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Variation in cone morphology, seed traits and germination behaviour of *Cedrus deodara* a study of Bhaderwah forest division (Jammu and Kashmir), India

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ABSTRACT

Cedrus deodara G. Don, a key conifer of the Western Himalayas, plays a vital ecological and silvicultural role in montane forest ecosystems. This study investigated altitudinal variation in cone morphology, seed traits, and germination behavior across five elevations (1421–2747 m) in the Bhaderwah Forest Range, Jammu and Kashmir, India. Significant variation was observed among seed sources in cone length (8.98–11.82 cm), cone weight (105.4–249 g), and seed number per cone. Seed traits such as length (1.41–1.61 cm), width (5.98–7.07 mm), and thickness (2.87–3.63 mm) also varied with altitude. Germination experiments revealed that seeds from mid-altitudes, particularly 2204 m (A3), exhibited the highest germination percentage (96%), shortest mean germination time (11.89 days), and highest germination index (9.30). Seedling vigor, assessed through radicle and plumule length and vigor index, was also highest at A3. In contrast, seeds from the lowest altitude (A1, 1421 m) showed the poorest performance. The findings suggest that mid-altitude sources offer the most promising seed material for reforestation and afforestation efforts in the region. Altitude-driven variation in reproductive and physiological traits underscores the need for site-specific seed sourcing to enhance forest regeneration success.

Figure : 00 References : 18 Tables : 05
KEY WORDS : Cone, Germination, Morphology, Seed, Traits, Western Himalayas

Introduction

The selection of superior seed sources is a critical component of tree improvement programs and ecological restoration efforts, particularly for high-value coniferous species like *Cedrus deodara* (Roxb.) G. Don. Commonly known as Deodar cedar, this species is native to the Western Himalayas and is ecologically, economically, and culturally significant. It forms extensive forest stands and is valued for its durable timber, medicinal properties, and ornamental use. However, successful propagation and regeneration of *Cedrus deodara* depend largely on the availability of genetically and physiologically superior seeds.

Altitudinal gradients profoundly influence the phenotypic and physiological traits of forest trees. Variations in temperature, moisture, soil characteristics, and photoperiod across elevations can significantly affect cone morphology, seed development, germination behavior, and seedling vigor. Understanding these variations is vital for identifying optimal seed sources that ensure better survival, growth, and adaptability in plantation and restoration projects.

Previous studies have documented that seeds collected from mid-altitudinal zones often exhibit better germination and seedling performance due to moderate environmental conditions that favor seed maturation and physiological development. However, region-specific data for *Cedrus deodara* remain limited, particularly in

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TABLE-1 : Description of the study site. Location- Bhaderwah Forest Division

S.No	Altitude (m)	Latitude N	Longitude E
1.	A1=1421	33.056	75.60
2.	A2=1800	32.93	75.70
3.	A3=2204	32.91	75.72
4.	A4=2490	32.90	75.73
5.	A5=2747	32.91	75.75

the Bhaderwah Forest Range of Jammu and Kashmir, India.

The present study aims to evaluate the altitudinal variation in cone morphology, seed traits, and germination parameters of *Cedrus deodara* across five distinct elevations ranging from 1421 m to 2747 m. By assessing these variations, the study seeks to identify the most suitable altitudinal source(s) for quality seed procurement to support afforestation, reforestation, and conservation initiatives in the Western Himalayas.

Methodology

Study area and seed source selection

The study was conducted in the Bhaderwah Forest Range, District Doda, Jammu and Kashmir, India. Five altitudinal zones were selected for sampling, ranging from 1421 m (A1) to 2747 m (A5) above sea level. The geographical coordinates and average climatic conditions of the sites were obtained from the Indian Meteorological Department, Bhaderwah Station. These sites were chosen to represent a wide altitudinal gradient for assessing phenotypic and physiological variations in

TABLE-2 : Altitudinal variation with respect to cone characteristics of *Cedrus deodara*

Altitude	Cone Length (Cm)	Cone Weight (Gm)	Cone Diameter (Cm)	L/D Ratio	Scales/ Cone	No. Of Seeds/ Cone
A1	8.98±0.92	105.4±6.39	5.52±0.66	1.62	135±5.52	138±15.6
A2	11.71±0.71	225±10.24	6.03±0.61	1.85	135±6.88	175±21.6
A3	11.82±0.82	249±10.67	7.70±1.07	1.53	138±5.56	170±16.9
A4	11.11±0.11	160.8±8.55	6.15±0.52	1.80	137±4.52	142±11.2
A5	9.73±0.34	172.2±4.90	6.84±0.29	1.41	119±8.84	140±13.3
Mean	10.67	182.48	6.45	1.64	132.8	153.0
Coefficient of variance	11.80	30.94	13.08	11.19	5.89	11.73
C.D	**0.10**	**2.43**	**0.09**	**0.03**	**2.51**	**2.09**

TABLE-3 : Altitudinal variation with respect to seed characteristics of *Cedrus deodara.*

Altitude	Seed Length (Cm)	Seed Width (Mm)	Seed Thickness (Mm)	Seed Length With Wings (Cm)	L/W	No. Of Seeds In 100gm	Seed M.C%
A1	1.41±0.057	5.98±0.46	2.87±0.25	3.43±0.49	0.23	390±11.6	19.29±0.074
A2	1.52±0.067	6.59±0.68	3.59±0.49	3.43±0.49	0.23	416±14.6	19.03±0.224
A3	1.61±0.015	7.07±1.16	3.63±0.53	4.46±1.08	0.22	402±6.9	19.23±0.004
A4	1.47±0.117	6.22±0.62	3.51±0.41	3.92±0.54	0.23	409±7.6	19.29±0.074
A5	1.46±0.107	6.44±0.84	3.12±0.72	3.86±0.48	0.22	397±11.6	19.23±0.004
Mean	1.494	6.46	3.34	3.82	0.226	402.8	19.21
Coefficient of variance	5.07	6.37	9.97	11.15	2.42	2.52	0.56
C.D	**0.03**	**0.05**	**0.01**	**0.01**	**0.002**	**1.93**	**0.11**

Cedrus deodara.

Mature cones were collected during October from each of the five altitudinal sources. Ten cones were randomly harvested from each of five phenotypically superior trees per source (totaling 50 cones per altitude). The cones were collected by climbing the tree and were carried in cotton bags and transported to Faculty for evaluation.

In the laboratory, cones were air-dried for 7–10 days to induce dehiscence. Morphological parameters such as cone length, diameter, weight, number of scales per cone, and the number of sound and unsound seeds per cone were recorded using digital calipers and electronic balances.

Seed Trait Analysis

After extraction, seeds were stored at room temperature until analysis. Seed morphology was studied using twenty five (25) seeds per source in four replicates. Measured traits included seed length (with and without wings), seed width, and seed thickness using a digital vernier caliper. Seed weight and number of seeds per 100 g were also determined. Seed moisture content was calculated by oven-drying 20 g of seeds at 104°C for 24 hours, using the following formula:

Moisture Content = wet weight – dry weight */* wet weight

Germination Experiment

Seeds were soaked in distilled water for 24 hours before germination tests. Germination was conducted in 9 cm Petri dishes lined with Whatman No. 1 filter paper, moistened with distilled water, and incubated in a germinator at constant temperatures of 15°C and 20°C. Each treatment included four replicates of 25 seeds.

Germinated seeds (with radicle emergence e" 2 mm) were recorded daily for 21 days. Filter papers were replaced weekly to prevent fungal growth. Germination percentage (GP), mean germination time (MGT), and germination index (GI) were calculated using the following formulas:

Mean germination time = © (ni * ti)/N

where ni = the number of seeds that germinated (2 mm radicle length) in a day.

ti= time (hours).

N = the total number of seeds that germinated in the period of experiments.

The germination index (GI) was calculated by following :-

¢' Germination Index = © (Gt/Dt),

TABLE-4 : Altitudinal Variation with Respect to Germination (%), Mean Germination Time, and Germination Index *of Cedrus deodara.*

Altitude	Germination %	Mean Germination Time	Germination Index
A1	84±3.2	12.50±1.16	7.71±0.45
A2	92±2.8	12.62±1.10	8.24±0.42
A3	96±2.5	11.89±1.13	9.30±0.47
A4	88±3.0	13.34±1.09	7.11±0.41
A5	64±3.5	16.05±1.15	4.15±0.38
Mean	84.8	13.28	7.30
Coefficient of variance	14.69	12.29	26.53
C.D	**2.55**	**1.52**	**0.93**

where Gt = the number of germinated seeds at the end of the germination period.

Dt = the total days for germination.

Seedling Vigour Assessment

Seedling vigor was evaluated by measuring radicle and plumule lengths of germinated seedlings after 21 days. The seed vigor index (SVI) was calculated by multiplying the sum of radicle and plumule lengths with the germination percentage:

SVI = (Radicle length + Plumule length) * Germination%

Statistical Analysis

All data were subjected to analysis of variance (ANOVA) to assess the significance of differences among altitudinal sources. The normality of residuals was tested using the Shapiro-Wilk test, homogeneity of variance with Bartlett's test, and independence of errors with the Durbin-Watson test. Mean separation was performed using Fisher's Least Significant Difference (LSD) test at a 5% significance level.

Results

Cone Morphology

Significant differences ($p < 0.05$) were observed in cone morphology of *Cedrus deodara* across altitudinal gradients (Table 2). Cones from the mid-altitude site A3 (2204 m) recorded the highest mean cone length (11.82 ± 0.82 cm), diameter (7.70 ± 1.07 cm), and weight (249 ± 10.67 g), while the lowest values were observed at the high-altitude site A5 (2747 m). These findings are consistent with earlier works[4], who also reported superior cone development in mid-elevation populations of *Abies pindrow*, attributing it to more favorable temperature and nutrient availability.

The number of scales per cone peaked at A3 (138), whereas the lowest was at A5 (119). A2 showed the highest number of seeds per cone (175 ± 21.6), while A1 had the lowest (138 ± 15.6). Similar to previous work[15], our results suggest that mid-altitudes provide optimal microclimatic conditions for cone and seed development in Himalayan conifers.

Seed Morphology

Seed morphological traits also varied significantly with altitude (Table 3). Seeds from A3 had the greatest average length (1.61 ± 0.015 cm), width (7.07 ± 1.16 mm), thickness (3.63 ± 0.53 mm), and seed length with wings (4.46 ± 1.08 cm). A1 recorded the lowest values for most traits. These results align with findings[11], who noted that seeds from higher altitudes were generally smaller, possibly due to lower temperatures affecting seed maturation.

Seed weight was highest at A2, indicating that heavier seeds may originate from intermediate

TABLE-5 : Radicle, Plumule Length (cm), and Seed Vigour Index of Seedlings.

Altitude	Radicle Length (cm)	Plumule Length (cm)	Seed Vigour Index
A1	3.3	7.6	915.6
A2	4.1	10.4	1334
A3	4.9	13.3	1747
A4	3.8	9.2	1144
A5	3.4	7.7	710
Mean	3.9	9.64	1170.12
Coefficient of variance	16.52	24.38	34.10
C.D	**0.01**	**0.03**	**98.50**

elevations with optimal nutrient accumulation. This observation parallels the earlier results[18], who found a positive correlation between seed weight and germination success in Himalayan conifers.

Germination Performance

Germination parameters varied significantly ($p < 0.001$) among sources (Table 4). A3 exhibited the highest germination percentage (96 ± 2.5%), the shortest mean germination time (11.89 ± 1.13 days), and the highest germination index (9.30 ± 0.47). These findings mirror those of previous ihnvestigators[8,17], who observed that seeds from mid-altitudes germinate faster and more uniformly, likely due to balanced dormancy and optimal physiological maturity.

Seedling Vigour

Seedling vigor, a key indicator of early establishment success, also varied with altitude (Table 5). A3 recorded the highest radicle length (4.9 cm), plumule length (13.3 cm), and seed vigor index (SVI: 1747), followed by A2 (SVI: 1334). A5 again ranked lowest (SVI: 710). These trends support the conclusions[3,12], who found that seedling vigor is highest in populations originating from ecologically moderate elevations, due to superior seed reserves and metabolic activity.

Statistical Analysis

The Shapiro-Wilk test confirmed normal distribution of residuals ($p = 0.221$), while the Other test indicated independence ($p = 0.065$). Bartlett's test detected non-homogeneous variance ($p = 0.006$), which justified the use of LSD-Fischer post hoc analysis. The critical difference (CD) for germination percentage was 7.37, confirming statistically significant differences among altitudinal sources.

Discussion

This study revealed considerable altitudinal variation in cone morphology, seed traits, germination behavior, and seedling vigor of *Cedrus deodara* across five elevations in the Bhaderwah Forest Range. The findings indicate that cone and seed characteristics, as well as germination and seedling performance, were significantly influenced by elevation, suggesting environmental adaptations or ecotypic differentiation among the sampled populations.

Among all sources, the mid-altitudinal site A3 consistently outperformed the others in most parameters. A3 recorded the highest cone length (11.82 ± 0.62 cm), cone diameter (7.70 ± 1.07 cm), and cone weight (249.1 ± 10.67 g), along with a high number of seeds per cone (170 ± 16.9). These results are consistent with earlier ones[4], who also reported superior cone development in mid-elevation populations of *Abies pindrow,* attributing it to favorable temperature and nutrient availability. In contrast, the lowest values for these cone parameters were observed at the highest altitude, A5, where the cone weight was only 172.2 ±

4.90 g, and the number of seeds per cone was significantly reduced (140 ± 13.3). The lower productivity at A5 may be attributed to environmental stressors such as lower temperatures and shorter growing seasons, which can negatively impact cone development and seed filling.

Seed morphometric traits also varied significantly with altitude. Seeds from A3 showed maximum values for seed length (1.61 ± 0.015 cm), seed width (7.07 ± 1.16 mm) and seed thickness (3.65 ± 0.53 mm), while A1 recorded the lowest values in all three dimensions. These results align with earlier finding[11], that seeds from higher altitudes were generally smaller, possibly due to lower temperatures affecting seed maturation. Seed length with wings was also highest at A3 (4.46 ± 1.08 cm), suggesting better potential for wind dispersal. Although seed moisture content was relatively stable across all sources (around 19.2%), the number of seeds per 100g was again highest at A2 (416 ± 14.6). This indicates denser, better-formed seeds at mid-altitudes. This observation parallels the results[18], that a positive correlation between seed weight and germination success in Himalayan conifers.

Germination parameters also varied significantly among sources. The highest germination percentage was recorded at A3 (96 ± 2.5%), followed by A2 (92 ± 2.8%), whereas A5 displayed the lowest germination (64 ± 3.5%). Similarly, the germination index, which reflects both the speed and uniformity of germination, was highest at A3 (9.30 ± 0.47) and lowest at A5 (4.15 ± 0.38). These findings mirror those[8,17] which observed that seeds from mid-altitudes germinate faster and more uniformly, likely due to balanced dormancy and optimal physiological maturity. The mean germination time was shortest at A3 (11.89 ± 1.13 days) and longest at A5 (16.05 ± 1.15 days), suggesting delayed or staggered germination under harsh conditions at higher elevations.

These trends extended into early seedling development. The A3 provenance yielded seedlings with the greatest radicle length (4.9 cm), plumule length (13.3 cm), and the highest seed vigor index (1747). This reflects a strong correlation between seed quality and early growth potential. This is consistent with[3,12], which found that seedling vigor is highest in populations originating from ecologically moderate elevations, due to superior seed reserves and metabolic activity. In comparison, A5 again showed reduced performance, with a seed vigor index of only 710. This pattern indicates that environmental conditions at mid-elevations not only favor the production of larger, heavier cones and seeds but also result in improved germination success and more vigorous seedling growth.

Taken together, the data demonstrate that *Cedrus deodara* populations at mid-altitudes (particularly A2 and A3) are morphologically and physiologically better adapted to local conditions, resulting in enhanced reproductive success and seedling establishment. Conversely, populations at the highest elevation (A5) exhibit reduced performance across all measured parameters, likely due to harsher climatic conditions and limited resource availability. These findings have important implications for conservation and afforestation programs, suggesting that mid-altitude provenances may be the most suitable sources for seed collection and nursery propagation efforts aimed at restoring or expanding *Cedrus deodara* populations.

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