shade for 24 h. The sample collected from each provenance was then placed in a cotton bag, allotted an accession number (name of place), and stored in a cooling incubator for further experiments.

Seed Morphology

The moisture percentage of each seed sample was determined on a fresh weight basis by drying the seeds at $103 \pm 3^\circ\text{C}$ as per ISTA (1999) rules. Seed length and breadth (in the middle portion of the seed) were measured on five replicate samples, each consisting of 100 seeds randomly drawn from each seed lot using micrometer (Besto make). Seed weight (g/100 seed) was recorded by choosing eight random samples of each population, i.e., 100 seeds per seed lot (ISTA, 1999). Five samples (each of 100 seeds) were drawn from seed lot of each provenance and numbers of seeds damaged due to insect attack and healthy seeds were determined.

Seed germination and seedling growth traits

Eight replicates (of 100 seeds each) were used for germination. Petri dishes (12 cm diameter) were placed in the germinators pre fixed at 25°C constant temperature regimes. Distilled water (1 ml) was used daily to moisten Whatman filter paper in germinator. Radicle protrusion was used as the indicator of the germination. Germination per cent was the percent of the sown seeds germinated at the completion of test period, i.e., 28 days after sowing (ISTA, 1999). Germination value was also calculated according to CZABATOR (1962) as $\text{GV} = \text{PV} \times \text{MDG}$, where, GV=germination value; PV=the peak value of germination, and MDG=mean daily germination.

Germinating seeds of each population were transferred into polythene bags (1 kg volume) containing

sand, soil and farmyard manure in 1:2:1 ratio and placed in the experimental garden of Forestry Department, Srinagar, Uttarakhand, India (situated between $30^\circ 13' \text{N}$ latitude and $78^\circ 48' \text{E}$ longitude at an elevation of 530 m asl). The seedlings of each population (four replicates, 25 each) were randomly tagged and maintained in nursery for one year. At the end of one year's growth, a tagged seedlings were uprooted and assessed for their shoot length, root length, collar diameter and number of leaves/plant was counted. Root length was divided by the shoot length of the same seedling to

Figure 1. – Seed collection sites (Provenances) of *Quercus leucotrichophora*.

1. Dov Srikot; 2. Bankura; 3. Baijron; 4. Ranpunga; 5. Budashu; 6. Mandal; 7. Solan; 8. Bersuni; 9. Jamu; 10. Kandoliya; 11. Khirsu; 12. Randhar; 13. Voranibeta; 14. Damta; 15. Gumkhal; 16. Kasturgamirgbihar; 17. Budna; 18. Chaurangikhal.

determine the root/shoot length ratio. These 100 seedlings of each provenance were divided into root, shoot and leaves, and oven dried for a period of 48 h at $98 \pm 2^\circ\text{C}$ before determining their dry weight.

Statistical Analysis

The seed and seedling attributes were statistically analyzed by SPSS software package, version 10.0.1 (SPSS Inc., Chicago, USA) for analysis of variance, and correlation coefficients to record the effect of altitude on germination and growth performance of seedlings. Tukey-test (BARTZ, 1988) was used to estimate the variation of seed, seedling growth and germination parameters with provenance. Broad sense heritability and genetic gain were determined as suggested by JOHNSON et al. (1955).

Results

Morphological studies

Among provenances, seed length ranged from 1.98 (Bajiron) to 2.65 cm (Kasturgamrigbihar) and breadth extended from 12.28 (Solan) to 15.53 mm (Kandoliya). Similarly, seed weight ranged from 107.0 to 258.33 g/100 seed. On average, there was 1.33, 1.26 and 2.41-fold variation between highest and lowest values of seed length, breadth and weight, respectively, irrespective of provenances. Among various morphological characters, maximum variations were recorded in seed weight and minimum in seed breadth. The maximum (98.0%) healthy seed was affirmed in Bersuri and lowest (62.0%) in Budashu provenance. Similarly, maximum (38.0%) damaged seed was recorded in Budashu and minimum (2.0%) in Barsuri provenance.

Coefficient of variation (CV) showed that all the characters were not equally variable and it was highest

(63.48%) to damaged seeds and lowest (5.85%) variation was recorded in seed breadth (Table 2).

Germination

Used temperature accelerated optimal germination in almost all the populations, however, the germination per cent ranged from 77.0 (Ranpunga) to 100.0% (Mandal) among provenances. The germination value ranged from 0.77 to 1.83 among the provenances. Coefficient of variation for germination value and germination per cent was 28.40 and 6.28, respectively (Table 3).

Growth studies

Survival per cent of seedlings in nursery ranged from 78.5 (Dovsrikot) to 95.5 (Solan) in different provenances. Maximum (95.08%) plantable seedling was recorded in Budashu and minimum (62.15%) in Randhar provenance (Table 3).

Shoot length was the highest in Budashu (39.55 cm) and the lowest (31.81 cm) in Dovsrikot provenance. Likewise, root length was maximum (41.86 cm) in Bankura and minimum (15.43 cm) in Bersuri among various provenances. Root/shoot ratio was recorded maximum (1.14) in Bankura and minimum (0.47) in Solan provenance. Collar diameter of seedlings was recorded maximum (3.80 mm) in Bersuri provenance and minimum (2.76 mm) in Solan provenance. Maximum (12.44) number of leaves per plant was recorded in Kandoliya provenance. Among various components of seedlings, roots contributed the highest biomass followed by leaves and shoot, irrespective of provenances. On average, there were 4.62, 1.97 and 2.86-fold variations between minimum and maximum values of biomass partitioned by roots, shoot and leaves, respectively, irrespective of provenances. However, among various provenances, seedlings of Kandoliya exhibited the high-

Table 2. – Provenance variation in different seed characteristics in *Q. leucotrichophora*. Values in the same column with the same letter do not differ significant ($p < 0.05$).

Provenances	Altitude (m asl)	Length (cm)	Breadth (mm)	Weight (g/100acorn)	Healthy seeds %	Damaged seeds %
Dovsrikot	1015	2.01 ^{ij}	13.46 ^{efg}	107.00 ^a	73.0 ^{gh}	27.0 ^{bc}
Bankura	1100	2.06 ^{hij}	13.03 ^{hi}	125.00 ^{fgh}	80.0 ^{def}	20.0 ^{def}
Bajiron	1350	1.98 ⁱ	12.37 ^{kl}	122.66 ^{gh}	84.0 ^{cd}	16.0 ^{efg}
Ranpunga	1400	2.46 ^c	13.74 ^{cd}	159.33 ^{de}	85.0 ^{cd}	15.0 ^{fg}
Budashu	1450	2.00 ^{ij}	13.70 ^{defg}	131.33 ^{fgh}	62.0 ⁱ	38.0 ^a
Mandal	1600	2.09 ^{ghi}	14.12 ^{bc}	186.66 ^{bc}	97.0 ^a	3.00 ⁱ
Solan	1650	2.17 ^{efg}	12.28 ^l	132.33 ^{fgh}	78.0 ^{fg}	22.0 ^{cd}
Bersuri	1650	2.14 ^{ghf}	13.39 ^{fgh}	146.00 ^{cd}	98.0 ^a	2.0 ⁱ
Jamu	1700	2.56 ^{ab}	12.84 ^{ij}	133.33 ^{fgh}	68.0 ^f	32.0 ^b
Kandoliya	1700	2.24 ^{de}	15.53 ^a	196.66 ^b	79.0 ^{cd}	21.0 ^{cd}
Khirsu	1800	2.25 ^{de}	13.02 ^{hi}	250.00 ^a	62.0 ⁱ	38.0 ^a
Randhar	1830	2.44 ^c	12.88 ^{ij}	248.00 ^a	79.0 ^{cd}	21.0 ^{cd}
Voraniheta	2000	2.48 ^{bc}	12.59 ^k	170.00 ^{cd}	84.0 ^{cd}	16.0 ^{efg}
Damta	2020	2.32 ^d	13.55 ^{defg}	258.33 ^a	89.0 ^{bc}	11.0 ^{an}
Gumkhal	2025	2.04 ^{ij}	13.88 ^{cd}	205.00 ^a	79.0 ^{cd}	21.0 ^{cd}
Kasturgamrigbihar	2150	2.65 ^a	14.39 ^b	253.33 ^a	94.0 ^{ab}	6.0 ^{hi}
Bunda	2300	2.19 ^{ef}	13.84 ^{cd}	196.66 ^b	95.0 ^a	5.0 ⁱ
Chaurangikhal	2400	2.32 ^d	13.34 ^{gh}	185.00 ^{bc}	95.0 ^a	5.0 ⁱ
C.V.		9.17	5.85	28.02	13.67	63.48

C.V. = Coefficient of variation.

Table 3. – Variation in seed germination, germination value and survival among the provenances of *Q. leucotrichophora*.

Provenances	G%	GV	Survival %	Plantable seedling (%)
Dovsrikot	90.00 ^{cd}	0.83 ⁱ	78.5 ^{ik}	64.17 ⁱ
Bankura	90.00 ^{cd}	1.14 ^{tg}	88.7 ^{cdef}	80.67 ^{el}
Bajiron	97.00 ^{aa}	1.10 ^g	85.5 ^{elg}	85.58 ^{cd}
Ranpunga	77.00 ^f	1.28 ^c	80.75 ^{hij}	90.83 ^{ab}
Budashu	97.00 ^{aa}	0.86 ^f	75.10 ^k	95.08 ^a
Mandal	100.00 ^a	0.94 ^t	95.0 ^{ab}	80.40 ^f
Solan	93.00 ^{bc}	0.96 ^{ti}	95.5 ^a	75.11 ^g
Bersuri	93.00 ^{bc}	0.91 ^{ti}	90.8 ^{bcd}	85.21 ^{cde}
Jamu	87.00 ^{de}	1.51 ^c	95.0 ^{ab}	70.17 ^h
Kandoliya	87.00 ^{de}	1.20 ^{ef}	90.5 ^{cd}	84.20 ^{def}
Khirshu	93.00 ^{bc}	0.95 ^{ti}	85.0 ^{fg}	85.73 ^{cd}
Randhar	93.00 ^{bc}	1.83 ^d	92.0 ^{abc}	62.15 ^j
Voranibeta	87.00 ^{de}	1.07 ^{gh}	92.0 ^{abc}	73.24 ^{gh}
Damta	97.00 ^{aa}	1.74 ^b	89.5 ^{cde}	69.43 ^g
Gumkhal	83.00 ^e	0.81 ^f	84.0 ^{gh-i}	89.56 ^{bc}
Kasturgamirgbihar	93.00 ^{bc}	1.61 ^{bc}	80.0 ^{ij}	84.68 ^{cdf}
Bunda	97.00 ^{aa}	0.77 ^k	90.0 ^{cd}	81.73 ^{cdf}
Chaurangikhal	93.00 ^{bc}	1.34 ^c	87.0 ^{defg}	92.62 ^{ab}
C.V.	6.28	28.02	6.80	11.90

G% =germination percent, GV=Germination value, Values in the same column with the same letter do not differ significant ($p < 0.05$).

est total biomass (4.92 g/plant) and Gumkhal the lowest (2.20 g/plant) (Table 4).

For seedling growth traits, maximum coefficient of variation was recorded for root/shoot ratio (28.07), followed by root length (26.67%). Number of leaves and collar diameter had the lowest coefficient of variation (Table 4).

Correlation Coefficient

Significant positive ($p < 0.01$) relationship was recorded for seed length-germination value, healthy seed-

damage seed, seed weight-healthy seed, germination value-shoot dry weight, plantable seedling-shoot length, root length-root-shoot ratio, shoot dry weight-total dry weight, root dry weight-root/shoot dry weight, root dry weight-total dry weight and leaves dry weight-total dry weight. Significant ($p < 0.05$) positive correlations were recorded between seed length-seed weight, seed length-shoot dry weight, seed weight-germination, seed weight-germination value, germination value-total dry weight, survival-plantable seedlings, survival-shoot length, shoot length-root length and shoot dry weight-root-shoot dry weight. Significant ($p < 0.05$) inverse correlation was

Table 4. – Seedlings growth of *Q. leucotrichophora* after one year at nursery stage.

Provenance	Shoot length (cm)	Root length (cm)	Root/Shoot ratio	Collar diameter (mm)	Number of Leaves	Shoot dry weight (gm)	Root dry weight (gm)	Root/Shoot dry weight ratio	Leaves dry weight ratio	Total dry weight (gm)
Dovsrikot	31.81 ⁱ	26.30 ^{gh}	0.83 ^{ef}	2.85 ^{ij}	11.66 ^b	0.51 ^k	1.53 ^{ad}	3.00 ^a	0.89 ^h	2.93 ^{ijk}
Bankura	36.60 ^{de}	41.86 ^a	1.14 ^g	3.10 ^{gh}	10.66 ^{cf}	0.78 ^{de}	1.12 ^{gh}	1.44 ^{bi}	1.33 ^{bc}	3.23 ^{cijk}
Bajiron	38.15 ^{bc}	28.28	0.74 ^{ef}	3.06 ⁱ	10.00 ^e	0.83 ^{bcd}	1.47 ^{de}	1.77 ^{fg}	1.24 ^{cde}	3.54 ^{de}
Ranpunga	36.56 ^{de}	27.46 ^{fh}	0.75 ^{ef}	2.89 ⁱ	10.00 ⁱ	0.86 ^{bc}	1.68 ^e	1.95 ^{vi}	1.42 ^b	3.96 ^e
Budashu	39.55 ^a	23.76 ^h	0.60 ^h	3.19 ^{efi}	10.00 ⁱ	0.79 ^{de}	1.27 ^{efi}	1.61 ^{va}	1.44 ^b	3.50 ^c
Mandal	34.32 ^{fg}	18.70 ⁱ	0.54 ^{hi}	3.12 ^{gh}	11.11 ^{cd}	0.58 ^{ij}	1.39 ^{def}	2.40 ^{bc}	1.89 ^a	3.86 ^{cd}
Solan	33.50 ^{gh}	15.70 ^j	0.47 ⁱ	2.76 ^j	11.44 ^{bc}	0.75 ^{ef}	1.09 ^{gh}	1.45 ^{bi}	1.16 ^{ef}	3.00 ^{ghij}
Bersuri	32.24 ^{hi}	15.43 ^j	0.48 ⁱ	3.80 ^e	10.33 ^{fg}	0.67 ^{gh}	1.41 ^{def}	2.10 ^{de}	1.19 ^{cdef}	3.27 ^{cig}
Jamu	31.95 ⁱ	28.60 ^{fn}	0.90 ^{de}	3.22 ^{dci}	11.11 ^{cd}	0.95 ^a	1.95 ^h	2.05 ^c	1.42 ^b	4.32 ^e
Kandoliya	34.44 ^f	25.60 ^{gh}	0.74 ^{ef}	3.12 ^{gh}	12.44 ^a	0.83 ^{bcd}	2.35 ^a	2.83 ^a	1.41 ^b	4.92 ^e
Khirshu	36.38 ^e	26.66 ^{fh}	0.73 ^g	2.92 ^j	10.33 ^{fg}	0.54 ^{ik}	1.26 ^{fi}	2.33 ^{bcd}	0.93 ^h	2.73 ^{is}
Randhar	32.00 ^j	23.78 ^h	0.74 ^{ef}	3.17 ^{efi}	10.00 ⁱ	0.79 ^{de}	1.92 ^h	2.43 ^b	0.66 ⁱ	3.37 ^{cij}
Voranibeta	32.66 ^{hi}	32.44 ^{de}	0.99 ^{bcd}	3.24 ^{de}	12.33 ^a	0.71 ^{fg}	1.09 ^{gh}	1.54 ^{cd}	1.08 ^f	2.88 ^{ijk}
Damta	33.00 ^{gh}	30.40 ^{ez}	0.92 ^{cd}	3.32 ^{cd}	10.00 ⁱ	0.81 ^{cde}	1.23 ^{fg}	1.52 ^{cd}	1.31 ^{bcd}	3.35 ^{cij}
Gumkhal	32.55 ^{hi}	27.80 ^{fg}	0.85 ^c	3.20 ^{cd}	10.00 ⁱ	0.48 ^k	1.02 ^h	2.13 ^{cde}	0.70 ⁱ	2.20 ^j
Kasturgamirgbihar	39.00 ^{ab}	40.13 ^{ab}	1.03 ^{ab}	3.51 ^b	11.11 ^{cd}	0.84 ^{bcd}	1.69 ^e	2.01 ^{ef}	1.39 ^b	3.92 ^e
Budna	37.78 ^{bcd}	36.00 ^{cc}	0.95 ^{bcd}	3.17 ^{efi}	11.00 ^{de}	0.63 ^{hi}	1.51 ^{cd}	2.40 ^{bc}	1.32 ^{bc}	2.46 ^{nl}
Chaurangikhal	37.00 ^{cde}	37.25 ^{bc}	1.01 ^{bc}	3.25 ^{de}	11.00 ^{de}	0.88 ^b	1.07 ^{gh}	1.22 ⁱ	1.17 ^{cdf}	3.12 ^{ghij}
C.V.	7.59	26.67	28.07	7.60	7.39	18.65	24.98	24.74	24.13	19.76

Values in the same column with the same letter do not differ significant ($p < 0.05$).

found between shoot length- root/shoot dry weights (Table 5a).

Altitude had significant positive relationship with seed weight ($p < 0.01$), seed length, germination per cent and collar diameter of seedling ($p < 0.05$). Latitude was significantly ($p < 0.05$) negatively correlated with plantable seedling. Longitude had significant ($p < 0.05$) positive correlation with shoot length. Rainfall was positively significantly ($p < 0.01$) correlated with seed length and healthy seed. Damaged seed per cent was negatively correlated with rainfall. Rainfall was positively correlated with shoot dry weight and negatively correlated

with root/shoot dry weight ratio. Soil pH of different provenance had significant ($p < 0.01$) positive correlation with seed weight and germination (Table 5b).

Heritability (h^2) board sense:

Heritability (h^2) broad sense was calculated the highest (92.26) for seed weight followed by germination value (91.67), and the lowest (10.00) for collar diameter. Seed length, seed breadth, seed germination, root length, root/shoot length ratio, number. of leaves/plant, shoot dry weight, root dry weight and leaves dry weight all showed moderately high heritability. Genetic gain

Table 5a. – Correlation coefficient between and among the various traits *Q. leucotrichophora*.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	0.04																	
3	0.47*	0.34																
4	0.14	0.22	0.20															
5	-0.14	-0.22	-0.20	1.00**														
6	-0.16	0.39	0.51*	0.31	-0.31													
7	0.72**	-0.01	0.49*	0.12	-0.12	-0.06												
8	0.18	-0.24	0.07	0.29	-0.29	0.38	0.17											
9	-0.23	0.32	-0.06	0.10	-0.10	-0.15	-0.38	0.43*										
10	-0.08	0.20	0.02	0.09	-0.09	-0.25	-0.11	0.55*	0.73**									
11	0.32	0.07	0.18	0.15	-0.15	-0.13	0.28	-0.27	0.13	0.45*								
12	0.37	0.01	0.18	0.10	-0.10	-0.09	0.34	-0.15	-0.09	0.18	0.96**							
13	0.30	-0.21	0.11	0.06	-0.06	0.15	0.26	0.21	-0.08	-0.03	0.11	0.11						
14	0.17	0.37	-0.12	0.21	-0.21	0.22	-0.16	0.27	-0.19	-0.23	0.08	0.15	-0.12					
15	0.50*	0.06	0.00	0.11	-0.11	-0.34	0.68**	0.14	0.05	0.26	0.26	0.22	0.16	-0.01				
16	0.37	0.23	0.00	-0.30	0.30	-0.23	0.50	0.02	-0.24	-0.23	-0.23	-0.17	0.03	0.17	0.43*			
17	-0.01	0.16	-0.05	-0.41	0.41	-0.03	0.04	-0.14	-0.29	-0.43*	-0.42	-0.32	-0.12	0.17	-0.28	0.73**		
18	0.07	0.21	-0.30	0.31	-0.31	-0.19	-0.03	0.04	0.35	0.39	0.01	-0.11	0.11	0.17	0.36	0.10	-0.17	
19	0.37	0.33	-0.12	-0.04	0.04	-0.28	0.45*	0.07	0.03	0.08	-0.09	-0.12	0.09	0.24	0.66**	0.83**	0.38	0.60**

* Significant at $p < 0.05$; ** Significant at $p < 0.01$.

Abbreviation: 1. Seed length, 2. Seed breadth, 3. Seed weight, 4. Healthy seed, 5. damage seed, 6. Germination, 7. Germination value, 8. Survival, 9. Plantable seedling, 10. Shoot length, 11. Root length, 12. Root/shoot ratio, 13. Collar diameter, 14. No of leaves, 15. Shoot dry weight, 16. Root dry weight, 17. Root/shoot dry weight, 18. leaves dry weight, 19. Total dry weight.

Table 5b. – Correlation coefficient between different seed and seedling and three geographical variables.

Geographical Attributes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Altitude	0.49*	0.17	0.68**	0.39	-0.39	0.45*	0.27	0.22	0.14	0.08	0.31	0.31	0.43*	0.04	0.08	-0.29	-0.42	-0.12	-0.23
Latitude	0.39	-0.11	0.12	-0.10	0.10	-0.07	0.17	0.29	-0.47*	-0.32	-0.29	-0.23	0.11	-0.02	0.08	0.14	0.01	0.03	0.10
Longitude	0.33	0.01	-0.08	0.34	-0.34	-0.11	0.06	-0.06	0.32	0.43*	0.24	0.10	0.15	0.24	0.30	0.04	-0.15	0.19	0.16
Rainfall	0.68**	0.11	0.11	0.57**	-0.57**	0.08	0.41	0.30	-0.05	0.06	0.24	0.23	0.04	0.19	0.45*	-0.12	-0.48*	0.14	
pH	0.13	0.33	0.57**	0.36	-0.36	0.67**	0.18	0.15	0.05	0.02	0.16	0.15	0.20	-0.19	-0.05	-0.26	-0.27	-0.20	-0.28

* Significant at $p < 0.05$; ** Significant at $p < 0.01$.

Abbreviation: 1. Seed length, 2. Seed breadth, 3. Seed weight, 4. Healthy seed, 5. Damage seed, 6. Germination, 7. Germination value, 8. Survival, 9. Plantable seedling, 10. Shoot length, 11. Root length, 12. Root/shoot ratio, 13. Collar diameter, 14. No of leaves, 15. Shoot dry weight, 16. Root dry weight, 17. Root/shoot dry weight, 18. Leaves dry weight, 19. Total dry weight.

Table 6. – Estimation of genetic parameters for seed, seedling and germination in laboratory condition.

Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Heritability (Broad sense)	61.90	76.72	92.26	77.00	91.67	32.34	43.32	63.85	83.33	10.00	80.10	84.21	73.47	27.78	82.42
Genetic gain	14.29	10.86	50.14	1.77	18.10	8.00	9.89	59.85	15.85	1.58	6.94	71.62	46.21	6.91	41.80

Abbreviation: 1. Seed length, 2. Seed breadth, 3. Seed weight, 4. Germination, 5. Germination value, 6. Survival, 7. Shoot length; 8. Root length, 9. Root/shoot ratio, 10. Collar diameter, 11. No of leaves, 12. Shoot dry weight, 13. Root dry weight, 14. Root/shoot dry weight, 15. leaves dry weight.

Table 7. – Analysis of variance for various seed and seedling characteristics among and within the provenance of *Q. leucotrichophora*.

Source of variation	DF	Mean Sum of Squares of seed and seedling characters										RDW	TDW
		SL	SB	SW	G %	GV	SL	RL	CD	NOL	SDW		
Population	17	0.21**	3.09**	2462.0**	93.85**	0.33**	28.21**	225.56**	0.24**	2.55**	0.07**	0.53**	1.76**
Families	4	0.01	0.01	26	54.69	0.001	0.54	0.36	0.01	0.11	0.001	0.004	0.002

** Significant at ($p < 0.01$).

Abbreviations: DF=degree of freedom, SL=Seed length, SB=Seed breadth, SW=Seed weight, G%=Germination percent, GV=Germination value, SL=Shoot length, RL=Root length, CD=Collar diameter, NOL=Number of leaves, SDW=Shoot dry weight, RDW=Root dry weight, TDW=total dry weight.

was the highest (71.62%) for shoot dry weight, followed by root length (59.85%) and minimum (0.95%) for shoot length (Table 6).

Analysis of variance

Analysis of variance between the provenance for different seed and seedling characteristics exhibited highly significant ($p < 0.01$) variations. However, all these traits were not significantly different among the provenances (Table 7).

Discussion

The provenance of *Q. leucotrichophora* exhibited considerable amount of variation in morphological traits of seeds. Significant ($p < 0.05$) variations were obtained in seed length, breadth and weight among the provenances. The magnitude of variations was the highest for seed weight and the lowest for seed breadth (Table 2). These variations in seed morphological characters of *Q. leucotrichophora* may probably be due to resource availability, which varies over seasons and therefore, may influence the seed size (MURALI and SUKUMAR, 1994). The coefficients of variation were low with regard to seed size (5.85–9.17%) while moderate for seed weight (28.85%) and highest (63.48) for damaged seeds (Table 2). Similarly, difference in seed weight between provenances could have been a result of differences in the environmental conditions, e.g., nutrients, light or water to which the mother plants were subjected during the growing season (WOLFE, 1995) or due to different positions on mother plants, resulting in differences in seed filling (GUTTERMAN, 1992). Various researchers have reported that seed origin influence greatly seed and seedling characteristics of many species e.g. *Grewia optiva* (UNIYAL et al., 2002), *Albizia chinensis* (DHANAI et al., 2003), *Celtis australis* (SINGH et al., 2006), *Cordia africana* (LOHA et al., 2006), *Dalbergia melanoxylon* (AMRI et al., 2008), *Pinus roxburghii* (GHILDIYAL et al., 2009), *Quercus glauca* (SINGH et al., 2010). The seeds were collected from different locations, from trees approximately of the same age, therefore, differences observed in seed characters may be result of adaptation to diverse environmental conditions prevailing in their distribution range (MATHUR et al., 1984).

It has been observed that seed germination of *Q. leucotrichophora* is temperature dependent and constant temperature of 25°C induces the highest germination, irrespective of provenances. On average, 13 provenances

out of 18 showed <90% germination at 25°C. Altitude affects the germination of this species. Significant ($p < 0.05$) variations have been recorded for germination response of provenances (Table 3). Germination of the seeds of *Q. leucotrichophora* is hypogeal with the nut splitting towards the apex and the radicle emerging and growing downward to form a young taproot. Similar finding was recorded in *C. australis* by SINGH et al. (2004). Several workers also reported that seed germination is temperature dependent and constant temperature 25°C accelerate germination in *Albizia chinensis* (DHANAI et al., 2003), *A. lebbek* (TODARIA et al., 2002) and *Dalbergia sissoo* (SINGH and BHATT, 2008a).

Significant ($p < 0.05$) variations have been recorded for growth of seedlings among provenances. The average shoot length was 34.96 cm for one year old seedlings, irrespective of provenance. Similarly, average root length was 28.12 cm, irrespective of provenance after one year of growth. Significant variations were also obtained for collar diameter of seedlings of different provenances. Further, significant ($p < 0.05$) variations were also recorded in biomass allocation of seedlings among provenances. On average, roots partitioned the highest biomass followed by leaves and shoot.

The biomass of the seedlings, root length and root/shoot ratio exhibited moderate coefficient of variation while, shoot length, collar diameter and number of leaves exhibited lower values of coefficient of variation (Table 4). In an earlier study, NEGI and NAITANI (1995) suggested that growth of *Q. leucotrichophora* seedling in forest stand is slow and during first year, the seedling may attain a height of only 5–12.5 cm with 2–5 leaves per plant. During the course of present investigation, the seedling growth was comparatively higher and it may be attributed to the fact that, seeds were harvested from promising ideotypes which resulted into high seedling vigour. Several studies have been carried out to examine the variation in seedling traits among the seed sources in different species in Garhwal Himalaya viz. *Terminalia tomentosa*, *T. bellerica*, *T. chebula* (CHAUHAN et al., 2007), *Grewia optiva* (UNIYAL et al., 2002), *Albizia chinensis* (DHANAI et al., 2003), *Celtis australis* (SINGH and BHATT, 2008b) and the present findings are in conformity with the findings of these earlier workers.

Various workers have proved that seed size affect the seedling vigour (VERE, 1997; SINGH et al., 2006), however, growth of the seedlings in *Q. leucotrichophora* was not affected by seed size (Table 5a), but seed weight was significantly positively correlated with altitude indicat-

ing that higher elevational seed source produce heavier seed in this species. Seedling growth traits, however, did not exhibit any positive or negative trend with altitude except collar diameter. Latitude of seed source was inversely correlated with plantable seedling indicating that these traits showed southern trend. The longitude exhibited positive correlation with shoot length indicating this trait increased towards eastern extremes. Similarly, soil pH was also significantly positive correlated with seed weight and germination indicating that higher soil pH was more suitable for production of vigour seeds.

The variance registered in *Q. leucotrichophora* for seedling growth and biomass parameters showed considerable variation. For the utilization of observed variation in species, it is a prerequisite to know the extent of variation and also that whether it is due to the genetic or the environmental factors. Hence information on variation among the desirable parameters and their correlation is vital for any breeding program (JOHNSON et al., 1955). Seed and seedling characteristics of *Q. leucotrichophora* exhibited a wide range of variation among provenances. On average, seed weight exhibited the highest heritability and genetic gain. This signified that seed weight is under strong genetic control (Table 3).

Higher values for broad sense heritability and genetic gain were estimated for seed weight, root length, shoot dry weight, root dry weight, leaves dry weight and moderately high for seed length, seed breadth, germination value, root/shoot ratio, indicating better chance of improving these characteristics at early stages through provenance and parent tree selection in *Q. leucotrichophora*. This supports earlier findings of SRIVASTAVA et al. (1993), GWAZE (1997), DHANAI et al. (2003) and SINGH et al. (2008a). MANTOVEN (2002) also reported that variation on the provenance level in *Prosopis flexuosa* was related to the elevation, geographic location and some abiotic conditions of the seed source. DHILLON and KHAJURIA (1994) also recorded more than 75.0% heritability for various seed traits of *Acacia nilotica*. Moderate high heritability estimation with moderate genetic advance has earlier been reported for plant height of *Terminalia arjuna* (SRIVASTVA et al., 1993), plant height and stem diameter of *Grewia optiva* (SHARMA and SHARMA, 1995), *Eucalyptus grandis* (SUBRAMANIAN et al., 1995) and *Dalbergia sissoo* (GERA et al., 2000).

In general, heritability estimated along with genetic gain was reported more useful than the heritability alone in predicting the resultant effect for selecting the best genotypes for a given trait (VOLKER et al., 1990; SINGH and CHAUDHARY, 1993). The observations incorporated in this investigation bring out fact that, seeds of *Q. leucotrichophora* collected from different provenances show large variation in seed morphology, seed weight, germination and seedling parameters. However, the variations were random between provenances. Therefore, all these characters should be considered as important traits for the selection because seedlings of seed lots selected on the basis of one character alone may some time not give the desired level of superiority. Seed source selection should be made on the basis of multi

traits consideration as reported by GINEWAL et al. (1996) and VAKSHASYA et al. (1992).

Out of nineteen characters of seed and seedlings, ten characters were significantly correlated with geographical variables (altitude, latitude and longitude), and soil pH of the seed populations. The existing positive significant correlation between seed weight and altitude of seed source indicates a trend of increasing heavy seeds towards higher elevational sources which could be important criterion for seed source selection. Further more, higher germination was recorded in heavier seeds. Most of the provenances proved better germination at 25°C. The middle to higher altitudinal population exhibited stable performance in seedling growth and biomass production indicating that species is most suitable for planting in middle to higher elevational ranges, where it is adapted genetically and physiologically. The characters, which showed greater influence, can be directly screened/selected for the improvement of this potential tree species, i.e., shoot dry weight, root length and seed weight. Root and leaf dry weight which indicate high heritability with moderately high genetic gain could be selected and considered for possibility of rapid genetic improvement of this potential tree at nursery stage to obtain quality seedlings for mass afforestation in Central Himalaya, India.

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