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Original Article

Provenance Variation in Cone Morphology, Seed Traits, and Seed Germination of *Cedrus deodara* from Uttarakhand Himalaya

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ABSTRACT

Cedrus deodara is an important tree species and needs to be a plantation in a large area for the present scenario of climate change mitigation and global warming. For large-scale afforestation and reforestation activity, suitable seed sources are needed to produce quality planting stock. Therefore, the present study was conducted to understand the amount and patterns of variation in morphometric characteristics of *Cedrus deodara* cones, seeds, and their germination. Cone of *Cedrus deodara* was collected from ten different provenances of Western Himalaya. Significant variation ($p < .05$) was recorded for different morphological characteristics of cones, seeds, and seedlings among different provenances. Cone weight, seed moisture content, and seed weight were the most variable characters among the studied traits. On average, cone length, cone weight, and cone diameter were 8.85 cm, 104.59 g, and 6.39 cm, respectively. While the seed length, seed width, and seed thickness were 1.20, 0.46, and 0.27 cm, the seed weight was 9.70 g, respectively. The maximum (92.10%) germination was recorded at 15°C. Most of the cone and seed traits showed high heritability with genetic gain, indicating that strong genetic control should be considerable for the further improvement in *Cedrus deodara*. The variability appeared to be naturally structured and would be mainly hereditarily controlled. On the basis of cone morphology, seed traits, and seed germination, Kandolia, Dhanaulti, and Dandachalli were the best provenances. The results of the present study help collect quality seeds for producing the quality planting stock for these tree crops for plantations in Uttarakhand, Himalaya.

Keywords: *Cedrus deodara*, cone weight, genetic variation, germination, heritability, seed weight

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Introduction

Scanning of the best seed provenances determines the greatest adaptation characteristics of species in a suitable environment, which would be used as a geographical marker for obtaining the best quality seeds (Fornah et al., 2017). Selection of provenances is a foremost step toward tree improvement programs, which offer the requirement about the geographical knowledge of environments as well as genetic variation (Li et al., 2020). Distinct geographical locations affect the various characteristics of the species, *viz* morphological traits of seed, seed germination, and seedling growth (Singh et al., 2006a, 2006b). Explaining the variability that exists among the geographically distinct populations is necessary for gaining privileged production and subsequent future reproduction effort (Li et al., 2020). Variation in morphological seed characteristics of seeds amongst the seed provenances of a species was described to be helpful for tree improvement programs (Fredrick et al., 2015; Saklani et al., 2012). Hence, understanding of the geographical distribution of morphologically relevant genetic variations and environmental factors driving adaptive divergence within the species will recover appropriate sourcing material not only for industrial use but also for tree improvement (Thangjam et al., 2020). The absence of quality tree seeds has been a significant constraint on afforestation and reforestation in different land restoration activities (McCormick et al., 2021). Due to this, tree seed programs were distinguished in numerous countries to diminish the scarcity of quality tree seeds (Gregorio et al., 2017). Variation studies on cone and seed traits and germination among the provenances have been reported for several conifer tree species, i.e., *Abies pindrow* (Bhat et al., 2018), *Picea smithiana* (Singh et al., 2017), *Pinus wallichiana* (Rahman et al., 2017), *Cedrus deodara* (Mughal & Thapliyal, 2013), *Pinus halepensis* (Guemri et al., 2019), *Pinus silvestris* (Batjhuu et al., 2020), and *Pinus pinea* (Balekoglu et al., 2020, 2021).

Cedrus deodara (Roxb.) G. Don. (commonly known as Deodar, belongs to the family Pinaceae) is an indigenous species of the Himalayan mountain regions from the North-Western Himalayas, Jammu, and Kashmir to

Northern Pakistan to Afghanistan, Tibet, and Western Nepal (Mughal & Thapliyal, 2013). It grows naturally between 1800 and 2600 m elevation (masl), occasionally between 1200 and 3000 m (Sinha, 2018). *Cedrus* deodara is commonly a monoecious species; however, subdioecious populations (with five different sexual morphs, i.e., pure male, pure female, predominantly male, predominantly female, and mixed monoecious) were also apparent in the Himalayan region (Khanduri et al., 2021). A good seed year occurs once in 4–5 years (Sofi et al., 2016). It is an important timber tree extensively used for building houses, doors, frames, windows, railway sleepers, bridges, and carriages (Srivastava et al., 2021). Cedar essential oils are used as antiseptics, antimicrobials, insecticides, molluscicides, germicidal, and anti-tuberculous agents. **(**Kumar et al., 2019). The objective of the present study is to know the variations among different provenances in the cone, seed morphology, and seed germination in the Garhwal Himalaya aimed to answer the following questions: (i) Do the geographically distinct populations cause variation in cone and seeds traits of *C. deodara*? (ii) Does the variation affect seed germination of selected provenances of *C. deodara*? (iii) Is there any relationship that exists between cone, seed, and germination parameters with geographic coordinates, climate, and edaphic factors of different provenance studied?

Material and Methods

To study the variation in cone, seed, and seed germination in laboratory conditions, the provenances of *C. deodara* were selected from different geographic locations, spread over seven districts of Uttarakhand, i.e., Kandolia, Chamoli, Uttarkashi, Rudraprayag, Almora, Nainital, and Tehri Garhwal, ranging from latitude 29° 27′ 36″ to 31° 1′ 48″ N and longitude 77° 52′ 12″ E to 79° 33′ 36″ E with the elevation ranges from 1698 to 2620 masl. The detailed geographical and meteorological attributes of various provenances are given in Table 1 and Figure 1.

The cones were collected in October from each provenance when they had become fully matured. The cones were collected by directly climbing the tree or by breaking the branches along with the cones. Ten ripe cones from each of the superior trees were collected randomly for each provenance (a total of 100 cones from each population) and kept loosely inside cotton bags, properly marked, and brought to the laboratory.

In the laboratory, cone length and cone diameter of 50 cones (five replicates of ten each) from each provenance was measured with the help of a vernier caliper. The cone length/diameter ratio was calculated as the cone length divided by the cone diameter. The cone weight of five replications (ten each) from each seed source was taken by electronic balance. The number of scales per cone was counted manually in five replications (ten each) from each provenance. Further, the cones from each provenance were kept in sunlight for seven to ten days for dehiscence. When the cones were burst, the number of sound seeds per cone and unsound seeds per cone from each provenance was counted manually in five replicates with ten cones each.

The extracted seeds were kept in cotton bags and stored at room temperature for measuring the morphology of seed traits and their germination in the laboratory. Seed length with wings was measured by using measuring scales in centimeters for which 20 seeds with five replications for each provenance were taken. Seed length, width, and thickness were measured (20 seeds with five replications from each provenance) by using a digital vernier caliper. For the determination of moisture content, 20 seeds and five replicates from each provenance were weighed in an electronic balance and placed in an oven at 104°C temperature for 24 hours, and moisture percent was calculated per the standard formula.

Seeds of each provenance were soaked in distilled water for 24 hours before subjecting them to germination tests. Twenty seeds of five replications were kept in 9 cm glass Petri dishes each on 2-layer filter paper (Whatman No. 1) and moistened with distilled water. Petri dishes were kept in a germinator and prefixed to constant temperature regimes of 15°C and 20°C. Filter papers in Petri dishes were replaced at weekly intervals to avoid fungal growth on seeds. Petri dishes were examined daily, and germinated seeds were counted after 21 days and until there was no further germination for at least one weeks. The emergence of the radicle was used as an index of germination. The germination percentage was calculated by using the standard formula. Mean germination time (MGT) was calculated by the formula given by Martin et al. (2018).

$$\text{Mean germination time} = \Sigma\, (ni \times ti)/N \qquad (1)$$

where ni = the number of seeds that germinated (2 mm radicle length) in a day, ti = time (hours), and N = the total number of seeds that germinated in the period of experiments.

Table 1.
Geographical, Meteorological, and Soil Descriptions of Different Seed Sources of Cedrus deodara

S. No	Seed Source	District	Altitude (m)	Latitude (N)	Longitude (E)	Temperature °C	Mean annual rainfall (mm)	pH	Electric conductivity (dS/m)
1.	Kandoliya	Pauri	1698	30° 8′ 24″	78° 46′ 48″	18.12	1155.00	5.18	0.08
2.	Jageshwar	Almora	1870	29° 37′ 48″	79° 50′ 60″	17.41	950.00	6.47	0.14
3.	Gwaldam	Chamoli	1940	30° 0′ 36″	79° 33′ 36″	16.75	1078.00	6.10	0.13
4.	Dandachalli	Tehri Garhwal	2100	30° 18′ 36″	78° 25′ 12″	19.50	963.00	6.08	0.11
5.	Chakrata	Dehradun	2118	30° 41′ 60″	77° 52′ 12″	17.54	1084.00	6.99	0.18
6.	Dhanolti	Tehri Garhwal	2159	30° 24′ 36″	78° 13′ 48″	16.06	985.00	6.80	0.16
7.	Mukteswar	Nainital	2171	29° 27′ 36″	79° 39′ 0″	16.30	964.00	6.15	0.12
8.	Hulanakhal	Tehri Garhwal	2200	30° 24′ 36″	78° 45′ 36″	18.75	1025.00	5.28	0.09
9.	Chopta	Rudraprayag	2608	30° 20′ 24″	79° 2′ 60″	18.20	1125.00	5.90	0.10
10.	Harshil	Uttarkashi	2620	31° 1′ 48″	78° 44′ 24″	18.05	1265.00	6.78	0.16

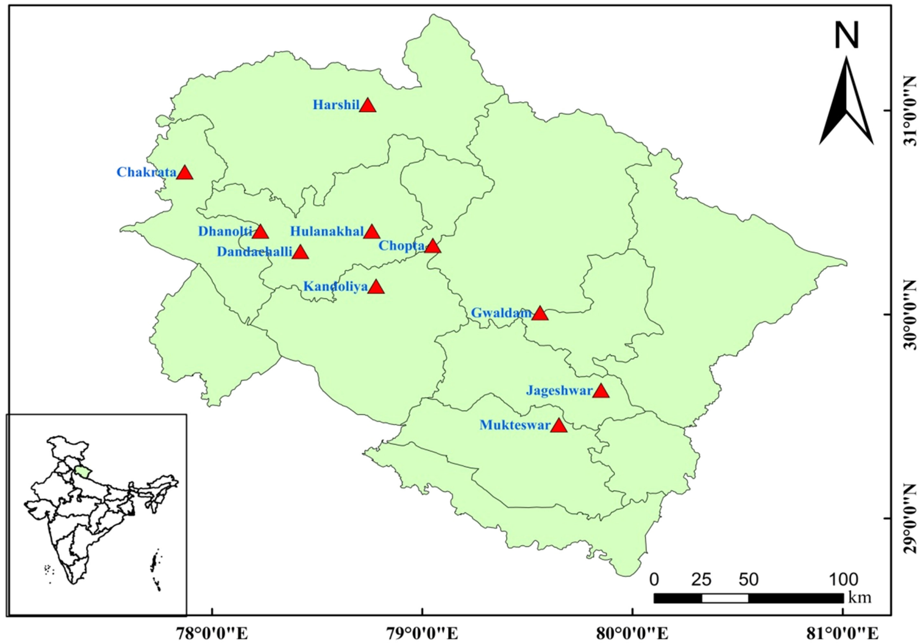

Figure 1.
Map Showing Gographic Location of Seed collection sites.

The germination index (GI) was calculated by following the method of Tan et al. (2017).

$$\text{Germination Index} = \sum (Gt/Dt), \quad (2)$$

where Gt = the number of germinated seeds at the end of the germination period and Dt = the total days for germination.

Computation of Variability Parameters
Based on the two-way analysis of variance, the genotypic, phenotypic, and environment variances were calculated using the following equations:

$$\text{Genotypic variance } (Vg) = \frac{Mt - Me}{R} \quad (3)$$

$$\text{Phenotypic variance } (Vp) = Vg + Ve \quad (4)$$

$$\text{Environmental variance } (Ve) = Me \quad (5)$$

where, Mt = mean sum of squares due to treatment, Me = mean sum of squares due to error, and R = number of replications.

Phenotypic Coefficient of Variation
It is the measure of total variation existing in a character, which was calculated as suggested by Burton and Devane (1953):

$$\text{PCV } (\%) = \frac{\sqrt{Vp}}{\bar{X}} \times 100 \quad (6)$$

where PCV = phenotypic coefficient of variation, ± = mean of the character, and Vp = phenotypic variance.

Genotypic Coefficient of Variation
Genotypic coefficient of variation represents the manner of total genetic variability existing in a character, and it was calculated as suggested by Burton and Devane (1953):

$$\text{GCV}(\%) = \frac{\sqrt{Vg}}{\bar{X}} \times 100 \quad (7)$$

where GCV = genotypic coefficient of variation, ± = mean of the character and Vg = genotypic variance

Environmental Coefficient of Variation
It was the measure of environmental variation existing in a character, and it was calculated as suggested by Burton and Devane (1953):

$$\text{ECV } (\%) = \frac{\sqrt{Ve}}{\bar{X}} \times 100 \quad (8)$$

where ECV =environmental coefficient of variation, ± = mean of the character, and Ve = environmental variance

Heritability in the Broad Sense (h^2)
Heritability is the ratio of genetic variance to the total phenotypic variance which was estimated as suggested (Burton & Devane, 1953; Johnson et al., 1955):

$$h^2(\%) = \frac{Vg}{Vp} \times 100 \quad (9)$$

where h^2 = broad sense heritability in percent, Vg = genetic variance, and Vp = phenotypic variance

Genetic Advance

Genetic advance is the expected increase in the magnitude of a character when a selection pressure of chosen intensity is applied. This was calculated as per Johnson et al. (1955):

$$\text{Genetic advance}\left(\text{GA}\right) = K.\sqrt{VP} * \text{h}^2 \qquad (10)$$

where K = selection intensity at 5%, which is equal to 2.06 (Allard, 1960),

Vp = phenotypic variance and h^2 = broad sense heritability (%)

Genetic Gain

Genetic gain expressed as a percentage of the mean was calculated using the formula given (Johnson et al., 1955):

$$\text{GA} = \frac{GA}{\overline{X}} \times 100 \qquad (11)$$

where GA = genetic advance and ± = mean of the character.

Data Analysis

Data were arc sine transformed for the estimation of the correlation coefficient, Pearson correlations (Karl Pearson's), and two-way analysis of variation for 16 cones, seed morphology, and seed germination traits by using the statistical software package and Web Agri Stat Package IGAR Goa.

Results

Analysis of Variance

Analysis of variance was calculated for cone, seed, and germination parameters within and among the provenances, and data showed that all the studied parameters were significantly ($p < .01$ & $p < .05$) varied among the provenances except seed length/width ratio (Table 2).

Significant ($p \leq .05$) variation has been recorded for cone characteristics, i.e., cone length, cone width, cone weight, number of scales per cone, number of sound seeds per cone, number of unsound seeds per cone, and cone length/diameter ratio. Cones collected from the Harshil have found a maximum cone length, whereas a minimum cone length was recorded for Dandachalli provenance. Cone diameter was noticed to be the highest at Kandolia, whereas it was the lowest at Dandachalli provenance. The highest and lowest cone weights were recorded for Harshil and Chakrata provenances, respectively. The number of scales per cone was found to be the highest for Mukteswar, followed by Gwaldam and lowest for Dhanaulti provenance. Interestingly, Mukteswar provenance proclaimed minimum number of sound seeds per cone and Kandolia had highest seeds per cone. Maximum and minimum unsound seeds per cone were recorded for Mukteswar and Dandachalli provenances, respectively. The highest and lowest cone length/diameter ratio was recorded for Harshil and Dhanaulti provenances, respectively. Among the cone parameters, number of unsound seeds per cone was the most variable characters and cone diameter was the least variable (Table 3).

Morphological characteristics of seeds of *C. deodara* also showed significant ($p \leq .05$) variation among the seed sources except seed length/width ratio. Seed length with wings was recorded maximum at Hulanakhal and minimum at Gwaldam provenance. The seed length was recorded highest for Kandolia, whereas the lowest was found for

Table 2.
Analysis of Variance for Morphological and Germination Characteristics of Cedrus deodara

Source of Variation	*df*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Treatment	9	76.75**	49.72**	50.38**	390.12**	26.09**	41.87**	8.290**	8.57**	2.86**	4.99**	2.27*	1.25 ns	10.67**	59.97*	3.67**	5.86**	8.20**	7.74**
Replication	4	3.42**	2.05**	1.49 ns	1.71 ns	3.34*	2.65 ns	0.536 ns	0.73 ns	0.24 ns	0.86 ns	0.44 ns	1.04 ns	0.71 ns	9.56 ns	0.34 ns	1.02 ns	1.71 ns	0.52 ns

Note: 1, cone length; 2, cone diameter; 3, cone weight; 4, number of scales per cone; 5, number of sound seeds per cone; 6, cone length/diameter ratio; 7, Number of number of unsound seeds; 8, seed length; 9, seed width; 10, seed thickness; 11, seed length with wings; 12, seed length/width ratio; 13, seed weight; 14, seed moisture content; 15, germination; 16, radical length; 17, plumule length; 18, seed vigor index.
Note: ns = nonsignificant.
*Significant at $p < .01$.
**Significant at $p < .05$.

Table 3.
Seed Source Variation with Respect to Cone Characteristic3s (mean ± SD) of Cedrus deodara

Seed Source	Altitude (m)	Cone Length (cm)	Cone Weight (gram)	Cone Diameter (cm)	Number of Scales/Cone	Number of sound Seeds Cone	Cone Length/ Diameter Ratio (cm)	Number of unsound Seeds
Kandoliya	1698	9.80 ± 0.22[ab]	107.6 ± 7.42[bc]	7.79 ± 0.22[a]	110.48 ± 3.85[ab]	180.84 ± 12.69[a]	1.26 ± 0.05[de]	27.0 ± 7.68[cd]
Jageshwar	1870	9.05 ± 0.46[c]	108.68 ± 7.19[bc]	6.017 ± 0.30[e]	107.16 ± 14.81[ab]	121.4 ± 10.62[d]	1.51 ± 0.05[b]	26.0 ± 2.23[cd]
Gwaldam	1940	8.22 ± 0.03[c]	101.15 ± 1.48[cd]	6.29 ± 0.18[d]	111.48 ± 7.27[ab]	123.36 ± 9.77[d]	1.31 ± 0.03[cd]	47.0 ± 4.92[ab]
Dandachalli	2100	6.17 ± 0.22[f]	95.00 ± 1.18[de]	5.18 ± 0.15[f]	104.2 ± 3.41[ab]	166.32 ± 12.50[b]	1.19 ± 0.07[ef]	16.0 ± 3.43[d]
Chakrata	2118	9.92 ± 0.78[a]	88.49 ± 10.40[e]	6.32 ± 0.25[d]	89.4 ± 5.51[cd]	142.32 ± 7.82[c]	1.57 ± 0.10[ab]	38.0 ± 7.06[bc]
Dhanaulti	2159	7.14 ± 0.21[e]	101.64 ± 6.83[bc]	6.26 ± 0.17[de]	88.84 ± 3.71[d]	120.76 ± 4.10[d]	1.14 ± 0.04[f]	28.0 ± 5.90[cd]
Mukteswar	2171	9.46 ± 0.54[bc]	117.52 ± 6.22[b]	7.00 ± 0.25[b]	115.4 ± 19.41[a]	116.44 ± 5.99[d]	1.35 ± 0.06[e]	56.0 ± 24.81[a]
Hulanakhal	2200	10.02 ± 0.14[a]	100.73 ± 2.09[cd]	6.50 ± 0.15[cd]	102.36 ± 5.75[b]	125.64 ± 13.02[d]	1.54 ± 0.04[ab]	16.0 ± 8.09[d]
Chopta	2608	8.58 ± 0.28[d]	100.42 ± 5.91[cd]	6.62 ± 0.15[c]	106.96 ± 2.81[ab]	148.28 ± 6.82[c]	1.30 ± 0.03[ed]	48.0 ± 7.47[ab]
Harshil	2620	10.10 ± 0.29[a]	124.70 ± 16.45[a]	6.28 ± 0.07[d]	100.72 ± 2.87[bc]	120.4 ± 17.72[d]	1.61 ± 0.04[a]	21.0 ± 0.75[d]
Mean		8.85	104.59	6.39	103.70	136.58	1.39	32.68
Coefficient of variation		3.84	7.73	3.29	8.64	7.13	4.16	33.64

Note: Means followed by the same letter are not significantly ($p < .05$) different.

Chakrata provenance. The recorded seed width and thickness was highest for Kandolia and Hulanakhal, respectively. However, the lowest value of both variables was recorded for the Chakrata provenance. The highest seed weight was recorded for Kandolia, whereas the lowest was observed for Mukteswar provenance. Seed length width ratio was recorded maximum for the Hulanakhal and minimum for Gwaldam provenance. Seed moisture percent was recorded maximum for Jageshwar and minimum for Hulanakhal provenance. For the seeds traits, seed weight was the most variable character and seed length was the least variable character (Table 4).

The germination percentage, MGT, and GI were found significant ($p \leq .05$) among the provenances. The highest seed germination percent was recorded for Kandolia and Dhanaulti, whereas the lowest was recorded for Harshil at 15°C. Similarly, at 20°C, the highest and lowest germination was recorded for Dhanaulti and Gwaldam provenances, respectively. However, maximum and minimum MGT at 15°C was observed for Gwaldam and Kandolia provenances, respectively. The MGT was recorded maximum in Hulanakhal and minimum in Dhanaulti provenance at 20°C. The GI values at 15°C recorded a maximum for Chakrata provenance and minimum for Harshil provenance, respectively, which at 20°C were observed for Dhanaulti and Gwaldam provenances, respectively (Table 5).

The study exposes that the values of plumule length, radicle length, and seed vigor index were found to be significant ($p \leq .05$) among seed sources. The coefficient of variation (CV) values were minimum for plumule lengthh and maximum for radicle length at 15°C, and plumule length showed minimum CV while the maximum CV was recorded for seedling vigor index at 20°C for different seed sources (Table 6).

Significant ($p \leq .05$) variation has been recorded for the plumule length among different seed sources. The maximum plume length was recorded in Dhanaulti at 15°C and Dhanaulti at 20°C. Lowest plumule length was found in Jageshwar at 15°C and 20°C, respectively. Significant ($p \leq .05$) variation has been observed for the radicle length of seedling among different seed sources. An average, radical length was highest in Pauri seed source at 15°C and 20°C, respectively. Radicle length was lowest was observed in Chopta seed source at 15°C and 20°C (Table 5).

Genetic and Phenotypic Variability

The genetic, phenotypic, and environmental CVs were recorded maximum for number of unsound seeds. Minimum genetic and environmental CV was recorded for cone diameter, and phenotypic CV was minimum for the number of scales per cone. The heritability was recorded maximum for cone length and minimum for the number of scales. The genetic advance was recorded maximum for cone weight and minimum for cone diameter. The genetic gain was maximum for the number of unsound seeds per cone.

In seed traits, maximum genetic and environmental CV was recorded for seed moisture percent and maximum phenotypic CV was recorded for seed weight. The minimum genetic CV, phenotypic CV, and environmental CV were recorded for seed width, seed length with wings, and seed thickness, respectively. The broad-sense heritability was calculated highest for seed length and lowest for seed moisture percent, while genetic advance was recorded maximum for seed weight and minimum for seed length with wings. As far as the genetic gain is concerned, it was found maximum for the seed thickness and minimum for seed moisture percent (Table 7).

Correlation of Geographical, Climatic and Edaphic Variables with Cone, Seed, and Germination Parameters

Altitude showed a significant ($p < .01$) positive correlation with cone weight and significant ($p < .05$) positive correlation with cone length/diameter ratio, seed length with wings, and seed length/width ratio. Altitude also revealed a negative significant correlation with the number of unsound seeds per cone at $p < .01$ level of probabilities, while a negative significant correlation was found at $p < .05$ level of probabilities with cone diameter, number of sound seeds per cone, seed width, and seed germination was evident (Table 8).

Similarly, latitude demonstrated a significant ($p < .01$) positive relationship with cone weight, number of unsound seeds per cone, seed

Table 4.
Seed Source Variation with Respect to Seed Characteristics (Mean ± S.D.) of Cedrus deodara

Seed Source	Altitude (masl)	Seed Length (cm)	Seed Width (mm)	Seed Thickness (mm)	Seed Length with Wings (cm)	Seed Length/Width Ratio	Seed Weight (100 Seeds) (g)	Seed Moisture Content (%)
Kandoliya	1698	1.33 ± 0.08[a]	0.51 ± 0.02[a]	0.29 ± 0.01[ab]	2.80 ± 0.19[abc]	2.70 ± 0.19[NS]	11.36 ± 1.04[a]	12.49 ± 2.73[c]
Jageshwar	1870	1.19 ± 0.04[cd]	0.47 ± 0.02[ab]	0.27 ± 0.01[abc]	2.62 ± 0.21[c]	2.52 ± 0.10[NS]	10.56 ± 1.40[a]	14.33 ± 2.35[ab]
Gwaldam	1940	1.20 ± 0.06[bc]	0.47 ± 0.06[ab]	0.27 ± 0.02[abc]	2.47 ± 0.41[bc]	2.48 ± 0.13[NS]	8.66 ± 1.72[bc]	12.59 ± 2.19[bc]
Dandachalli	2100	1.10 ± 0.04[d]	0.42 ± 0.06[cd]	0.28 ± 0.04[ab]	2.82 ± 0.28[ab]	2.71 ± 0.13[NS]	7.29 ± 0.66[cd]	12.11 ± 2.28[c]
Chakrata	2118	1.00 ± 0.09[e]	0.41 ± 0.05[d]	0.22 ± 0.10[d]	2.88 ± 0.19[a]	2.64 ± 0.15[NS]	10.11 ± 1.91[ab]	12.52 ± 1.34[bc]
Dhanaulti	2159	1.25 ± 0.06[abc]	0.47 ± 0.02[abc]	0.28 ± 0.02[ab]	2.94 ± 0.08[a]	2.67 ± 0.09[NS]	11.36 ± 1.55[a]	13.51 ± 2.68[abc]
Mukteswar	2171	1.17 ± 0.08[cd]	0.43 ± 0.05[bcd]	0.25 ± 0.02[cd]	2.66 ± 0.38[abc]	2.66 ± 0.38[NS]	7.30 ± 1.80[d]	14.19 ± 2.73[ab]
Ghansali	2200	1.30 ± 0.02[ab]	0.46 ± 0.01[abc]	0.30 ± 0.01[a]	2.94 ± 0.05[a]	2.84 ± 0.26[NS]	9.88 ± 1.29[ab]	11.09 ± 2.66[c]
Chopta	2608	1.26 ± 0.02[abc]	0.47 ± 0.01[ab]	0.26 ± 0.02[bc]	2.76 ± 0.30[abc]	2.69 ± 0.35[NS]	10.24 ± 1.02[a]	11.41 ± 1.92[c]
Harshil	2620	1.23 ± 0.10[bc]	0.44 ± 0.04[bcd]	0.27 ± 0.03[ab]	2.96 ± 0.05[a]	2.83 ± 0.06[NS]	10.21 ± 2.04[a]	13.30 ± 2.92[abc]
Mean		1.20	0.46	0.27	3.07	2.67	9.70	12.75
Coefficient of variation		6.11	8.72	8.19	10.40	8.62	17.38	8.49

Note: Means followed by the same letter are not significantly ($p < .05$) different.

length with wing, and seed weight. The length/diameter ratio had a significant positive correlation with the latitude at the p <.05 level of probabilities. A significant negative (p <.01) correlation was recorded for the number of scales with latitude. Longitude has shown a significant (p <.01) positive correlation with the number of scales and is inversely (p<.01) correlated with the number of unsound seeds, seed length with wings, seed moisture content, germination percent, and seed vigour index. Longitude also proclaimed a significant inverse correlation with the number of sound seeds, seed length, and seed weight. A significant positive correlation was recorded for temperature with the number of sound seeds at the p <.01 level of probabilities and with seed thickness and radicle length at p <.05 level of probabilities. Temperature also showed a significant (p <.05) inverse correlation with cone diameter Rainfall revealed a significant positive correlation with cone length, cone diameter, cone weight, and seed weight at the p <.01 level of probabilities and with cone length/diameter ratio, seed length, and seed length/width ratio at the p <.05 level of probabilities.The soil pH of different provenances demonstrated a significant (p <.05) positive relationship with cone weight and MGT. The soil pH of the studied provenance sites had a significant (p<.01) inverse correlation with cone diameter, number of scales, number of unsound seeds, number of sound seeds per cone, seed length, seed width, seed thickness, radicle length, total length, and seed vigour index. While, an inverse correlation (p<.05) was recorded with germination and plumule

Table 5.
Seed Source Variation with Respect to Germination (%), Mean Germination Time, and Germination Index of Cedrus deodara *at Different Temperature Regimes*

		Germination %		Mean Germination Time		Germination Index	
Seed Source	Altitude	15°C	20°C	15°C	20°C	15°C	20°C
Kandoliya	1698	99.0 ± 2.24[a]	84.0 ± 6.52[ab]	3.36 ± 0.69[d]	4.66 ± 0.67[NS]	4.71 ± 0.11[a]	4.00 ± 0.31[ab]
Jageshwar	1870	83.0 ± 4.47[cd]	56.0 ± 8.02[d]	4.02 ± 0.70[d]	3.90 ± 0.38[NS]	4.57 ± 0.11[a]	2.62 ± 0.48[d]
Gwaldam	1940	93.0 ± 4.47[ab]	55.0 ± 7.07[d]	6.75 ± 0.76[a]	3.44 ± 0.12[NS]	3.95 ± 0.21[cd]	2.62 ± 0.34[d]
Dandachalli	2100	96.0 ± 2.24[a]	92.0 ± 9.08[a]	5.23 ± 0.38[bc]	4.31 ± 0.57[NS]	4.43 ± 0.21[ab]	2.86 ± 0.46[d]
Chakrata	2118	97.0 ± 2.74[a]	66.0 ± 2.62[bcd]	5.42 ± 0.51[b]	5.37 ± 0.49[NS]	4.62 ± 0.13[a]	3.14 ± 0.43[bcd]
Dhanaulti	2159	99.0 ± 2.24[a]	98.0 ± 4.47[a]	6.14 ± 0.41[ab]	3.27 ± 0.46[NS]	4.71 ± 0.11[a]	4.67 ± 0.21[a]
Mukteswar	2171	87.0 ± 8.57[bc]	84.0 ± 8.22[ab]	3.72 ± 0.36[d]	4.01 ± 0.88[NS]	4.48 ± 0.20[ab]	2.91 ± 0.46[bcd]
Ghansali	2200	96.0 ± 4.18[a]	80.0 ± 9.35[abc]	5.29 ± 0.43[bc]	6.75 ± 0.46[NS]	4.14 ± 0.88[bc]	3.81 ± 0.45[abc]
Chopta	2608	94.0 ± 4.18[a]	60.0 ± 2.36[cd]	5.17 ± 0.83[bc]	4.94 ± 0.71[NS]	4.57 ± 0.20[a]	4.38 ± 0.43[a]
Harshil	2620	77.0 ± 5.70[d]	61.0 ± 3.70[bcd]	4.28 ± 0.53[cd]	4.38 ± 0.73[NS]	3.67 ± 0.27[d]	4.00 ± 0.39[ab]
Mean		92.10	73.50	4.94	4.49	4.39	3.50
Coefficient of variation		7.22	25.28	17.54	39.04	7.22	25.28

Note: Means followed by the same letter are not significantly ($p < .05$) different.

Table 6.
Radicle, Plumule Length (cm), and Seed Vigor Index (Mean ± S.D) of Cedrus deodara *Seedlings at Two Temperature Regimes*

		Radicle Length (cm)		Plumule Length (cm)		Seed Vigor Index	
Seed Source	Altitude	15°C	20°C	15°C	20°C	15°C	20°C
Pauri	1698	6.22 ± 0.86[a]	5.70 ± 0.72[a]	7.89 ± 1.05[ab]	8.12 ± 0.81[ab]	1395.85 ± 99.96[a]	1160.91 ± 104.65[a]
Jageshwar	1870	4.05 ± 1.18[cd]	3.25 ± 0.96[de]	4.66 ± 0.47[e]	4.77 ± 0.52[e]	722.51 ± 76.35[d]	435.75 ± 232.56[d]
Gwaldam	1940	4.72 ± 0.66[bc]	4.04 ± 0.41[bcd]	6.45 ± 0.72[bcd]	6.28 ± 0.70[cd]	1035.35 ± 73.47[bc]	565.17 ± 67.31[cd]
Dandachalli	2100	5.17 ± 0.62[abc]	4.87 ± 0.48[ab]	7.18 ± 0.63[abc]	7.03 ± 0.71[bc]	1197.25 ± 85.48[ab]	709.6 ± 248.91[bc]
Chakrata	2118	4.49 ± 0.97[bc]	3.54 ± 0.78[cde]	5.03 ± 0.38[de]	4.86 ± 0.45[e]	895.48 ± 86.01[cd]	541.59 ± 130.32[cd]
Dhanaulti	2159	4.05 ± 1.17[cd]	3.40 ± 0.47[de]	8.57 ± 1.75[a]	8.63 ± 1.09[a]	1251.94 ± 234.96[ab]	1179 ± 90.86[a]
Mukteswar	2171	4.31 ± 1.21[bcd]	4.00 ± 0.94[bcd]	5.48 ± 0.91[de]	5.30 ± 0.65[de]	872.08 ± 307.39[cd]	586.32 ± 291.[cd]
Ghansali	2200	5.51 ± 1.29[ab]	4.55 ± 1.08[bc]	7.20 ± 0.96[abc]	6.75 ± 1.05[bc]	1218.65 ± 87.52[ab]	897.37 ± 143.80[b]
Chopta	2608	3.08 ± 0.39[d]	2.75 ± 0.51[e]	5.06 ± 1.43[de]	5.27 ± 1.22[de]	782.89 ± 166.26[d]	734.26 ± 149.13[bc]
Harshil	2620	3.97 ± 0.33[cd]	3.73 ± 0.33[cde]	5.97 ± 0.71[cde]	4.90 ± 2.01[de]	767.68 ± 144.89[d]	723.63 ± 179.74[bc]
Mean		4.56	3.98	6.35	6.19	1013.97	753.36
Coefficient of variation		22.39	20.03	18.15	17.76	17.95	27.08

Note: Means followed by the same letter are not significantly ($p < .05$) different.

length. The electric conductivity of soil showed a significant ($p < .05$) positive correlation with cone weight, cone length/diameter ratio, and MGT. However, the electric conductivity has shown a significant inverse correlation with cone width, number of scales, number of sound seeds, number of unsound seeds, seed length, seed width, seed thickness, and seed vigour index at $p < .01$ level of probabilities and with germination percent, radicle length, plumule length, and total length at $p < .05$ level of probabilities (Table 8).

Pearson correlations (Karl Pearson's) was used for 190 parameters of cone, seed traits, and seed germination in combination with each other. Significant correlation ($p < .01$ & $p < .05$) were estimated between the cone, seed, and seed germination parameters, viz. cone length vs. cone diameter, cone weight, cone length/width ratio, seed width, seed length/width ratio, seed weight, and seed germination percent. Cone width vs. number of scales per cone, number of unsound seeds per cone, seed length, seed length/width ratio, seed moisture percent and MGT. Cone weight vs. number of sound seed per cone, cone length/diameter ratio, seed length/width ratio, seed germination percent and MGT. Number of scales per cone vs number of unsound seeds per cone, seed length, seed width, seed length/width ratio, seed weight, seed moisture, and seed germination percent. Number of sound seeds per cone vs. cone length width ratio, seed width, seed length/width ratio, seed moisture percent, seed germination percent, and MGT. Cone length/diameter ratio vs. seed width, seed thickness, seed length/width ratio, and seed germination. Number of unsound seeds per cone vs. seed width, seed weight, seed moisture percent, and MGT. Seed length vs. seed width, seed thickness, seed length with wing, seed length/

Table 7.
Estimation of Variance and Coefficient for Various Cone and Seed Characteristics of Cedrus deodara

	Coefficient of Variance					
Characters	GCV	PCV	ECV	Heritability % (Broad Sense)	Genetic Advance	Genetic Gain (%)
Cone length (cm)	15.43	14.94	3.83	93.83	2.56	28.95
Cone diameter (cm)	10.79	10.29	3.26	90.86	1.26	19.61
Cone weight (g)	25.48	24.28	7.72	90.81	51.21	46.27
Number of scales cone	11.50	7.59	8.64	43.55	10.39	10.02
Number of sound seeds/cone	17.50	15.98	7.13	83.38	39.85	29.18
Number of unsound seed/cone	52.74	40.62	33.64	59.32	20.42	62.57
Seed length (cm)	17.67	18.67	5.91	90.08	1.38	115.02
Seed width (mm)	11.96	13.70	9.96	77.74	0.38	80.61
Seed thickness (mm)	16.29	20.00	7.41	85.07	0.39	122.07
Seed length with wing (cm)	13.01	4.29	12.27	10.88	0.08	2.83
Seed weight (g)	31.60	26.39	17.38	69.74	4.16	44.07
Seed moisture content (%)	45.53	5.61	45.18	1.52	0.23	1.38

Note: GCV = Genotypic coefficient of variance; PCV = Phenotypic coefficient of variance; ECV = Environmental coefficient of variance.

Table 8.
Correlation Computed Between Geographical Variables with Cone, Seed, Germination, and Growth Parameters in Cedrus deodara

Geographical Variables	Cone, Seed, and Seedling Parameters																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Altitude	0.07	−0.24*	0.47**	−0.16	−0.28*	0.24*	−0.37**	0.01	−0.28*	−0.09	0.31*	0.28*	0.02	−0.12	−0.24*	−0.02	−0.46**	−0.24*	−0.40**	−0.41**
Latitude	0.11	−0.18	0.35**	−0.49**	0.12	0.28*	0.34**	−0.05	−0.19	0.03	0.45**	0.13	0.42**	0.19	0.00	−0.17	−0.04	0.15	0.08	0.05
Longitude	0.13	0.16	0.13	0.60**	−0.33*	0.05	−0.43**	0.23*	0.19	0.05	−0.46**	0.08	−0.23*	−0.34**	−0.34**	0.19	−0.12	−0.32*	−0.28*	−0.34**
Temperature	−0.07	−0.30*	−0.05	0.08	0.53**	0.14	−0.03	−0.03	0.13	0.24	0.09	−0.16	0.05	−0.01	0.12	0.04	0.26*	0.02	0.15	0.15
Rainfall	0.48**	0.35**	0.60**	−0.03	0.17	0.32*	0.08	0.23*	−0.01	−0.02	0.15	0.26*	0.43**	0.14	−0.19	−0.16	−0.03	−0.03	−0.04	−0.11
Soil pH	−0.12	−0.39**	0.23*	−0.44**	−0.40**	0.18	0.05	−0.45**	−0.40**	−0.41**	0.07	−0.09	−0.02	−0.10	−0.31*	0.26*	−0.40**	−0.29*	−0.41**	−0.43**
EC	0.01	−0.37**	0.23*	−0.48**	−0.46**	0.31*	−0.37**	−0.49	−0.45**	−0.42**	0.13	−0.08	0.04	−0.08	−0.31*	0.25*	−0.32*	−0.25*	−0.31*	−0.36**

Note: 1, cone length; 2, cone diameter; 3, cone weight; 4, number of scales; 5, number of sound seeds; 6, cone/diameter ratio; 7, number of unsound seeds; 8, seed length; 9, seed width; 10, seed thickness; 11, seed length with wings; 12, seed length/width ratio; 13, seed weight; 14, seed moisture content; 15, germination percent; 16, mean germination time, 17, radicle length; 18, plumule length; 19, total length; 20, seed vigor index.
NS = Nonsignificant.
*Significant at $p < .01$.
**Significant at $p < .05$.

width ratio, and MGT. Seed width vs. seed thickness, seed length/ width ratio, MGT. Seed length with wing vs. seed weight and MGT. Seed weight vs. seed moisture and MGT. Seed moisture percent vs. seed germination percent and MGT. Other parameters had shown nonsignificant relationship with each other (Table 9).

Discussion

In the present study, significant ($p > .05$) variations were observed in cone parameters. Maximum cone length, cone weight, and cone length/ diameter ratio were observed in Harshil, whereas maximum cone diameter and number of sound seeds per cone were observed in Kandolia provenance. Number of scales per cone was recorded maximum in Mukteswar. A significant ($p > .05$) variation among seed sources in cone length and cone diameter of *C. deodara* from Jammu and Kashmir, India, was reported by Mughal and Thapliyal (2013). Similar results with respect to cone morphological characteristics were reported for *Pinus wallichiana* (Rahman et al., 2017) and *Pinus halepensis* (Guemri et al., 2019). The cone characters varied in population due to genotypes of the trees and effects of environmental factors, which vary with locations and populations and within locations depending on the genotype (Cendán et al., 2013; Zas et al., 2015).

Seed morphology of *C. deodara* varied among the seed source. The seed weight was a more variable trait among the seed morphometric traits and would be used for selection purpose. Seed size and weight regulate the seedlings survival under stressful conditions because larger seeds have more reserves of food materials and carbohydrates for emerging seedlings. (Salazar et al., 2020). The observed variations in seed parameters may be attributed to the different genetic structure developed because of adaptation to diverse environmental conditions prevailing throughout their distributional range (Cendán et al., 2013; Zas et al., 2015). Similar results were also reported in *Pinus wallichiana* (Rahman et al., 2017), *Pinus sylvestris* (Sevik & Topacoglu, 2015) *Pinus halepensis* (Guemri et al., 2019**)**, and *Bauhinia variegata* (Nagar et al., 2022).

Seed germination of *C. deodara* was varied among the seed source. Variation in seed germination is due to a complexity of environmental and genetic factors during seed formation and subsequent handling of treatments (Zhang et al., 2020). Variation is apparent in seed germination of a single species when collected from different sources or from different elevations (Singh et al., 2004). These variations may be because the *C. deodara* grows over a wide range of climatic conditions as well as soil types and altitudes. Seed germination of *C. deodara* was varied among the seed sources, and 15°C temperature was found most suitable for the seed germination as compared to 20°C temperature. Thus, the seed size and weight reflect the maximum germination at suitable temperature. Seed size and weight have also been reported as pronounced effects on seed germination in *Celtis australis* (Singh et al., 2006a). Generally, large seeds have fast and uniform germination due to more endosperm nutrient pool (Okonwu et al., 2022). Seeds of *C. deodara* did not reveal any dormancy in present study. Variations in germination from different provenances have also been reported for *Lophozonia glauca* (Santelices et al. 2017), *Bauhinia variegata* (Nagar et al., 2022), and *Suaeda fruticosa* (Shah et al., 2022).

Maximum germination was found at 15°C (lower temperature) as compared to 20°C, supported by the findings of Ullah et al. (2022**)** who have reported that the germination decreased with the increased constant temperatures. In *Cedrus libani*, the highest and the lowest average germinations were obtained at temperatures of 4ºC and 24ºC, respectively.

Table 9.
Correlation Coefficient Between Different Cone, Seed Traits, Germination, and Growth Parameters of Cedrus deodara

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2	0.60**																		
3	0.37**	0.09^{ns}																	
4	0.10^{ns}	0.23*	0.02^{ns}																
5	−0.15^{ns}	0.16^{ns}	−0.23*	0.04^{ns}															
6	0.76**	−0.05	0.39**	−0.05^{ns}	−0.32*														
7	0.08^{ns}	0.30*	−0.15^{ns}	0.23*	−0.15^{ns}	−0.14^{ns}													
8	0.15^{ns}	0.47**	0.15^{ns}	0.23*	−0.04^{ns}	−0.19^{ns}	−0.06^{ns}												
9	−0.24*	0.18^{ns}	−0.18^{ns}	0.24*	0.30*	−0.41**	0.01^{ns}	0.54**											
10	−0.20^{ns}	−0.03^{ns}	0.05^{ns}	0.11^{ns}	0.01^{ns}	−0.23*	−0.40**	0.48**	0.36**										
11	−0.01^{ns}	−0.04^{ns}	0.15^{ns}	−0.44**	0.02^{ns}	0.01^{ns}	−0.13^{ns}	−0.06^{ns}	0.03^{ns}	−0.02 ns									
12	0.38**	0.32*	0.36**	0.02^{ns}	−0.35**	0.23*	−0.07	0.53**	−0.43**	0.16^{ns}	−0.10^{ns}								
13	0.24*	0.20^{ns}	0.19^{ns}	−0.26*	0.07^{ns}	0.16^{ns}	-0.27*	0.31*	0.23*	0.13^{ns}	0.26*	0.11^{ns}							
14	0.05^{ns}	0.23*	−0.16^{ns}	−0.24*	0.29*	−0.10^{ns}	−0.25*	0.10^{ns}	0.08	0.18^{ns}	0.16^{ns}	0.00^{ns}	0.42**						
15	−0.29*	0.06^{ns}	−0.57**	−0.27*	0.44**	−0.43**	0.01^{ns}	0.06^{ns}	0.12^{ns}	0.18^{ns}	−0.09^{ns}	−0.06 ns	−0.05^{ns}	0.34**					
16	−0.16^{ns}	−0.34**	−0.23*	−0.05^{ns}	−0.24*	0.08^{ns}	0.33**	−0.43**	−0.27*	−0.16 ns	−0.29*	−0.19 ns	−0.47**	−0.29*	0.01^{ns}				
17	0.07^{ns}	0.18^{ns}	−0.13^{ns}	−0.08^{ns}	0.36**	−0.07^{ns}	−0.30*	0.08^{ns}	0.24*	0.23*	0.13^{ns}	−0.16 ns	0.13^{ns}	0.24*	0.30*	−0.24*			
18	−0.28*	0.04^{ns}	-0.06^{ns}	−0.17^{ns}	0.24*	−0.39**	−0.37**	0.29*	0.29*	0.39**	0.24*	0.03^{ns}	0.18^{ns}	0.30*	0.42**	−0.41**	0.34*		
19	−0.15^{ns}	0.12^{ns}	−0.11^{ns}	−0.16^{ns}	0.36**	−0.31*	−0.41**	0.25*	0.33**	0.38**	0.23*	−0.07 ns	0.19^{ns}	0.34**	0.45**	−0.41**	0.76**	0.87**	
20	−0.25*	0.13^{ns}	−0.28*	−0.23*	0.43**	−0.40**	−0.33**	0.24*	0.30*	0.37**	0.16^{ns}	−0.07 ns	0.14^{ns}	0.39**	0.68**	−0.34**	0.71**	0.84**	0.96**

1, cone length; 2, cone diameter; 3, cone weight; 4, number of scales per cone; 5, number of sound seeds; 6, cone/diameter ratio; 7, number of unsound seeds; 8, seed length; 9, seed width;10, seed thickness; 11, seed length with wings; 12, seed length/width ratio; 13, seed weight; 14, seed moisture content; 15, germination percent; 16, mean germination time; 17, radicle length; 18, plumule length, 19, total length; 20, seed vigor index.
ns = nonsignificant.
*Significant at $p < .01$.
**Significant at $p < .05$.

Thus, the rate of germination is strongly temperature dependent (Yilmaz & Tonguc, 2014). Similarly in *Pinus bungeana*, seed germination occurs in a comparatively cool temperature range of 15–20°C (Guo et al., 2020). Temperature plays an important role in controlling the growth and development of plants, and the effect of temperature on seed germination is quite complex because it affects each stage of germination process in a different way and is not independent of other factors (Singh et al., 2004).

Maximum MGT recorded in Gwaldam and the Dandachalli seed source indicated late and slow germination. Minimum MGT days recorded for Kandolia showed early and rapid germination compared to other provenances. Mean germination time indirectly expresses the rapidity of germination, and lower the MGT faster the germination, which was evidenced from the value of MGT (Singh et al., 2004). Seeds collected from different seed source take maximum time to germinate at 20°C and minimum time to germinate at 15°C with corresponding GI.

The ($p \leq .05$) significant variations have been noted in initial seedling growth characteristics of different seed sources (Table 8 and 9). Seed germination at lower temperature produces larger seedlings. Qu et al. (2023) noted in *Rorippa* that low temperature is more beneficial to the accumulations of the seedlings. The differences in germination patterns and seedling growth rates may be related to climatic and geographic influences or more importantly even to genetic differences. It is clear from the result that maximum seedling growth was obtained at Pauri seed source which consists of maximum seed weight and germination percent. It is interesting to note that the seed source which had heavier seeds, had greater seed germination and produced superior seedlings in terms of weight. The result of the present study strongly supports this hypothesis as seed sources having higher seed germination also had better seed growth (Singh & Bhatt, 2008). Similar finding was also recorded in *Quercus glauca* (Singh et al., 2010), *Quercus leucotricophora* (Saklani et al., 2012) *Pinus sylvestris* (Sevik & Topacoglu, 2015), *Madhuca latifolia* (Nayak & Sahoo, 2020), and *Pinus wallichiana* (Kaur et al., 2022).

The maximum heritability (broad sense) and genetic gain were recorded for cone weight, which indicates that the heritability in broad sense would have useful indication about the relative value of the selection. Soro et al. (2022) have seen that the heritability estimates along with genetic gain are more useful than the heritability alone in predicting the resultant effect of selecting the best genotypes for a given trait. Results obtained in genetic parameters indicate better scope for improvement in a breeding program to enhance the high plant growth through these characters. The wide variation coupled with genetic component offers the opportunity for genetic improvement. Therefore, results from this study would be a key to screen the best traits among a pool of traits that could be improved with success. The phenotypic CV of the traits evaluated in the present study was lower than the genotypic CV, indicating lesser effect of phenotype over genotype. Nevertheless, heritability with genetic gain estimates of these traits found huge influence of environmental factors. Similar results on the variability parameter estimates considering genetic parameters were observed for *Celtis australis* (Singh & Bhatt, 2008), *Quercus glauca* (Singh et al., 2010), *Quercus leucotrichophora* (Saklani et al., 2012), *Caespalpinia sapppan* (Arthanari et al., 2013), *Madhuca latifolia* (Nayak & Sahoo, 2020), and *Emblica officinalis* (Naithani et al., 2020).

Simple correlations of cone, seeds, and seed germination parameters with geographic, abiotic, and soil factors (latitude, longitude, altitude, rainfall, temperature, soil pH, and electric conductivity) show a significant ($p \leq .01$ and $p \leq .05$) positive correlation. Correlation is one of the significant biometric tools which measure the degree and magnitude of associations between various traits in a tree improvement programme. A clear understanding of association among different traits is of great importance, as it confirms the choice of one character to other. Also, these quality parameters of seed would be influenced by climatic factors like temperature, rainfall, sunshine, air current, nutritional status of soil, moisture condition of soil, and pH of soil of the area. Positive correlations with cone weight and seed number were reported for *C. deodara* (Mughal & Thapliyal, 2013) and *Pinus halepensis* (Singh et al., 2018). A significant variation in morphological traits of *Cola millenii* fruits was recorded between phyto districts due to the environment heterogeneity of sites (Lawin et al., 2021). Roman et al. (2022) also reported that the genotypes and environmental heterogeneity of the seed source within the provenances may finally result in diverse performances. Positive correlations of seed physical traits with laboratory germination may be because of more food reserve in the endosperm. These traits therefore may be given priority for improving germination. The present study indicated that cone weight, cone length/diameter ratio, seed length with wing, and seed length/width ratio increase with increasing altitude of provenance, while the number of unsound seeds per cone, cone diameter, number of sound seeds per cone, seed width, and seed germination percent were decreased with increasing the altitude of provenance. Latitude showed a positive relationship with cone weight, number of unsound seeds per cone, seed length with wing, seed weight and cone length/width ratio, indicating northern trend, and was inversely correlated with the number of scales indicating southern trend. The longitude exhibited a positive correlation with the number scales per cone and seed width, claiming that these traits are increasing toward eastern extremes. The inverse correlation of longitude with the number of nonviable seeds per cone, seed length with wings, seed moisture content, germination percent, number of sound seeds per cone, and seed weight indicates that these traits are increasing toward western extremes. The temperature was inversely correlated with cone diameter, indicating that the trait was decreased with increasing temperature. The high rainfall increased the cone length, cone diameter, cone weight, seed weight, cone length/ diameter ratio, seed length, and seed length/width ratio. Soil pH of studied sites had influenced the cone weight, while higher soil pH of the studied sites decreased the cone diameter, number of scales per cone, number of sound seeds per cone, seed length, seed width, seed thickness, and germination percent. Electric conductivity of soil influenced the cone weight, cone length/diameter ratio, and MGT. However, the higher electric conductivity decreased the cone width, number of scales per cone, number of sound seeds per cone, number of unsound seeds cone, seed length, seed width, seed thickness, and seed germination percent.

The correlation coefficient computed between 20 parameters had revealed a significant ($p < .05$) variation for all the seed characters, which directly expose significant relationships for all the combinations. Out of 190 correlation coefficient values, 100 were found significant at $p < .01$ and $p < .05$ level of probabilities. These correlations were expected because of interdependence of all the combinations with each other, which means if one value increases other value will also increase or decrease. The correlation studies among various characters help in developing tree improvement strategies considering direct selection, as suggested by Singh and Bhatt (2010) in *Dalbergia sissoo.*

The present study on provenance variation is very important for the further improvement program of *C. deodara* that grows in a wide range of geographical and climatic conditions throughout the Himalayan regions. The provinces namely Pauri, Dhanaulti and Dandachali provenances have been identified as the best based on the cone, seed traits, and seed germination. The 15°C temperature is most favorable for obtaining the highest, uniform, and quick germination without any pretreatment. The higher heritability with a genetic gain was the important parameter for the selection of the traits for tree improvement programs. Based on these two parameters, morphological characteristics of cone and seed, the cone length, cone diameter, cone weight, number of viable sound seeds per cone, seed length, seed thickness, and seed weight are the important characteristics that are under strong genetic control and can be exploited for the further improvement of *C. deodara* in the Himalaya region for mass multiplication under different reforestation and afforestation programs.

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