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Investigating source variation in cone and seed morphology, germination dynamics and genetic traits of *Abies pindrow* Royle across Kashmir Himalayas

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Abstract

A study conducted at the Division of Forest Biology and Tree Improvement laboratory, SKUAST-K, assessed cone and seed morphology variation, germination traits, and genetic variability in *Abies pindrow* Royle across three forest divisions of the Kashmir. The analysis included eight phenotypically superior trees from three forest divisions: Pir Panchal, Tangmarg and Sindh forest division, focusing on cone length, diameter, weight, specific gravity, average number of seeds per cone, average number of filled seeds, average number of empty seeds, seed length, seed diameter and 1000-seed weight and germination characteristics. Significant variation was observed among seed sources in cone dimensions, seed and germination traits. T₃ of Pir Panchal division exhibited superior cone traits including highest cone length (11.46 cm), cone diameter (5.39 cm), cone weight (68.22 g), cone specific gravity (1.33), number of seeds per cone (378.77) and number of filled seeds per cone (299.83) and in terms of morphological traits of seed, maximum seed weight (68.17 g), seed length (9.49 mm) and seed width (5.63 mm) was also recorded in seeds collected from tree T₃ of Pir Panchal division respectively as compared to other trees. Germination parameters such as germination percentage, germination energy, germination value, peak value, mean daily germination, root vigor index and shoot vigor index also varied significantly, with T₃ of Pir Panchal showing the best performance. The study found T₃ of Pir Panchal division consistently demonstrate superior cone and seed morphological traits and germination characteristics, indicating its potential for tree improvement programs. Genetic analysis indicated highest PCV (24.63) and GCV (21.82) was recorded for root vigor index. Highest heritability (h²) was observed in seed length (83%) and cone length (82%) indicating strong genetic control over these traits. This research highlights the importance of understanding cone and seed morphology as well as germination characteristics in relation to source variation, providing insights for improving *Abies pindrow* Royle under diverse environmental conditions in the Kashmir Valley.

Keywords: Cone, seed, source variation, morphology, germination characteristics, *Abies pindrow* Royle

Introduction

Firs (*Abies*) constitute a genus comprising 48-56 species of perennial conifers belonging to the Pinaceae family. *Abies pindrow* Royle, although globally distributed, flourishes primarily in North and Central America, Europe, Asia, and North Africa. This majestic tree adorns the Western Himalayas of India, Afghanistan, Nepal, and Pakistan, flourishing at elevations ranging from 2000 to 3600 meters above sea level (Kunwar *et al.*, 2020) [32]. While often found in pure clusters, it also gracefully shares its habitat with species such as *Abies spectabilis*, *Pinus wallichiana*, *Picea smithiana*, or *Cedrus deodara* (Tiwari *et al.*, 2020) [50].

In the enchanting valleys of Kashmir, *Abies pindrow* colloquially known as the Western Himalayan Fir, Silver Fir, Pindrow Fir, Pindrau and Buddul in Kashmiri language a prominent member of the conifer family, extends its reach from Kashmir to Nepal, thriving at altitudes between 2550-3350 m above sea level (Joshi and Samant, 2004) [25]. Occasionally, it graces ravines as low as 2150 m or soars to majestic heights of 3650 m above sea level. Standing tall as an evergreen giant, the Fir tree ascends to heights of 40 to 60 meters with a circumference of up to 7.5 m, boasting a singular sturdy trunk and modest branches. Its needle-like, lustrous dark green foliage ranks among the lengthiest in the fir lineage.

Notably, the species unique foliar disposition and the presence of dual silver streaks beneath the leaves of *Abies pindrow* Royle distinguish it (Kumar and Kumar, 2017) ^[30]. Initially cloaked in a dark purple hue, the seed cones mature into a rich reddish-brown color. The monoecious plant bears fan-shaped seed scales and a sleek surface adorned with concealed bracts (Farjon, 2010) ^[14].

Abies pindrow Royle has got significance due to their demand as timber for construction purpose, raw material for joinery, paneling and furniture industries (Tiwarei *et al.*, 2020) ^[50]. Over time, local populations in the Himalayan area have been documented to employ Silver Fir extensively for medicinal, non-medicinal and structural uses as well. It is considered highly durable and impervious to the majority of microorganisms and insects (Khan *et al.*, 2010) ^[27]. Its cones are also recognized to be highly attractive and are used for decoration (Sinha, 2019) ^[48]. The seeds contain fair percentage of essential oil which can be exploited commercially. In J&K and Ladakh bark extract is used to treat constipation, asthma, bronchitis, cold, cough, stomach ache, cuts, ulcers and wounds (Gairola *et al.*, 2014) ^[16]. However, despite its importance, *Abies pindrow* Royle faces numerous threats, including anthropogenic impacts and natural factors that hinder its regeneration and survival. Natural factors such as poor regeneration due to undecomposed humus and low seed germinative capacity contribute to the species degradation, compounded by high percentages of empty seeds in poor seed years (Kimothi *et al.*, 2021) ^[29]. Its ability to thrive under different site condition make it an ecologically important tree species to investigate the cone, seed and germination behavior under different prevailing site conditions as environmental conditions have been reported a cause of high variability (Petros *et al.*, 2008) ^[37]. Identification of sites characterized with quality seed production can be an important strategy to compensate the shortages during the poor seed cycle (Bhat *et al.*, 2018) ^[7]. Also, the species potential for genetic variability remains largely unexplored. Investigating cone and seed morphology, germination behavior, and genetic traits offers insights into its adaptability and productivity (Zobel & Talbert, 1984; Bhat & Chauhan, 2003) ^[6, 58]. These insights are pivotal for identifying superior genotypes, ensuring sustainable utilization, and enhancing the productivity of this valuable species (Graudal & Kjaer, 2000) ^[15].

The study aims to explore source variation in *Abies pindrow* Royle across the Kashmir Himalayas. Through an analysis of cone and seed morphology, germination characteristics and genetic traits, this study seeks to provide a comprehensive understanding of the species genetic potential and its adaptability to diverse ecological conditions. The findings are expected to play a pivotal role in identifying superior genotypes, facilitating mass propagation, and supporting the conservation of this important Himalayan tree species (Zobel & Talbert, 1984; Bhat & Chauhan, 2003) ^[6, 58].

Materials and Methods

The study was conducted in 2023-2024 at the Division of Forest Biology and Tree Improvement, Faculty of Forestry, SKUAST-K, Benhama, Ganderbal, Kashmir, under controlled laboratory conditions. An exhaustive survey was conducted across three Divisions of Jammu and Kashmir Forest Department, within the

Srinagar Circle. These divisions include the Pir Panchal Forest Division, Tangmarg Forest Division and Sindh Forest Division. Through purposive sampling, a total of eight sites were identified for assessment. At each site, which represents distinct sources, a careful selection process that identified healthy, middle-aged, and phenotypically superior *Abies pindrow* trees were selected for cone collection. The morphological characteristics of eight mother trees selected for collection are outlined in Table-01.

Mature cones were harvested from selected trees in October. The cones collected were transported to the Faculty of Forestry. Upon arrival, cones were evaluated to assess dimensions-length and diameter, weight, cone specific gravity, average number of seeds per cone, average number of filled and empty seeds per cone. For cone dimension determination four replications of ten cones were randomly selected from each source and measured using a digital caliper. For weight determination, four replications of ten cones per source were weighed using top balance. The specific gravity was determined by floating test or water displacement method (Barnett, 1979) ^[3] and value was determined by the ratio of unit weight to unit volume of cone. Number of seeds per cone was determined after seeds were extracted manually from the cones (Johnson *et al.*, 2003) ^[24]. The assessment of filled and empty seeds was determined using floating test and embryo excision test. The seeds were cut longitudinally for embryo observation and declared as empty (without embryo) and filled (with embryo).

The cone scales were detached from cone axis to obtain seed yield. The seeds were de winged and the respective seed dimensions were recorded for each source. Like cone dimensions, seed length and width was recorded using digital caliper with millimeter precision for four replications of ten seeds from each source. For weight determination, four replications of 1000 filled seeds per source were weighed using an analytical balance, following the guidelines outlined by ISTA (1966). For germination testing four replications of 100 seeds per source were placed on moistened filter paper in 90 mm Petri dishes and incubated in a seed germinator at 25±1 °C and 80±5% relative humidity. Germination was recorded everyday in all seed lots until no more germination was observed. Seed germination was defined as radicle emergence (>2 mm), and germinated seeds were left in the Petri dish until normal seedlings were produced. A normal seedling is defined as growth to show developed cotyledons, hypocotyls and roots, and without visible abnormalities (ISTA 2017). The germination data were analyzed using the formula by Shannon *et al.*, (1983) ^[44], with germination energy calculated as per Williams (1985) ^[53]. Germination value, peak value, and mean daily germination were calculated following Czabator's method (1962) ^[9]. Number of cotyledons was counted at the time of emergence of seedling in petri dishes. Root vigor index and shoot vigor index was calculated using formula of Abdul Baki and Anderson (1973) ^[1]. The germination process was monitored daily, with appropriate sterilization procedures to prevent contamination, and seeds were checked regularly for fungal or bacterial growth. The data obtained were analyzed for genetic parameters-Phenotypic and genotypic coefficient of variation, heritability using R statistical software.

Table 1: Phenotypic characteristics of selected mother trees of *Abies pindrow* Royle

Source			Tree height (m)	DBH (cm)	Crown height (m)	Crown length (m)	Crown Spread (m)
Forest Division	Mother Trees	Location					
Pir Panchal	T ₁	33°87'45"N 74°57'91"E	30.16	40.15	3.09	27.07	4.16
	T ₂	33°87'43"N 74°57'94"E	25.25	30.23	2.60	22.40	3.43
	T ₃	33°87'49"N 74°57'96"E	35.10	45.40	3.50	31.60	4.61
Tangmarg	T ₄	34°02'31"N 74°46'12"E	40.09	54.17	3.10	36.99	5.41
	T ₅	34°02'24"N 74°46'32"E	42.12	57.47	4.60	37.52	5.61
	T ₆	34°11'71"N 74°27'47"E	45.13	63.38	4.07	41.03	4.74
Sindh	T ₇	34°21'42"N 74°99'80"E	44.33	62.38	5.16	39.16	3.92
	T ₈	34°21'38"N 74°99'84"E	43.24	60.57	4.20	39.04	4.04

Results and Discussion

This study explores the variation in cone and seed morphology, germination characteristics, and genetic traits of *Abies pindrow* Royle across three forest divisions of Srinagar Circle of the Kashmir Himalayas. The findings reveal significant differences in cone and seed parameters, which have crucial implications for the development of tree improvement programs and the identification of superior seed sources for both propagation and conservation efforts in the region. Understanding this variation provides insights into optimizing *Abies pindrow* propagation strategies and enhancing its genetic resource management.

In the present study, cones collected from selected mother trees showed significant variation in morphological characteristics. The data present in Table-02 depicted that maximum cone length (11.46 cm), cone diameter (5.39 cm), cone weight (68.22 g), cone specific gravity (1.33), number of seeds per cone (378.77) and number of filled seeds per cone (299.83) was recorded in tree T₃ of Pir Panchal. Minimum cone length (8.16 cm), cone diameter (3.17 cm), cone weight (47.95 g), cone specific gravity (0.95), number of seeds per cone (283.90) and number of filled seeds per cone (183.69) was recorded in T₇ of Sindh forest division.

Similarly, number of empty seeds per cone were found highest (121.77) in cones collected from T₁ of Pir Panchal division. Lowest number of empty seeds per cone were recorded in 78.94 in T₃ of Pir Panchal division.

Tripathi and Barik (2001) [51] emphasized that cone traits are largely determined by the genetic constitution of individual trees, with environmental influences playing a relatively minor role, as earlier noted by Khalil (1974) [28]. According to Isik (1986) [23], cone morphology is mainly controlled by maternal genetics and further influenced by factors like the tree's age, health, and its specific micro and macro environmental conditions.

Variations in cone traits such as length, diameter, and weight can also stem from geographic and environmental differences, including soil type, climate, and overall tree health. These factors can act individually or in combination to affect growth, and ultimately originate from variation in seed sources. Rawat and Bakshi (2011) [39] suggested that differing natural constraints and favorable environmental settings across locations may account for observed differences in cone dimensions, which in turn affect the number of seeds produced per cone.

The difference in the number of filled and empty seeds in *Abies pindrow* is primarily due to its wind pollination mechanism. Favorable wind conditions enhance pollination success, leading to more viable seeds, while inadequate pollination results in a greater number of empty seeds and lower seed quality (Yadav *et al.*, 2011; Woods *et al.*, 1989) [54, 56].

Significant variation was observed in terms of seed morphological traits in the present study. Maximum seed weight (68.17 g), seed length (9.49 mm) and seed width (5.63 mm) was

recorded in seeds collected from tree T₃ of Pir Panchal division. Minimum seed weight (47.87 g), seed length (6.95 mm) and seed width (3.98mm) was recorded in seeds collected from T₇ of Sindh division. (Table-03). A relatively high seed weight is often preferred since it is associated with quick germination and healthy seedling establishment.

Seed weight variability is often linked to the diverse environmental conditions where *Abies pindrow* grows. Guterman (1992) pointed out that differences in seed traits among various trees and seed sources may result from environmental factors such as nutrient availability, sunlight, and water during seed development. Given the broad geographic range of *Abies pindrow*, such variability is expected. Harper *et al.* (1970) [20] supported this view, noting that both internal (genetic and maternal) and external (environmental) conditions during seed formation influence seed size.

Since the seeds in the present study were collected from different trees and locations, the variation in seed traits can be attributed to the genetic diversity that has evolved in response to varying environmental conditions across the species' distribution range (Salazar and Quesada, 1987) [42]. Similar approaches have been employed in previous research: Dubey and Tripathi (2018) [12] identified two superior seed sources of *Dalbergia sissoo* based on seed traits; Jyothi *et al.* (2014) [26] evaluated six seed sources of *Zanthoxylum rhetsa* for the same purpose. The findings of this study also align with those of Mukherjee (2005) [36] in *Pinus roxburghii*, Zargar (2012) [57] in *Cupressus torulosa*, and Bhat *et al.* (2018) [7] in *Abies pindrow*.

On studying the different parameters of germination it revealed that seed source have significant effect on germination percent, germination energy, germination value, peak value, mean daily germination, number of cotyledons, root vigor index and shoot vigor index of seeds. The maximum values for germination percent (55.40%), germination energy (43.72%), germination value (6.12), peak value (3.08), mean daily germination (2.13), number of cotyledons (6.02), root vigor index (1843.82) and shoot vigor index (2512.80) was recorded in seeds collected from T₃ of Pir Panchal division. Minimum values for germination percent (40.11%), germination energy (28.28%), germination value (4.09), peak value (2.18), mean daily germination (1.45), number of cotyledons (3.99), root vigor index (948.21) and shoot vigor index (1536.49) in seeds collected from T₇ of Sindh forest division. (Table-04).

Germination behavior in forest trees often varies by origin, as observed by Gupta and Sehgal (1999) [18]. The high germination rate of T₃ seeds from the Pir Panchal division in this study is likely due to favorable environmental factors and beneficial maternal effects during seed development, resulting in higher seed vigor and successful seedling establishment (Guterman, 1992). Similar trends have been noted by Daneva *et al.* (2018) [10] in *Ailanthus excelsa* and Thakur & Thakur (2015) [49] in *Melia azedarach*. Ambalal (2016) [2] also found significant

germination variation among different sources of *Bauhinia variegata*, highlighting how seed source influences germination behavior.

Our findings regarding the variation in germination traits among different seed sources are further supported by studies such as Kumar *et al.* (2022) [31] in *Melia*, Pradhan *et al.* (2020) [38] in *Acacia mangium*, and Rawat and Bakshi (2011) [39] in *Pinus wallichiana*. The high germination energy of seeds from T₃ of Pir Panchal suggests their superior vigor and potential for quick, uniform seedling emergence (Wu *et al.*, 2024) [55]. Conversely, the weaker performance of T₇ seeds from the Sindh division may be attributed to environmental stresses like nutrient deficiencies, unfavorable climate, or developmental issues that compromise seed quality.

The relationship between seed size and germination success is well-documented, highlighting a trade-off between producing numerous small seeds with limited nutrient reserves and fewer large seeds that contain more stored energy (Ekpo, 2004) [13]. Typically, larger seeds tend to germinate more effectively, likely because their greater nutrient content supports the energy demands of germination (Cideciyan, 1982; Ekpo, 2004) [8, 13]. Additionally, studies have demonstrated that both the genetic makeup of seeds and the environmental conditions experienced during their development play a crucial role in determining germination behavior (Loha *et al.*, 2006; Gush *et al.*, 2011) [19, 33]. This is known as the provenance effect, which refers to the influence of local environmental factors on seed development and, consequently, germination success (Benowicz *et al.*, 2000; 2001) [4, 5]. Such environmental differences can lead to substantial variability in germination performance.

The analysis of phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV) and heritability (h²) of cone and seed morphological and germination parameters highlighted the genetic variability of cone, seed and germination traits. (Table-05). Highest PCV was recorded for root vigor index (24.63) followed by shoot vigor index (22.82). Lowest

PCV was recorded for seed length (11.77). Similarly, highest GCV (21.82) was recorded for root vigor index followed by shoot vigor index (19.05). Lowest GCV was recorded for average number of seeds per cone (9.22). The minute differences that existed between PCV and corresponding GCV showing these characters are under genetic control.

Traits such as cone length, cone weight, seed length, cone diameter and root vigor index exhibited highest heritability values ranging from 0.83 to 0.78 indicating strong genetic control. Additionally, for all the characters under examination, the relative size of the phenotypic coefficients of variation was higher than the genotypic coefficients of variation, showing the influence of the environment on the traits.

High heritability values reflect the reliability of selecting traits based on observed phenotypes. Traits that show high heritability are particularly valuable in advanced breeding programs, as they respond well to selection efforts. Previous studies have underscored the importance of genetic variation in tree improvement and conservation, including the work of Rawat and Bakshi (2011) [39] on *Pinus wallichiana*, Mukherjee *et al.* (2004) [34] on *Pinus roxburghii*, and Selvan and Guleria (2012) [43] on *Acacia catechu* Willd.. Similar findings regarding phenotypic and genotypic coefficients of variation (PCV and GCV) and heritability were reported by Roy *et al.* (2004) [41] in *Pinus roxburghii*, Singh and Bhat (2006) [46] in *Pinus kesiya*, Sharma (2014) [42] in *Cedrus deodara*, Uniyal *et al.* (2016) [52] in *Abies pindrow*, and Rahman *et al.* (2017) in *Pinus wallichiana*.

In *Abies pindrow*, the observed genetic diversity has a notable effect on cone and seed morphology as well as germination behavior, as indicated by Singh & Pokhriyal (2000) [47]. This variability is critical for enhancing growth and adaptability, particularly under the pressures of changing climate conditions (Dawson *et al.*, 2011) [11]. Consequently, the findings of this study offer valuable insights for utilizing genetic variation in seeds and seedlings to support selective breeding and conservation efforts in *Abies pindrow*.

Table 2: Average Cone Characteristics of selected mother trees of *Abies pindrow* Royle

Source		Cone Length	Cone diameter	Cone weight (g)	Cone Specific gravity	Number of seeds per cone	Number of filled seeds per cone	Number of empty seeds per cone
Forest Division	Mother Trees	(cm)	(cm)					
Pir Panchal	T ₁	9.05 ^e	3.43 ^e	52.65 ^d	1.12 ^{bcd}	334.83 ^{ab}	213.06 ^e	121.77 ^{ab}
	T ₂	11.24 ^a	4.80 ^b	67.26 ^a	1.30 ^{ab}	369.70 ^a	274.40 ^b	95.03 ^d
	T ₃	11.46 ^a	5.39 ^a	68.22 ^a	1.33 ^a	378.77 ^a	299.83 ^a	78.94 ^e
Tangmarg	T ₄	10.27 ^c	4.31 ^{cd}	58.40 ^{bc}	1.21 ^{abc}	360.70 ^a	249.25 ^{cd}	111.45 ^{bc}
	T ₅	10.63 ^b	4.68 ^{bc}	62.60 ^b	1.26 ^{ab}	368.96 ^a	256.79 ^c	112.17 ^{cd}
	T ₆	9.90 ^d	4.09 ^d	55.34 ^{cd}	1.18 ^{abc}	359.23 ^a	237.98 ^d	121.25 ^{ab}
Sindh	T ₇	8.16 ^f	3.17 ^e	47.95 ^e	0.95 ^d	283.90 ^b	183.69 ^f	100.21 ^a
	T ₈	8.94 ^e	3.31 ^e	51.12 ^{de}	1.02 ^{cd}	295.23 ^b	196.83 ^f	98.04 ^{ab}
C.D ($p \leq 0.05$)		0.35	0.47	4.34	0.20	53.53	13.98	3.59

Values sharing the same letter are statistically non-significant at 5%

Table 3: Average seed characteristics of *Abies pindrow* Royle.

Source		1000 Seed weight (g)	Seed length (mm)	Seed Width (mm)
Forest Division	Mother Trees			
Pir Panchal	T ₁	51.66 ^{cd}	7.62 ^{cde}	4.53 ^{cd}
	T ₂	63.15 ^b	9.16 ^a	5.60 ^a
	T ₃	68.17 ^a	9.49 ^a	5.63 ^a
Tangmarg	T ₄	54.65 ^c	8.32 ^{bc}	4.72 ^{bc}
	T ₅	55.07 ^c	8.97 ^{ab}	5.25 ^{ab}
	T ₆	53.84 ^{cd}	7.95 ^{cd}	4.69 ^{bc}
Sindh	T ₇	47.87 ^e	6.95 ^e	3.98 ^d
	T ₈	50.64 ^{de}	7.38 ^{de}	4.06 ^{cd}
C.D ($p \leq 0.05$)		3.48	0.84	0.67

Values sharing the same letter are statistically non-significant at 5%

Table 4: Seed germination parameters of selected mother trees of *Abies pindrow* Royle

Source		Seed germination percent (%)	Germination energy	Germination value	Peak Value	Mean daily germination	Number of cotyledons	Root vigor index	Shoot vigor index
Forest Division	Mother Trees								
Pir Panchal	T ₁	46.16 ^{cd}	33.46 ^{cd}	4.29 ^{cd}	2.36 ^{cde}	1.62 ^d	4.73 ^{cd}	1141.86 ^{cd}	1667.40 ^{cd}
	T ₂	52.31 ^{ab}	41.11 ^a	5.68 ^{ab}	2.84 ^b	1.86 ^b	5.80 ^a	1519.77 ^b	2444.80 ^a
	T ₃	55.40 ^a	43.72 ^a	6.12 ^a	3.08 ^a	2.13 ^a	6.02 ^a	1843.82 ^a	2512.80 ^a
Tangmarg	T ₄	48.27 ^{bc}	35.57 ^{bc}	4.80 ^{abcd}	2.53 ^c	1.72 ^c	4.94 ^{bc}	1206.84 ^c	1938.34 ^{bc}
	T ₅	51.42 ^{abc}	39.26 ^{ab}	5.55 ^{abc}	2.55 ^c	1.82 ^b	5.56 ^{ab}	1209.09 ^c	2297.63 ^{ab}
	T ₆	46.20 ^{cd}	34.31 ^{cd}	4.70 ^{bcd}	2.43 ^{cd}	1.65 ^{cd}	4.91 ^{bc}	1193.15 ^c	1750.08 ^{cd}
Sindh	T ₇	40.11 ^e	28.28 ^e	4.09 ^d	2.18 ^e	1.45 ^f	3.99 ^d	948.21 ^d	1536.49 ^d
	T ₈	42.82 ^{de}	30.39 ^{de}	4.22 ^d	2.24 ^{de}	1.54 ^e	4.50 ^{cd}	1035.13 ^{cd}	1562.06 ^{cd}
C.D (p≤0.05)		5.39	4.94	1.32	0.20	0.08	0.73	240.55	399.42

Values sharing the same letter are statistically non-significant at 5%

Table 5: PCV, GCV and heritability of various cone, seed and germination characteristics of *Abies pindrow* Royle

Cone and Seed Parameters	PCV	GCV	Heritability (h ²)
Cone length (mm)	11.84	10.38	0.82
Cone diameter (mm)	21.58	19.37	0.78
Cone weight (g)	13.25	11.52	0.80
Cone specific gravity	13.85	9.99	0.52
Average number of seeds per cone	12.59	9.22	0.53
Average number of empty seeds per cone	12.89	10.75	0.73
Average number of filled seeds per cone	17.10	14.40	0.69
Seed Length (mm)	11.77	10.74	0.83
Seed Width (mm)	14.34	12.59	0.77
1000 Seed weight (g)	12.46	11.69	0.66
Seed Germination%	11.79	9.98	0.71
Mean daily Germination	12.56	11.03	0.67
Peak value	12.63	10.44	0.76
Germination energy	16.28	14.01	0.74
Germination value	16.13	12.94	0.63
No of cotyledons	14.83	12.76	0.75
Root vigor index	24.63	21.82	0.78
Shoot vigor index	22.82	19.05	0.68

Conclusion

Based on the findings from the study, it can be concluded that significant variation exists in the cone and seed morphology, germination characteristics, and genetic traits of *Abies pindrow* Royle across different sources in the Kashmir Himalayas. This variation holds critical implications for tree improvement programs, especially concerning the selection of superior seed sources for propagation and conservation efforts. The study highlighted substantial differences in cone size and weight, seed size and weight, and germination behavior among the selected seed sources. Larger seeds, particularly those from the T₃ of Pir Panchal division, were associated with enhanced seed germination and seedling emergence reflecting the positive influence of maternal traits and favorable environmental conditions. These larger seeds are likely to perform better in propagation efforts, especially in seedling production and afforestation programs, and should be prioritized in future efforts to improve *Abies pindrow* Royle regeneration. Moreover, the study's examination of seed germination dynamics revealed promising variations across sources. This information is critical for optimizing germination techniques, improving seedling survival rates, and ensuring the successful establishment of *Abies pindrow* Royle. The significant genetic diversity observed in the morphological and germination traits of *Abies pindrow* Royle emphasizes the importance of selecting appropriate seed sources for genetic improvement. The findings underscore the need for further research to explore the genetic potential of this species. Finally, the insights gained from this study will support the development of sustainable forest management strategies, enabling the identification of superior genotypes that are well

sued to the region's climatic and ecological conditions.

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Author's contribution

All authors (MM, AAM, PAK, VD, MIJ and KAS) contributed to the lab work and to the writing and reviewing the manuscript. MIJ contributed to the data evaluation. Apart from that MM contributed also to the field collection

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